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[Cover photograph of 'Jumbo' storage bags taken at Mahboon Krong Ricemill Co., Pathum Thani Province, Thailand.]

Bulk Handling and Storage of Grain in the Humid Tropics

Proceedings of an international workshop held at Kuala Lumpur, Malaysia, 6–9 October 1987

Editors: **B.R. Champ and E. Highley**

Sponsored by:

Australian Centre for International Agricultural Research (ACIAR)
ASEAN–EEC Regional Collaborative Programme on Grains Postharvest Technology
ASEAN Grains Working Group
Malaysian Agricultural Research and Development Institute (MARDI)
National Paddy and Rice Authority (LPN), Malaysia
ASEAN Food Handling Bureau (AFHB)

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Address of Welcome

ON behalf of the organisers I have the pleasure to welcome Y.B. Encik Mohd Kassim Ahmed, Deputy Minister of Agriculture, distinguished guests, learned participants, and interested observers to this International Workshop on Bulk Handling and Storage of Grain in the Humid Tropics. I would also like to express our appreciation to Y.B. Encik Mohd Kassim for taking time from his busy schedule to address and declare open this workshop.

The objectives of the workshop are, as we are all aware, to review technical and economic aspects of bulk handling and storage of grain in the humid tropics, to identify constraints on the adoption of bulk handling methods, and to evaluate the potential social and private benefits and costs of bulk handling to communities considering its introduction.

Twenty-eight papers have been scheduled for presentation during the workshop, grouped into the following sessions:

- Perspectives on bulk handling and storage of grain
- Technical aspects of bulk handling and storage
- Case studies on bulk handling in the humid tropics
- General socioeconomic and technical considerations
- The prospects for bulk handling in ASEAN countries

Bulk handling, transportation, and storage are fundamental issues in the paddy and rice industries, which are of the utmost interest to us in Malaysia. As you may be aware, there exists a serious technological gap in the method of conveying paddy from the fields to the mills. The transportation of paddy in jute or hessian bags is very much traditional and found to be cumbersome, time-consuming, uneconomical, and creating bottle-necks in the postharvest activities. We therefore look forward to the deliberations and the findings of this workshop.

May I add that this workshop is being held during, and as part of, the 16th anniversary celebration of my organisation, the National Paddy and Rice Authority (LPN). We are honoured and privileged to cosponsor the workshop. I wish to add that during the last three years LPN, in collaboration with other agencies, has carried out some small-scale field trials on paddy bulk handling in Tanjung Karang (Selangor), Seberang Perak (Perak), Bukit Besar (Kedah), and Pasir Puteh (Kelantan). In addition, we have successfully carried out a research study on aeration of bulk stored paddy in Tanjung Karang, Selangor. This aimed to improve the storage life of paddy in tower silos. Currently, we are evaluating the feasibility of in-store drying of wet paddy in combination with the use of conventional high speed column dryers. It is our hope that, through this strategy of combination drying, greater efficiency and economy can be achieved in handling large influxes of wet paddy during peak harvest times.

Equal attention is being given to the area of milled rice storage, for which there are two existing projects evaluating the effectiveness of holding milled rice under carbon dioxide gas, without resorting to toxic chemicals such as methyl bromide or phosphine currently in widespread use. We will share our experiences on this method of storage with you during this workshop in the form of case studies.

Before I conclude, on behalf of the Malaysian Government, I would like to thank the ASEAN Grains Working Group, the ASEAN Food Handling Bureau, and the Australian Centre for International Agricultural Research for having kindly cosponsored this international workshop with LPN and MARDI.

To the donor organisations, namely the Australian International Development Assistance Bureau (AIDAB), the United States Agency for International Development (USAID), the Canadian International Development Agency (CIDA), the International Development Research Centre of Canada (IDRC), and last but not least, the Commission of the European Communities for South East Asia, I wish to thank them for their support in one form or another in the postharvest activities in this region.

May I wish the workshop every success and may your deliberations and findings during these three days be of benefit to academicians and practitioners alike in the ASEAN and other regions.

Abdul Kuddus Ahmad
Director-General
National Paddy and Rice Authority

Keynote Address

IT is indeed a great honour for me to be given an opportunity to address the assembly and to declare open this morning the International Workshop on Bulk Handling and Storage of Grain in the Humid Tropics.

I would like to take this opportunity to say 'selamat datang'—our Malaysian way of extending a very warm welcome to all the distinguished guests, learned participants, and observers who are attending this international workshop. I would like to congratulate the National Paddy and Rice Authority, the Malaysian Agricultural Research and Development Institute, ASEAN Grains Working Group, the Australian Centre for International Agricultural Research, and the ASEAN Food Handling Bureau for their joint effort in organising this technical workshop. I also wish to acknowledge the generous assistance given by the ASEAN–EEC Collaborative Programme which has made a significant financial contribution towards holding this workshop.

An underlying objective of this international workshop, as in previous such assemblies, is to provide an appropriate forum for the researchers and their respective agencies to present and discuss their research results pertaining to the various aspects of grain handling and storage, with particular reference to the hot and humid conditions in the Southeast Asian region. Apart from that, technical workshops of this type also serve to strengthen the cooperation among scientists and institutions both within and outside this region. I am especially delighted over the fact that we have in attendance our colleagues from overseas, particularly from the ASEAN countries, Australia, the United Kingdom, and the United States of America. I am given to understand that these participants are distinguished leaders in their respective fields of postharvest technology.

I consider this gathering most significant in view of the increasing concern among national governments in the region over the existing grain losses occurring at the various stages of postharvest operations. Here in Southeast Asia, there still exists a critical need for the adoption of appropriate technology and the institution of efficient measures for preventing grain deterioration in handling, drying, storage, and processing. I am confident that this workshop will provide some answers to our current postharvest problems which will enable us to institute more efficient handling, minimise losses in food grains, and preserve grain quality. I hope that during its deliberations the workshop will devote its attention towards appropriate technology which can be introduced without undue pressure on the resources of the country adopting it. It is imperative that local needs and constraints be given due consideration. A workshop which becomes too academic and theoretical will, I believe, not fully achieve its aims.

ASEAN countries are among the major rice consumers. In Malaysia, rice comprises more than 20% of the food consumed by the entire population. In terms of agricultural land utilisation, rice occupies only about 12% of the total cultivated land in Malaysia, but it holds a unique position in the socioeconomic framework of the country. The annual rice production is currently about 1.4 million tonnes involving a total of 300 000 farm families and 470 000 hectares of paddy land. It accounts for approximately 20% of total employment.

Rice growers in Malaysia are traditionally among the poorest sectors of the rural economy. Through the various programs of cropping intensification and income redistribution, the incidence of poverty among rice growers had declined from 88.1% in 1970 to 55.1% in 1983. While this reduction was a remarkable achievement, the incidence of poverty among rice growers continues to be high and above the national average, primarily due to the existence of a large number of uneconomic farm holdings and compounded by low yields in areas outside the major irrigation schemes. Presently, we are encouraging a larger scale, commercial estate type of rice production within the designated granary areas, learning perhaps from our successes with large plantations of rubber, oil palm, and cocoa. Such a goal may be realised through the sustained efforts of all concerned with the industry. One such effort is in the area of research and development (R&D). I am glad to inform the assembly that extensive R&D efforts and linkages are already in existence in Malaysia, involving the local agencies such as MARDI, LPN, UPM, and other universities and agencies; between Malaysia and ASEAN neighbours, particularly through the ASEAN–Australian and ASEAN–EEC Collaborative Programmes; and between Malaysia and other government and international agencies such as ACIAR, IDRC, FAO, and UNDP, through the respective bilateral arrangements.

Such linkages have provided us an opportunity to upgrade our skills and knowledge in a multidisciplinary approach to solution of the problems faced by the rice industry.

Regarding our efforts to improve the local postharvest handling and storage of grain, as has been mentioned by the Director-General of LPN in his speech of welcome and workshop objectives, LPN in collaboration with MARDI and other agencies has carried out a number of research studies including bulk storage aeration of dried paddy, in-store drying of paddy, controlled atmosphere storage of milled rice under plastic cover and in fumigable warehouses; integrated pest management for stored grains; and economic analysis of paddy bulk handling in Tanjung Karang, to name just a few. To date, some of these research findings have been implemented and incorporated in the existing facilities. As regards the project on economic analysis of paddy bulk handling in Tanjung Karang, I am happy to note that the study team, comprising members of UPM and ACIAR, has recently completed its study and will be presenting its research findings as part of this international workshop.

It is our expectation that views and comments of the participants will be incorporated in the final report, which will present a blueprint for large-scale adoption of paddy bulk handling, first in Tanjung Karang then other areas.

From the foregoing statement, it is evident that this international workshop is of great relevance and importance to the needs of the rice industry in Southeast Asia. It affords an opportunity for us to review the current state of the art in research and technology development in the grains postharvest field. It also provides important guidance for research planners by identifying gaps in existing programs and by generating new initiatives and determining priorities for further research work.

This workshop, which we are beginning today, is part of the increasing effort to improve grain postharvest facilities and systems, not only in the countries of our region, but in the rest of the world. I am confident that with the ensuing exchange of expertise and experiences we can come up with a truly effective solution to the postharvest problems that we commonly encounter in the handling, processing, and storage of grains in humid tropical areas.

In conclusion, I wish you success for this workshop; may this gathering be truly fruitful.

Hon. Encik Mohd. Kassim Ahmed
Deputy Minister of Agriculture

Executive Summary

THE traditional method of grain handling and storage in Southeast Asia is in bags. There are good reasons for this. Individual farms throughout the region are, in general, small and so, therefore, are the amounts of grain handled by individual farmers. While bag handling of grain is labour intensive, there is no shortage of cheap labour in many parts of the region. Also, farmers tend to be the poorest members of the community, with little or no spare cash to purchase equipment and facilities, such as might be needed if bulk handling of grain were adopted at the farm level.

On the other hand, the introduction of new, high-yielding, early maturing varieties of rice, and the development of irrigation systems permitting the cultivation of two crops a year, have created problems for the existing handling system. Both productivity and production have risen, so there is now more grain to be dealt with. Where a second crop is grown, it is harvested in the wet season and will rapidly deteriorate unless dried to a safe moisture content within a short time of harvesting. Since sun drying is unreliable during the wet season, this will generally mean use of some form of mechanical drying, technology that is more applicable to bulk than bagged grain, as is the use of pesticides in pest management programs. In some areas, combine harvesters are now used, further pushing the existing bag handling system towards the limits of its ability to handle the increased rate of inflow of grain.

Both the private and public sectors of the grain handling industries in the region are therefore looking increasingly towards bulk handling as a possible solution to these problems. There are, however, major issues to be addressed before there can be large-scale adoption of new grain handling technology. These include assessment of the most appropriate forms of equipment and facilities for the diverse circumstances encountered in the region, and determination of the level at which various facilities, e.g. for drying, should be incorporated in the postharvest chain. Underlying these basically technical questions is the fundamental issue of who would benefit from the introduction of improved grain handling technology, given that it is a major objective of most governments in the region to raise farmers' incomes.

This volume publishes the papers and records the discussions from an international workshop held in Kuala Lumpur, Malaysia to examine these issues in detail. Twenty-eight invited papers were presented over a three-day period to some 130 participants drawn from all the ASEAN countries, Australia, the UK, and USA. The papers and the ensuing discussions fully explored the crucial nexus between technical and economic factors in considering the introduction of bulk handling into the region. On the last day of the workshop, participants visited a grain drying, milling, and storage complex operated by Malaysia's National Paddy and Rice Authority (LPN), to view a display of grain handling techniques and facilities.

ACIAR support for the workshop was provided through its Grain Storage and Socioeconomics research programs. The other sponsors of the meeting were the ASEAN Grains Working Group, the Malaysian Agricultural Research and Development Institute (MARDI), LPN, and the ASEAN Food Handling Bureau (AFHB), based in Kuala Lumpur.

The workshop also provided the forum for presentation and discussion of the results of a major collaborative research project undertaken over the preceding two years by ACIAR (through the South Australian Department of Agriculture), Universiti Pertanian Malaysia (UPM), and LPN. The project's main objective, successfully accomplished, had been to develop appropriate methodology for analysis of the Malaysian rice industry and so enable recommendations to be made on matters relating to grain procurement practices, transportation, and storage, particularly as relating to bulk handling.

In a keynote address given at the commencement of the workshop, the Hon. Encik Mohd Kassim Ahmad, Deputy Minister of Agriculture of Malaysia, said that he considered the meeting most significant in view of the increasing concern among national governments in the region over the grain losses that were occurring at various steps in the postharvest chain. A critical need existed for the development of technology that can be adopted without undue pressure on the resources of the country involved. It was therefore important, he said, that the workshop not become too academic and theoretical and that its deliberations take account of local needs and constraints.

In the opening workshop session, three papers set the scene by giving a broad overview of technical and general social implications of bulk handling and storage. Each of these presentations sounded a cautionary note about precipitate adoption of technologies which, though highly successful in other parts of the world, may be inappropriate in ASEAN. This created a healthy mood of critical assessment that persisted throughout discussions at the workshop and confirmed at the outset that participants meant to assess, rather than promote the technologies available.

The next six papers concerned themselves with technical issues, giving a comprehensive overview of what their presenters saw as the state of the art in bulk handling and storage technology. The papers covered harvesting and procurement systems, grain drying, storage and ancillary equipment, integrated pest management, and port handling facilities.

The papers and discussion during this session provided strong evidence that technology appropriate to bulk handling and storage of grain in the humid tropics was already available. The challenge faced by governments and agencies was how best to introduce and use it so as to provide benefits that would accrue to all sectors of the postharvest chain, from farmers through to consumers.

Economics came to the forefront in the next session, when members of the joint Australian–Malaysian research team presented a series of six papers giving the final results of their comprehensive study of paddy and rice flows in Malaysia. Individual papers described the development of a detailed economic model of the Malaysian paddy and rice industry and the cost functions used in it, and gave the results of a comparative economic analysis of bulk handling methods and their rates of adoption, and of studies of the sensitivity of the model to price and quality parameters. The final paper in the series tied the results of the whole project together, outlining the policy and institutional changes thought necessary for the introduction of bulk handling and storage to proceed rationally and providing an agenda for reform of the Malaysian rice industry. The agenda generated much discussion within and outside the workshop. Key items in it were:

- the deregulation of the price of rice above grade 3;
- an increase in the penalty on low quality paddy;
- gradual removal of the price subsidy for paddy;
- provision of loans to the private sector for increased investment in modern postharvest facilities; and
- gradual reduction in LPN participation in the domestic rice market.

During the next session of the workshop, six case study papers were presented, giving the results of bulk handling research and development projects carried out in Indonesia, Malaysia, and Thailand. By and large, these were technical papers presenting the results of studies undertaken to seek technical solutions to various problems encountered in bulk handling operations. The speakers highlighted preliminary research findings and discussed technical constraints. The need for further work in the various study areas was stressed by those involved.

The two final sessions, involving seven presentations, covered general socioeconomic and technical considerations and the prospects for bulk handling in the region. As regards the latter, socioeconomic, engineering, and investment approaches related to the adoption of bulk handling systems in the ASEAN countries were presented. The presenters explored social benefit analyses for bulk handling and storage strategies in the Philippines, engineering considerations in drying and storage of grain, and a scenario of decreasing world prices and rising production costs as guideposts to investment decisions in the rice industry.

An open forum session followed the presentation of each group of papers. These sessions were extremely stimulating, exploring the complex issues involved in the topic, and revealed a broad diversity of views among workshop participants. While some were clearly committed to the concept of bulk handling, others still questioned the appropriateness to ASEAN of any of the technology available.

A number of participants questioned the rapid timetables that seemed to be inherent in some of the proposals for the adoption of new postharvest technologies in the region. It was pointed out more than once that, in other parts of the world, such changes have generally been evolutionary rather than revolutionary. Even in Australia, held up as a paradigm of bulk handling of grain, it took some 20 years to fully effect the transformation from bag to bulk handling of wheat, under circumstances perhaps more favourable than those currently applying in ASEAN.

Split systems, variously incorporating bulk or bag handling where appropriate, were mooted, and the 750 kg 'jumbo' plastic bag developed by the Mahboon Krong Ricemill Company in Thailand was put forward as a possible first step in the evolution of bulk handling systems suited to Southeast Asia. Mahboon Krong had used this method for successful storage of some 55 000 tonnes of milled rice for periods of up to three months. The bags can be treated with carbon dioxide or other fumigants and sealed, under which conditions safe storage for longer terms may be possible.

There was much discussion on the question of who would benefit from the introduction of bulk handling technologies. Some participants found it difficult to see how farmers, the group in greatest need of help, would gain. They saw consumers and the large traders and millers as the sole beneficiaries. Others pointed out that farmers must benefit from a reduction in grain losses and a general improvement in the quality of grain presented to consumers, particularly at a time when disposable incomes were rising throughout the region. There were eloquent advocates on both sides of the floor.

A related issue that received much airing was the introduction of greater incentives to farmers to deliver high quality grain to the mill and, conversely, of penalties for delivering wet or poor quality grain. It was pointed out that in some parts of ASEAN there are no such incentives or penalties at present and that this has led to a failure of the marketing system.

There was also much discussion of the need to stimulate more investment by the private sector in the grain handling and storage industries, though the problems of doing this during times of falling world grain prices did not escape the attention of participants.

If any consensus regarding adoption of bulk handling systems emerged from the workshop, it seemed to be 'proceed with caution'. The importance to the successful adoption of new postharvest technologies of the installation of appropriate policies and incentives, and of institutional reform, were also promoted, reinforcing the major conclusion of a previous ACIAR-cosponsored seminar, on technological change, held in Bangkok in September 1986.

In closing the workshop, ACIAR Director Professor J.R. McWilliam remarked that, irrespective of fluctuations in commodity prices and other economic factors, rice was still the most important food crop of the developing world and that rice production in Asia would need to double over the next 20 years to cover increasing demand. He said that the development of extra facilities to store this increased production necessitated a systems approach and that ACIAR would continue to give a high priority to this type of postharvest research. While bulk handling systems already exist in the region, their further development would take time. The greatest boost to their development might come from policy changes leading to institutional reforms in the paddy and rice sector, but care should be taken to ensure that government intervention did not stifle private initiative as it appeared to have sometimes done in the past.

Perspectives of Bulk Handling and Storage of Grain

Why Bulk Handling?

L.D. Bramall*

Abstract

Bulk handling is the term used to describe the movement of large parcels of a commodity by mechanical means. The implementation of this technology in Southeast Asia for the harvesting, procurement, drying, storage, milling, and distribution of grain, will bring with it the advantages of reduced losses and costs, while improving the working and living conditions of the people.

The losses associated with the bag storage technology currently practiced in Southeast Asia embrace:

1. physical spillage and weight losses due to rodent, insect, and bird attack;

2. quality losses due to slow harvesting, time delays before drying, poor drying procedures, and inefficient handling and milling; and

3. losses in value, due to both quantity and quality loss, to the farmer, trader, miller, and marketer.

Costs of implementing bulk handling technology are high, since the machinery and equipment are expensive. However, in considering the ability to overcome current losses, the benefits will ultimately outstrip the costs. Full integration of the system lends itself to efficient management by production programming and forward planning, and the net result is a greater quantity of a higher quality product.

By eliminating the intensive manual effort in the existing system, working conditions would be significantly improved, as would the lives and health of the rural community. In adopting bulk handling technology, due regard must be taken of the social changes which would accompany so dramatic a step. On a national basis, entire populations, particularly those in rural areas, are affected and susceptible. Any move towards bulk handling must therefore be done rationally, after considering all the influencing factors.

IN setting the scene for the next three days of presentations and discussions on the subject of bulk handling, it is important to first understand the meaning of the term. There are many interpretations of it and many physical examples of, and monuments to technology designated as bulk handling. Similarly there are degrees of bulk handling. So, just what do we understand by the term?

'Bulk' is defined, for our purposes, as 'a large mass'. However, it also has the connotation of the elimination of all things associated with manual labour. Therefore, in the grain industry, bulk handling should consider the full mechanisation of handling from seed preparation

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and planting through crop growing and harvesting, to procurement, drying, storage, milling, packaging, and distribution. This, however, involves far more than we could cover in the time allowed. Hence, we shall limit ourselves to the postharvest aspects of grain handling.

Bulk handling of grain immediately evokes images of mechanical harvesters, mobile field bins, large road haulage trucks, in-ground tipping hoppers, mechanical conveying systems, flow-through dryers, drying and storage bins, and large capacity mills, all with unit load capacities of 2–20 tonnes and flow rates of the order of 2–100 tonnes/hour. With such unit operations integrated into a complete system, full coordination of a harvest and its drying and storage, milling, and distribution is attainable.

In considering the implementation of bulk handling we must first look at the current situation as it exists in the humid tropics, in particular in Southeast Asia. Many of us have seen the situation first-hand, others have read about it in reports. To my knowledge, however, there are no examples of *total* integration of bulk handling technology in the grain industry in the region.

Auto headers operate in small paddy fields, then discharge onto the ground for bagging, followed by one-bag carting to the roadside. In moving paddy from the field through the many operations to produce milled rice, bagging and debagging may take place up to five times, with concomitant spillage and loss. Paddy is spread out on roads for drying with resultant quantity and quality loss. Freshly harvested grain is held at high moisture for too long before drying and proceeds to degrade due to bacterial and fungal activity. Bagged milled rice experiences further attack from storage insects thereby further reducing product quantity and quality. Directly associated with all these activities are high labour requirements, large numbers of bags, and operating costs of many small vehicles.

Basically, there are two objectives to the introduction and implementation of bulk handling technology: 1. to reduce losses; and 2. to reduce costs. There are other aspects, both beneficial and otherwise which require consideration. These are more aligned to the social well-being of the people.

Reducing Grain Losses

Once it has been determined that a crop is ready to harvest, there then begins a series of operations during which the grain can either hold its initial quality or deteriorate. Similarly, at each and every unit operation there is the possible loss of mass. With existing bag technology, as is the current practice throughout much of Southeast Asia, both qualitative and quantitative losses are exacerbated by the inadequacies of bag handling, and these losses have long been accepted as inevitable. The possibility for loss is far greater in bag technology than in bulk, simply because of the small unit size (50–100 kg/bag), the large number of units (bags), frequency of transferring grain from bag to bag and, most importantly, the time taken in simply getting the crop from the field and into a store at a safe moisture content. Bulk handling overcomes all these problems by increasing the unit size, by reducing the number of units, and by dramatically reducing the time factor.

Quantitative Losses

By adopting bulk handling techniques—from harvest, through milling, to the consumer—losses associated with multiple bagging/debagging operations, bursting bags, and rodent, bird, and insect attack, are eliminated or significantly reduced.

Auto headers reduce the harvest time and the spillage losses associated with manual harvest, threshing, and in-field bagging. Mobile field bins eliminate the need for in-field bagging and subsequent retipping. Bulk discharge into a road truck from the field bin, followed by direct delivery to a high capacity intake system at the drying and storage depot, reduces the potential for grain loss due to birds, rodents, insects, and spillage. High capacity drying systems, be they batch or continuous, remove the losses associated with bag stack and solar drying.

Bulk handling provides the opportunity for integrated pest control. Because the grain is moved and stored in large parcels, then the application of selected control agents becomes a simple process. A total hygiene program may be implemented, starting at the farmer's equipment and carrying through the various bins, sheds, and conveying equipment. General cleanliness around facilities, in association with a program of baiting and spraying and removal of trash, eliminates harbourage for rodents and insects.

In-silo or in-bin fumigation may quickly and conveniently make a mass of stored grain secure and, in certain circumstances, such as use of a controlled atmosphere, maintain the commodity in an insect-free environment until required.

Qualitative Losses

By far the most significant loss seen in rice in the tropics is a direct result of quality deterioration. From the very moment the grain is ready for harvest, it is destined to deteriorate, particularly the wet season crop. The quality deterioration is a result of poor management of the harvest, exacerbated by weather conditions, time delays, and incorrect procedures for handling, storage, and drying.

Grain headers operating in paddy fields properly designed to reduce the amount of non-harvesting time (i.e. crossing ditches, channels, turning, etc.), can harvest a ripe crop at the rate of 10–30 tonnes/hour. At this rate, the length of time a crop is at risk of weather damage is reduced. Similarly, the entire crop is harvested at a uniform level of maturity and moisture content. This of course implies that bulk handling techniques were used to sow the crop initially.

Once stripped, the moist grain must be brought to a safe moisture content as soon as possible. Here the link between the header and the drying facility must be well coordinated. Direct discharge of paddy into field bins awaiting alongside the header allows the machine to strip non-stop. The field bins then discharge to waiting trucks for immediate delivery to the storage and drying facility. With full coordination of stripping rate, bin and truck capacities, and transporting times to the depot, the time elapsed before the grain is safely into a bulk drying bin can be as short as 45 minutes. This is a vast improvement on the delays of up to 7 days sometimes experienced in Southeast Asia.

Long delays cause rapid deterioration of the harvested grain. The grain moisture content, often up to 28%, is ideal for mould growth, thereby inducing black discoloration in the bran and kernel. Heat of respiration, of the seed or insects, begins a process of yellowing as the chemical constituents of the rice begin to interact. These effects are irreversible and seriously reduce grain quality, resulting in a corresponding loss of value.

Bulk delivery of grain to a large, bulk drying facility allows the introduction of a crop segregation program. With adequate storage available, deliveries may be directed to specific bins depending on the grain variety, moisture content, and trash content. Inspection of the rice in bulk truck delivery is fast and, with a complementary computer system, all information concerning the grower and the delivery may be immediately recorded. Weighbridges may be directly linked to computers for accurate measurement of loads.

Segregation of the grain, initially by variety, ensures that consumer preferences may be met without admixture or contamination. In the drying of paddy, grain may be received at moisture contents varying from 15–30%. Segregation into at least three moisture classes allows for more efficient use of flow-through dryers and, with in-store drying, aeration strategies may be designed and implemented for controlled drying of the grain.

Drying is critical to the final quality of the milled rice. The removal of moisture from rice must occur gently and gradually. Extremes of temperature, high moisture removal rates, and the lack of tempering between passes in column dryers will cause kernel stresses that lead to grain breakage during milling. In-store drying, after moisture segregation, initially secures the crop under cover in nominated bins. Predetermined aeration and drying strategies may then be applied to reduce the moisture content of the grain to a level safe for storage or milling. These strategies are expressly designed to maintain grain quality by removing the moisture systematically, by selectively using the appropriate ambient air or by use of supplemental heating.

Since a single delivery is from one farmer's crop, the accumulation of samples drawn from all that farmer's deliveries enables an appraisal to be carried out. The quality appraisal of that farmer's entire crop may then form the basis for his payment.

It is also possible to appraise the accumulated samples of each delivery into each *bin*. The quality of the full bin contents may then be derived from a mass average of all deliveries, and bins may then be designated for specific use or markets.

Ideally, storage and drying facilities should be located throughout the growing area to allow for short travelling times from farms. To further improve efficiencies, a close-coupled milling facility may take full advantage of direct conveying of dry paddy from store to mill. Where paddy is stored and dried at remote locations, then large bulk trucks must be used.

Milling of paddy cannot remove any damage done during its previous handling. By the time the paddy enters the mill the basic quality of the finished product has already been determined. The level of damage to the white rice and the whole grain yield are reflections of the conditions to which the paddy has previously been subjected. The best the milling can do is control the level of bran removal and polish.

Final packaging of product from the mill usually depends on a customer's requirements. It is generally at this stage that a departure from bulk handling takes place, although road or rail truck or ship deliveries of product to large customers are common practice. Once in the distribution network, milled rice generally does not experience any further quality deterioration due to moisture. However, it is now the turn of insects, rodents, and birds to either bore into the grain or contaminate it with excreta. Controlled atmosphere storage of bulk milled rice has been implemented commercially, thereby guaranteeing the quality of the rice right up to the point of packaging for shipment to the consumer.

The integration of a bulk handling system is the only way to ensure that rice of the highest possible quality is produced from the paddy available. If there is just one weak link in the chain, the entire system will be reduced to the level determined by that link and quality will suffer.

Loss in Value

In terms of the payment received by the farmer for his paddy, 'loss of value' means loss of quantity and quality. Having been subjected to an appraisal scheme, the results of the milling analysis carried out on his delivery samples are used as a basis for his monetary return. Generally, such schemes operate with tonnes delivered (calculated to fixed moisture content), whole grain yield, immaturity, damaged grain, and dockage content, acting as the terms in the equation.

This appraisal of the incoming crop also gives some indication of the likely quality of the entire crop after it has been commercially dried and milled. However, since the delivery samples are dried and milled under strictly controlled laboratory conditions, they give only an approximate indication of the product likely to come from the commercial operation.

The paddy, having changed hands, is now the responsibility of the dryer/storage/mill owner. The wet paddy must be dried as soon as possible to prevent further deterioration of quality. Mismanagement or malpractice at the drying stage can seriously reduce the value of the rice in store. Teter (1983) estimated that paddy held in a wet state for 4 days will lose 27% of its value and after 7 days will have lost 34%.

At all stages of the procurement, drying, storage, and milling process the potential loss of value is a function of the method of handling. Fast, efficient bulk handling procedures dramatically reduce the losses to both the farmer and to the dryer/storage/mill facility owners, and reciprocally increase the financial return to these groups.

Costs

Overall, the implementation of bulk handling technology will significantly reduce the costs associated with the harvest, procurement, and subsequent handling of a grain crop. Initially, however, costs must be high due to the need to invest in expensive capital equipment such as auto headers, mobile field bins, tractors, road trucks, and high capacity drying, storage, and milling complexes.

Difficulties must arise, particularly where the individual farmer is concerned. No single farmer is likely to be able to afford the equipment and, even if he could, his farm would be too small to fully appreciate the benefits. Just to obtain a header, field bin, tractor, and two trucks, the total cost would be of the order of US$250 000–300 000.

The formation of farmer cooperatives or district associations to buy and share equipment and, where necessary, restructure farms would seem to be essential.

Government intervention and assistance in the financing of bulk handling equipment also appears to be the only alternative, although once a system has been put in place and has proven itself, private enterprise may then consider investing in the technology.

The establishment of satellite high capacity drying and storage facilities is essential to prevent the back-up of wet paddy awaiting drying. Such facilities are extremely expensive, costing somewhere in the order of US$100 per tonne for an in-store drying system, or a total of at least US$100 000 for a column dryer and associated bins.

The dry grain must be milled out before the arrival of the next crop, creating the need for an integrated rice mill of a capacity to meet the inputs from the rice drying and storage depot assigned to deliver to it. Estimated costs for establishment of a 20 tonne per hour mill are of the order of US$3 million.

Obviously, the total initial cost of adopting bulk handling technology is high. However, the benefits derived, particularly the reduction of quality losses and greater efficiencies achieved would ultimately outweigh the costs. It is essential that, as part of the fully integrated grain bulk handling system, proper and efficient management of the entire system be implemented. There are financial gains to be made by the use of computers in production programming and forward planning.

Social Impact

While the successful adoption of bulk handling would increase farmers' incomes and the quality and quantity of rice produced, these benefits and associated cost savings would also lead to a reduction in the size of the workforce needed for harvesting, handling, and processing the grain.

For this and other reasons, the introduction of bulk handling, for all of its benefits, must be considered in the light of the effects it may have on the socioeconomic situation of the rural population in particular, and the nation in general. The social structure of many Southeast Asian rural communities is centred on the rice industry. Particular relationships, both social and economic, exist between farmers, traders, millers, and labourers hired at harvest time. Each farmer owns a smallholding of land over which he has complete control. These circumstances would inevitably be altered if not eliminated as part of the social structure were bulk handling systems to be introduced.

Irrespective of the benefits of bulk handling, there would be a substantial reduction in the number of people employed, thereby changing the national social and financial structure. Redeployment of the unemployed would become a serious national consideration.

Physical restructuring of farms into larger areas, and grouping of farmers into larger cooperatives, will require time and cooperative effort from both private and government bodies.

Working Conditions

Having accepted that bulk handling eliminates all manual effort then the major benefit gained should be all round better health for the community. Manhandling of heavy bags of grain affects the posture of workers. Threshing, winnowing, bag tipping, and general grain handling generate inhalable dust which is responsible for respiratory complaints. Long hours in the field, working in high humidities and temperatures, lead to fatigue and slow progress. In general, conditions for workers in the grain industry in Southeast Asia are, by western standards, less than satisfactory.

While Southeast Asian farm labourers may be inured to harsh working conditions, the human cost to the community of bag technology will be reduced by the introduction of bulk handling and the benefits will ultimately be expressed in an improvement in the living conditions and general health of the population.

Conclusion

The implementation of bulk handling technology on an industry-wide basis will contribute to the reduction in postharvest losses associated with grain spillage and loss of quality. The costs of production on the farm and of subsequent handling and processing will be reduced. The combination of these two aspects will ensure that the consumer is supplied with a high quality product at the lowest cost and that the return to growers is improved.

Also, an improvement in the living conditions of the population could be expected to follow the change from labour-intensive, bag handling technology.

While bulk handling has many advantages, rationality must prevail in introducing it into an industry that employs a substantial percentage of the population. Serious consideration must be given to the likely impact of the introduction of bulk handling on the community as a whole. So great are the potential social and financial changes that the issue must be dealt with at a national political level.

Reference

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Key Considerations in the Adoption and Application of Bulk Handling and Storage Systems for Grain in Developing Countries

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Abstract

This paper outlines the key areas which must be considered when contemplating the change to bulk handling of grains within climatic and social conditions as found in Southeast Asia. It is essential that the adjustments required are incorporated in all sectors of the grain handling chain and not solely confined to certain operations. The paper details the relationship between the key sectors and reviews technical aspects relating to the changes required in the harvesting, handling, drying, and storage of the crop. An assessment is made of the marketing, quality incentives, and social implications that are an integral part of the introduction of bulk handling.

Examples are given of cost benefits and incentive premiums that have been introduced in certain areas to obtain higher quality grain in the bulk handling system. The paper also seeks to demonstrate the implications of introducing new technologies into the system without consideration of existing handling, storage, and related systems.

The paper draws largely on practical experiences derived from work carried out in Southeast Asia over a number of years. Particular emphasis is placed on the storage, drying, and handling of rice in Malaysia, Thailand, and Indonesia, together with experience gained in Thailand on programs to reduce aflatoxin in the maize crop by introducing changes to the drying, storage, and marketing chain.

THERE can be few subjects in the field of grains postharvest handling and marketing which have created more dialogue, controversy, and experimentation in recent years than that of bulk handling of grains in developing countries. In many cases, bulk handling has been held up as Utopia in the achievement of lower losses, higher quality, and reduced costs. It may be that this is so in specific areas, but I fear that many people have launched headlong down this road of development without fully considering all the various consequences.

In much of the so called 'developed' temperate zones, most grains are harvested, transported, stored, and processed in bulk. However, this did not happen overnight. The bulk handling process was introduced and refined over a long period, in response to changes in local farming methods. As new technologies are introduced and social patterns change in the future, this 'evolutionary' practice will continue.

Over the past 10 years or so we have seen much of this technology introduced into the developing countries. In some cases a structured introduction has taken place and success has followed. In many cases, however, the result has been disastrous due to the fact that the whole process chain was not reviewed and local conditions were not taken into account. This is the area that I will be concentrating on in this paper.

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Bulk handling is not a commodity that can be fitted in here and there without respect to its surroundings. It is a structured concept which, if applicable, must be introduced in sympathy with its surroundings and which may also result in changes to those surroundings. I therefore hope that at the conclusion of this workshop we will go away with not only a greater knowledge of the individual components which make up the subject, but also a fuller appreciation that success will come only if we consider these components as a whole and not just individually.

Overall Considerations Affecting the Adoption of Bulk Handling and Storage

The reasons for introducing bulk handling and storage have been fully covered in the paper before this one. However, before the decision is made, it is essential that an in-depth investigation be carried out into the overall crop production and marketing chain. This will dictate whether or not bulk handling should be introduced and, if so, in what form and to what extent other overall changes have to be made. As an illustration, let us look at two typical marketing and production chains: the private sector and the public sector.

Private Sector

Retailer, Exporter, Feed Miller

In many cases, this sector has to process its raw materials on a continuous-flow basis and, in the particular case of the large exporter (and feed miller), his customers will require him to supply the resulting commodities in bulk. Labour costs will be high in this type of situation and mechanical handling should therefore be utilised to reduce costs. This can also help to reduce losses, but this is more a function of good management than just a change in operating methods.

We therefore have a general situation whereby if the operation has sufficient capacity there can be genuine operational and technical reasons to introduce bulk handling and storage. Notice I did not say 'convert to' because at this stage it may be practical to introduce only certain operations.

Having accepted that change is required, how does it affect the other sectors in the chain?

Many of the merchants supplying the exporter or miller will still be delivering in bags; the grain recipients will therefore have to be able to accommodate both bag and bulk deliveries. In itself this should not be a problem, but particular attention must be paid to the labour situation. If other sections of the exporter's operations have already been converted to bulk handling and storage, the amount of labour may well have been reduced. During normal delivery rates this will not cause a problem, but at peak times it may result in unloading delays, and as we all know, truck drivers are not the world's most patient people.

The change in the labour situation can also affect the drying methods. I will go into greater depth on this in the next section, but if the exporter/miller has installed a modern dryer he will need a continuous inflow of grain. If the majority of the incoming grain is in bags, large amounts of labour may still be needed to ensure an unbroken flow. It also may be that he still has to use a sun drying floor during peak periods. This all too frequently coincides with the rainy season and the grain has often (in many cases too often) to be rapidly swept up before it rains. Here again he may find that he has insufficient labour if he has cut back in other areas. The introduction of casual labour, even at low pay rates, may have a significant effect on the viability of the bulk handling operation.

In summary, the large exporter/mill owner may be justified in introducing bulk handling and storage, *but* he must take into account how the grain is delivered to him and his labour situation.

Middle Merchant/Small Miller

The up-country merchant is a good example of this type of operation as he is buying directly from the farmers and selling to the exporters, larger feed mills, and other retail outlets. We can also include the smaller rice and feed mills in this section.

So why should this section of the trade consider the introduction of bulk handling and storage?

Firstly, there is the possible attraction of lower operating costs. This could be brought about by such factors as rising labour costs in the area and increases in the cost of bag purchase and repair. The availability of reliable labour could also be a factor. In many cases, these merchants rely on sun drying floors for drying and it is in this area, together with bag stacking and handling, where there is major labour usage. In these cases, the merchant may well be tempted to introduce bulk storage for the dried grains and invest in mechanised handling, such as front-end loaders and scrapers for clearing the sun drying floor.

In theory this is all well and good but, especially in the humid tropics, the wet season can play havoc with the sun drying floors. The net result can be wet grain being loaded into the bulk storage in order to make room for a new intake of grain to the sun drying floor. This can result in grain deterioration and losses even greater than if the grain were loaded directly into bags. The result is that the merchant still has to retain high levels of labour but, at the same time, has also introduced some expensive mechanical handling aids. Unless his customers will pay a price premium for grain in bulk, the small merchant may well be better off staying with his existing system.

Having painted a fairly bleak but, I believe, realistic picture of this first stage venture into bulk handling and storage, let me consider the addition of a mechanical dryer to the merchant's system.

We are now talking about high investment costs, so economic success of the operation is very dependent on the incentives available and the size of operation. For example, for an 8 tonne per hour dryer (at 5% m.c. removal) a monthly seasonal throughput of about 4000 tonnes has to be achieved. There are many factors, such as quality improvement and reduction in postharvest losses, which can contribute to the reasons for investing in a dryer. However, in many countries it cannot make economic sense, unless incentives are available for moisture content reduction and other quality factors, such as aflatoxin levels.

An accompanying Box gives an example of levels of profitability associated with use of an up-country dryer in Thailand.

There are many types of dryer to choose from and while this is outside the scope of this paper it is covered elsewhere in these proceedings. The type installed is, however, relatively unimportant as regards how it affects the overall question of bulk handling and storage (excepting those used with bag drying). To be fully efficient, any dryer must run close to its design capacity. Therefore, a constant flow of grain to it is of the utmost importance. With a large number of small farmers supplying grain, the situation will soon arise when either too much or too little grain is received *unless* it is correctly managed. With the former, wet grain will pile up and, given hot, humid conditions, will deteriorate before it can be dried. In the latter case, the dryer will be running under capacity and will be very uneconomical.

It can therefore be seen that, whatever form of drying is introduced, its success will depend largely on the consistency of the grain supply. With mechanical drying (particularly the continuous-flow type) this is of even greater importance, as an investment has been made of US$30–80 000 and a profitable rate of return has to be shown.

Before a bulk handling, storage, and drying system is installed, the merchant must therefore analyse the whole cycle of grain supply. The result may be that he has only to plan and manage his collection program effectively. However, it may mean that the farmer has to release his grain earlier to provide a constant grain flow (before prices have peaked?) and it may therefore be necessary to offer him a price incentive. Such a consideration affects not only the smooth running of the system but also can have a major reflection on its economic viability.

As regards labour costs, it is doubtful if there is any great saving at the middle merchant level. Data in Fredericks and Wells (1983) indicate that the difference in employment levels between bag and silo storage at this scale is small and the addition of the dryer will have little effect (the sun drying floor will still be used in most cases).

It is therefore very doubtful that the introduction of bulk handling and storage *for its own sake* is necessary or viable at the small to medium level of merchant (less than 1000 tonnes storage capacity). However, if other

A Sample Analysis of the Profitability of Up-country Drying

This is an example from Thailand, involving use of a continuous-flow dryer of nominal capacity 5 tonnes per hour, burning diesel fuel. Ambient temperature is 30°C and relative humidity 80%. Costs and benefits are given in Thai baht (approx. 26 baht = US$1).

Capital Costs

Dryer	1 040 000
Conveying, electrics, installation	300 000
Total	1 340 000

Fixed Costs

Depreciation: 10 years	134 000
Repairs and maintenance: 5% of capital cost	67 000
Interest: 13% of half capital cost	87 100
Permanent labour: 20 operators for 3 months	19 800
Total	307 900

Output

	August	September	October	Total
Moisture content reduction	25–14%	22–14%	20–14%	
Daily output capacity (t)	140	168	214	
Output at 80%: month (t)	3360	4032	5136	12 528
Output at 50%: month (t)	2100	2520	3210	7 830

Variable Costs

	August	September	October
Oil cost/t	84.0	69.6	54.9
Electricity cost/t	7.1	5.9	4.7
Labour & handling/t	18.7	19.1	18.9

Benefits

	August	September	October	Total
TMPTA* scale @ baht 2/kg	246.4	168.6	75.4	
Freight saving, say	10	10	10	
Quality premium, say	50	50	50	
	306.4	228.6	135.4	
Less variable costs, above	109.8	94.6	78.5	
Gross margin per tonne	196.6	134.0	56.9	
A. Gross margin at 80% drying capacity				1 491 048
B. Gross margin at 50% drying capacity				931 905
C. Gross margin at 80% drying capacity and 70% TMPTA scale				922 651
D. Gross margin at 50% drying capacity and 70% TMPTA scale				576 657

*TMPTA (Thailand Maize and Produce Traders' Association) scale benefits represent extra weight gained after actual moisture content adjustment, e.g. for grain purchased at 25% moisture content and sold at 14.5%:

Weight allowance per TMPTA scale	246.0 kg
Actual weight of water lost	122.8 kg
Extra weight gained	123.2 kg
Value at 2 baht per kg	246.4 baht

quality incentives are present then there will be a case for its introduction.

I would also stress that it should not be expected that the introduction of bulk handling and storage will automatically result in an increase in grain quality. A well-managed complete bag system of handling and drying can give the same results. Granted it is not as easy to control, but for the small operator it may be the answer. *It is the management of the system that is the most important factor.*

Farmer

As stated at the beginning of this paper, most of the farmers we are dealing with are small and have been trading in the same way for many years. We therefore have to be very careful in introducing changes. Any means of upgrading farmers' incomes is welcome and should be pursued. However, change for its own sake is unwelcome.

In many cases, farmers already practice bulk handling, e.g. the storage of maize on the cob and grain in small stores made from local materials. In the latter case, this is often the most economical method, but where the farmer is selling directly to his local merchant it is often necessary for him to use bags. It is therefore the merchant who dictates how the farmer presents and handles his crop, even to the extent of supplying the bags.

One further reason for a farmer continuing to use bags, even if the merchant is introducing bulk handling into his system, is the question of trust and control of his produce. I am not trying to suggest that the merchant is seeking to gain advantage, but it *has* been known and the use of bags can give the farmer greater confidence. In the long term, the introduction of weighing and recording equipment by the farmer will overcome this, but this costs money.

The small farmer therefore need not concern himself too much at the moment with bulk handling and storage. It would be better to concentrate on general quality improvements to his system and ensure that there is proper coordination with his customer, the merchant.

With regard to the larger farmer, then investment in bulk handling and storage equipment may be worthwhile, but again it must be in tune with the other sections of the marketing chain.

A further alternative is the use of contractors who specialise in bulk harvesting and handling and who can coordinate a number of small farmers and deal directly with the merchant. In this case, the identification of the individual farmer's crop may be a concern and a clear purchasing structure therefore has to be established.

Public Sector

At this point I would like to look at the situation in which a farmer sells directly to the government store or processing facility. In many respects, the basic principles which affect the introduction of bulk handling and storage into this sector are the same as already reviewed. However, the scope for its successful operation can be much greater. Government stores are generally erected to store and/or process grain for long periods and therefore require substantial holding capacity. This puts high demands on levels of management, cost control, and maintenance of quality. As with our previous review, we have to consider all the parameters before a recommendation can be made whether to use bags or to introduce bulk handling and storage.

It is often the economic considerations at the store which will determine the route to take. With large stores, the costs of labour and ancillary items such as bag replacement and repair can be high. The inclusion of mechanical drying and processing will reinforce the need for bulk handling and storage, but it must again be stressed that its success will primarily depend on the ability of the management.

As with the exporter, merchant, and farmer, the government store cannot be operated in isolation from the other components in the production and marketing chain. The most important factor is once again how the grain is presented to the store and the coordination in ensuring that the supply is in line with the demand or capacity of the store.

In a number of countries, notably Zambia, it has been recognised that government stores should not all be large central units. The large bulk stores are close to the centres of population, whereas those up-country are predominantly smaller bag stores (up to 5000 tonnes capacity). This permits a great deal of flexibility to be built into the system and with good management and mechanical aids to bag handling, they can be operated very efficiently. This can be a very attractive solution where farmers are supplying the grain in sacks and where the road and transport system is not capable of dealing with bulk transport. It should be stressed, however, that this form of storage is much easier to adopt and maintain in drier climates.

With large stores, which incorporate continuous-flow dryers and other bulk handling facilities, it is even more important to try to maintain a constant supply of bulk grain wherever possible, so as to ensure their most economic operation. If this situation cannot be achieved immediately (and this is invariably the case), then tolerances have to be built into the system. At peak times, the supply may exceed the dryer's capacity, and facilities have therefore to be provided to hold this grain so as to prevent deterioration before it can be put through the dryer. Whether the grain is in bulk or bags, these facilities must include some form of aeration, pre-drying, and grain cooling.

In areas of the world where bulk storage and transport is operated together with mechanical harvesting, it is generally the capacity of the dryer which dictates the speed of harvesting (ignoring abnormal weather conditions). The whole system is therefore integrated, but with large central stores and a multitude of small farmers, this is obviously difficult to achieve. In Malaysia we have a situation in which much of the rice crop is harvested by contract combines. This overcomes many of the problems of collecting from a large number of small farmers and provides an immediate incentive to promote bulk handling in other parts of the production and marketing chain. If this could be linked with efficient bulk transport to the present stores, then the overall efficiency of the system would increase dramatically. There must also be incentives to farmers to deliver drier grain to the procurement centres.

In summary then, those authorities contemplating the introduction of bulk handling and storage into their central storage/processing facilities must consider the following issues:

1. Does the scale of operation justify the capital cost of introducing bulk handling and storage? Do you have the necessary technical skills available at the operational level? Can you build into the system the necessary facilities to overcome the inflexibility of the bulk storage system?

2. If the above criteria can be met, then please consider the whole system from planting to processing before introducing any bulk handling systems. When starting from scratch you have the opportunity to 'get it right first time'. Take that opportunity.

3. If you already have bulk handling facilities, then fully integrate them into the system as soon as possible. If you do not, your original investment will be wasted and it will disrupt your present operation.

Component Application

The preceding sections have looked at the overall considerations prior to making a decision on the adoption of bulk handling and storage systems. We must now look at the individual equipment and practices which are incorporated within the production and marketing chain and how suited they are to bulk handling and storage.

As the purpose of this paper is to give an overview of the application of bulk handling and storage, I will again concentrate on the interrelationship of these 'components', especially as following speakers will be elaborating on individual aspects.

Cultivation and Planting

Where a fully integrated bulk handling scheme is to be introduced, the harvesting of the crop will almost certainly involve some form of combine harvester. Such a machine will work efficiently only if the fields are relatively level and are of sufficient size. In the case of paddy fields, they should be capable of being fully drained, so that wherever possible the combine is working in dry conditions. The method of planting should also be uniform and the variety suitable for mechanical harvesting, e.g. maize grown in straight rows and rice varieties that will stay erect during harvesting.

An analogy that could be drawn is that you were given a car but there were no roads. I suspect that you would not not be very pleased with it and certainly you would not be able to use it as the manufacturer intended.

The combine harvester's capacity must be considered. Sufficient bulk trailers are needed to prevent the combine stopping whilst harvesting, otherwise it cannot be operated efficiently. With so high a capital cost item its full potential has to be realised otherwise it is not cost effective. Easy access for the trailers to the road is also important, as are facilities to transfer the crop to the 'main road' transport.

Combine harvesters incorporate a great deal of sophisticated equipment to ensure that the crop is efficiently harvested, threshed, and cleaned. They must therefore be accurately set up in order to produce undamaged and clean grain. In consequence, it is essential that the operator has the experience to adjust the machine correctly and that the necessary spare parts and service are readily available.

Time spent on getting the harvest and pre-harvest sectors right will make postharvest operations easier.

Roads and Transport

This is a very obvious area of consideration, but one which is often overlooked. One of the major reasons for converting to bulk handling and storage is to reduce losses. However, poor transport can often completely negate the advantages gained. Transport is also one of the highest cost areas and its efficient management, both in terms of size and type, as well as scheduling, can have a significant effect on the overall viability of the operation.

The condition of the roads is also very important. Up-country areas often have poor roads which can be impassable by large trucks in the wet season, and which can therefore seriously affect the supply of grain as well as its quality.

Power Supply

Before we look at the 'in store' components, the power requirement of the equipment must be considered. Most bulk handling equipment is electrically powered, and ranges from large 10–75 h.p. (7.5–55 kW) fan motors, to small 1–2 h.p. (0.75–1.5 kW) motors driving elevators and conveyors. They all add up and it is therefore of prime importance that checks are made before equipment is ordered to ensure that the necessary power is available or can be obtained. Allowance must also be made for the high start-up power requirement of large fan motors. Adequate supplies of fuel for the dryer burners must also be available.

Cleaning and Handling Equipment

Bulk handling and storage relies very heavily on efficient handling equipment. The movement of the crop between the harvester, transport, dryer, storage, processing, and the customer is the 'glue' which bonds the whole system together. If this is not correct, then the whole system will collapse. Unfortunately, this is very often the case, with expensive components being linked together by poor handling equipment. Much of the grain handled in developing countries—especially paddy—is very hard on handling equipment. This is particularly critical when using screw augers (which are cheap to buy) and pneumatic conveyors (which are expensive, but flexible in use). Bucket elevators, chain and flight conveyors, and belt conveyors are less prone to wear, but here again the layout has to be properly designed in the first place. It is also essential that all handling equipment be properly maintained. It may not be the most expensive or glamorous section of equipment but, if it breaks, all else stops.

With bag handling, a certain amount of rubbish in the grain is acceptable, apart from quality reasons. However, with elevators, conveyors, and dryers in the system any straw, stones, etc., can seriously reduce equipment efficiency and even block the whole system. A correctly set combine harvester will minimise the problem, but it is also important to provide some form of pre-cleaning facility prior to drying/storage.

Drying and Storage

The incorporation of dryers into the bulk handling system has been discussed in the preceding sections and is dealt with in detail in other papers in these proceedings. I shall therefore make just a few comments on the subject.

The crop must be at a safe moisture content before it is stored for any length of time. That is an accepted fact. In the humid tropics, this means drying on a sun drying floor, in a mechanical dryer, or whilst in store.

Drying in the sun is common practice, but in the wet season can result in high losses and reduced quality through continual rewetting. It is also very labour intensive, even if mechanical handling methods are used. In short, it is generally incompatible with bulk handling.

Mechanical dryers are commonplace with exporters, larger mills, and government stores and processing facilities, and are slowly becoming more popular with up-country merchants. Their two biggest problems are that they cost money (both to run and purchase) and that they need strong management.

The two types of dryers in most common use in grain stores and mills are batch dryers and continuous-flow dryers.

The batch dryer can be used for both bags and bulk and is most suited to the operator who has a small to medium throughput of grain and requires flexibility to adjust to varying amounts of grain input. The main drawback is the need for large volumes of labour (especially for bags) for loading/unloading. Labour requirements may be only partially reduced by using elevators and conveyors.

Continuous-flow dryers are designed for bulk handling operations, but can be a very expensive investment if they and associated operations are not fully integrated. The whole *system* must be 'continuous flow' and therefore has to be planned to allow for fluctuations in the grain supply. This type of dryer is also dependent for its efficient operation on automatic controls which require higher levels of technical competence from the operator.

With certain crops, such as very wet rice, it may also be necessary to recirculate the crop in order to remove sufficient moisture. This can lead to much longer drying times than expected and, in consequence, higher costs. This also emphasises the need, during the design stage, to carefully select the size of dryer and other facilities, based on the worst possible case.

In Malaysia, LPN has shown that a combination of the two systems, i.e. batch and continuous-flow dryers, can be effective. The batch dryer is used to pre-dry the crop before it passes through the continuous-flow dryer. This may involve double-handling, but it reduces the number of passes through the continuous-flow dryer and thereby helps to reduce overall costs.

In-store drying and storage over ventilated floors or laterals have been proven to work in the humid tropics (Calverley 1986). Their application is still limited but, with good management, I believe they could well be the answer in many bulk storage situations, without the high capital cost of steel or concrete silos. They also permit greater flexibility and can utilise existing bulk handling equipment, such as tractor mounted front-end loaders.

Whether steel silos, concrete silos, or on-floor stores are used for grain storage they must be ventilated to ensure that the crop is maintained in a 'fresh' condition. There must also be the capacity to turn or recirculate the grain if monitoring equipment indicates damp patches and/or insect activity. Pre-dusting of the store is also advisable to minimise insect damage, as is efficient rodent control around the store complex. The increased testing and application of grain coolers in tropical stores should also be encouraged.

Maintenance

Bulk handling and storage requires a wide variety of mechanical and electrical equipment. Even the best designed and installed machinery will fail if it is not adequately maintained. A grain store produces a lot of dust, heat, and moisture which combine to create the worst possible atmosphere for electro-mechanical devices and, unless there is regular maintenance, failures will occur which can result in crop being lost.

Conclusion

Bulk handling and storage is a wide-ranging subject, embracing many diverse components. While each of these components is a subject in its own right, all are totally dependent on each other for their successful operation. In this paper, I have tried to show how important it is that these components be considered as a whole and not just individually. It is my personal experience that failure to do this is the major reason why many bulk handling and storage systems fail prematurely.

Before the decision to introduce bulk handling and storage systems is taken, I would caution everyone to think very carefully and ensure that all the parts of the jigsaw are present and that they fit together in the correct manner.

So is bulk handling and storage really needed? In many cases the answer is, I believe, 'no'. Each case is different and should be judged accordingly, but in many developing countries the small scale of operation, sociological factors, and the need for flexibility may not justify the investment and supposed quality improvements. The additional money and effort would be much better spent in upgrading the present systems.

In the case of the exporter, large merchant, and government store, the introduction of bulk handling and storage may well be justified. However, it must not be introduced without a full investigation of the grain supply chain.

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Overview of the Current Status of Bulk Handling of Grain in ASEAN

A.S. Cabigan*

Abstract

Bulk handling of paddy, rice, and maize in the ASEAN region is not yet a commercial reality, in contrast to the bulk handling practices employed by flour millers and animal feed processors in the same area.

Current problems addressed in technology transfer for bulk handling include mechanical conveying of produce at farm level, modular bulk transport through feeder roads en route to collecting centres, enhancement of drying capacities of continuous-flow dryers, condensation of moisture on the surfaces of storage silos, pest control, temperature regulation of bulk stores, and use of indigenous materials for construction of storages.

These problems are addressed through institution building for organised farmers' marketing groups, technology development for site-specific applications, and technology transfer of appropriate operating systems. The ASEAN countries are more advanced in the first two approaches. The third approach lends itself to new and more effective methods of technology adoption.

BULK handling of ASEAN's major cereals, paddy and maize, has been advanced as a logical consequence of improving yield levels, rising consciousness of quality factors in grain markets, increased trading volumes, and the need to reduce handling costs and postharvest losses. Some quarters even state that the decision is no longer based on whether or not bulk handling should be developed as the postharvest mode, but rather how fast its adoption can be accelerated while providing for a smooth transition from the current grain handling in bags.

An ACIAR-assisted study in the Philippines grains postharvest sector concluded that 'mechanical drying supported by a bulk storage system ... has the largest expected benefits' out of the several options evaluated for technology transfer.

However, bulk handling methods cannot be viewed as discrete phases in the postharvest system. Bulk handling needs to be addressed as a complete system which links the receival of grains at the farm gate, transport to collection or processing centres, cleaning, drying, and storage in terminal silos, milling and grading, and transport to markets and consumers. If this is not done, operational irrationalities will occur, since the need for reversion to bag handling cannot be avoided at points in the handling system where a bulk handling component is unavailable.

In commercial-scale handling of grains, the most notable models are those of flour millers who must handle imported bulk wheat through bulk unloaders, store it in concrete silos, and revert to bag handling only for finished flour and

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milling by-products. To a lesser degree, feedmillers for the poultry and pig industries undertake bulk handling as a necessary complement to milling and compounding operations. Only the finished product is bagged.

Large-scale operations of this type have not yet been observed as a commercial reality for handling paddy, maize, and rice in ASEAN.

While bulk handling has been a common practice in Europe, the United States, Australia, and elsewhere, it took some time even for these countries to effect a conversion to full-scale bulk handling. The problems the various countries have encountered during bulk handling technology development appear to be similar in many respects, but the solutions to these problems appear to be inappropriate to grain handling problems in ASEAN. The wide distribution of harvest seasons, the tropical climate, the fragmented landholdings among paddy and maize farmers, the large number of varieties and regional preferences and, to some extent, the lack of uniform grades and standards, all exacerbate the problems of bulk handling technology adoption.

Yet the ASEAN countries have not been remiss in identifying and proceeding with strategies to address the problems of bulk handling technology research and development, and technology transfer. Among the range of bulk handling studies undertaken are those concerning conveyors for grains at field level, at buying station level, and at the milling centres; modular bulk transport to move grains through feeder roads from the farm gate or from collection centres; tests of materials and designs for bulk storage, specifically in relation to moisture condensation and the general physics of the grain while in bulk storage; integrated pest management; control systems for the storage environment; and enhancement of efficiencies of mechanical dryers through multi-stage drying operations.

There is a feeling that the possibilities in the development stage of grain bulk handling have been adequately identified. Validation tests are underway, and there is optimism that appropriate types of grain bulk handling technology will emerge in the ASEAN region. With the guidance of development assistance agencies, whose technical and financial support gives substance to these concepts, it is anticipated that appropriate technology transfer can be achieved.

Various distinct programs for rural development are already coming together in most ASEAN countries, creating areas of effectiveness. Programs that encourage group marketing and cooperation among small farmers, for example, work towards increasing the volume of market-directed grain produce to levels that allow for economies of scale in bulk handling and storage. The development of pre-drying equipment for fast reduction of the moisture content of wet harvested grain, buys time between harvest and final drying, without incurring significant losses in grain quality. Aerated tempering bins, an essential complement to bulk storage silos, enhance the utility of costly but efficient large capacity, continuous-flow dryers so that they can be operated over a longer time span than peak procurement periods. Small capacity, aerated modular bulk transport equipment currently being validated, will improve the usefulness of narrow feeder roads as part of the grain collection networks.

These welcome developments occur spontaneously, disparately, and discretely as a result of fragmented implementation of projects, in response, most of the time, to specific terms of reference worked out between implementors and program sponsors. What ASEAN needs is a unified, regional approach to bulk handling as an entire system, qualitatively in the technical, economic, and social acceptability aspects; and structurally in conveying, drying, transport, storage, processing, quality control, and marketing aspects. Only a systems approach will work, and only a complete system will operate in a rational mode.

Finally, as a system, bulk handling must evolve into a set of practices which can be assimilated into the trading patterns of grain market participants. An innovation does not effect meaningful change until such a time that its 'foreign' identity as a change is lost and absorbed into common practice while retaining the essence of its efficiency.

Perspectives of Bulk Handling and Storage of Grain Session Summary

Chairman: Mohd Yusof bin Hashim*
Rapporteur: Abdul Rahim bin Muda*

THE three papers in this first working session gave a concise overview of the main issues that need to be addressed in considering the introduction of bulk handling and storage in the humid tropics. The papers dealt with:

- the rationale and practical aspects of bulk handling;
- the key considerations in adoption and application of bulk handling; and
- overview of the current status of bulk handling in ASEAN.

All three presenters have had wide experience and involvement in their respective fields in the ASEAN region. Their familiarity with the status of the technology, as well as economic, social, and political circumstances in the region, enabled them to identify the most relevant issues in considering the problems and constraints to adoption and application of bulk handling of grains. Indeed, the three authors were in unison in recognising several underlying facts pertaining to bulk handling in developing countries. These can be summarised as follows:

- The rationale for bulk handling is due to the need to reduce costs and losses at various stages in the postharvest chain.

- The prevailing bulk handling practices in this region are fragmented and do not integrate the whole range of bulk handling technology available to the grain industry.

- Farmers and authorities concerned with grain handling in developing countries recognise the need for mechanisation, but adoption is held back by the high costs involved, poor infrastructure, small land holdings, diverse cropping practices, and other social and economic limitations.

- Adoption of bulk handling cannot be achieved overnight. It is a gradual process and took a long time to complete in countries such as Australia, Europe, and the United States. It could reasonably be expected to take much longer in developing countries. What slowed down the progress of conversion from bag to bulk systems in developed countries was perhaps the technical changes required and the initial high capital costs. However, the large farm sizes and high labour costs left the farmers with little choice but to change to bulk handling. The situation is different in this region. Besides the cost, the appropriateness of the available technology is still debatable and, more important, the socioeconomic implications, such as the likely loss of jobs,

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need careful consideration. Perhaps, as suggested by one speaker from the floor, what is more appropriate at this juncture is to incorporate the most efficient aspects of bulk handling into existing handling systems.

Several general recommendations were made which could hasten the systematic conversion to bulk handling under prevailing constraints in this region. These included:

- restructuring of farms into larger units, by a group farming or estate management approach;
- establishment of satellite drying/storage facilities;
- government intervention to assist in organisational and financial requirements; and
- provision of incentives for the private sector to invest in the technology.

A number of important points and issues were raised during the general discussion that followed presentation of the three papers. On the technical side, the possible wider role of the so-called 'jumbo bags' as a component of a bulk handling system was considered. These large sacks, which hold 1 tonne of grain, are in widespread commercial use in Thailand. Most of the discussion, however, centred on socioeconomic issues. There was general concern to identify which groups would benefit most from the introduction of bulk handling and in particular what benefits, if any, might flow to farmers, the group in most need of help. Various speakers ventured opinions that all participants in the postharvest subsector—producers, traders, and consumers—stood to benefit from the introduction of appropriate forms of bulk handling technology, but that the greatest gains would probably be made by consumers in terms of the availability of higher quality grain and lower prices.

Technical Aspects of Bulk Handling and Storage—State of the Art

The Stages from Grain Harvesting to Procurement, Including Field Collection, Transport, and Grading

Loo Kau Fa*

Abstract

This paper describes the current paddy handling practices in Malaysia, from harvesting to procurement, including field collection, transport, and grading. The role that bulk handling can play in overcoming existing problems is examined, with particular reference to quality aspects, economics of operation, and general facilitation of grain movement and management. Finally, the technological changes that are needed to effect the conversion from bag to bulk handling, and their constraints, are identified.

IN Malaysia, paddy was traditionally cultivated once a year in rainfed, flooded fields. However, with the provision of proper irrigation and drainage facilities and the adoption of short-maturing varieties of paddy, double-cropping is now possible. With this change, the handling of wet paddy becomes a major problem, especially for the off-season crop which is harvested during the wet season. This is due to the fact that wet paddy of modern varieties exhibits lower seed dormancy and undergoes rapid deterioration in quality (Mendoza and Quitco 1984). With the implementation of double-cropping, farmers are faced with the problem of harvesting the first crop and planting the second crop all within a period of six to eight weeks, if the traditional, labour-intensive method of handling is to be maintained.

This paper first reviews the current practices in the various stages of postharvest operations, beginning with harvesting, and proceeding to threshing practices, in-field collection of grain, and transportation to the procurement centres. It also discusses the role that bulk handling can play in overcoming some of the existing problems, with particular emphasis on preservation of grain quality and facilitation of grain movement and management. The technological changes that are needed to facilitate the introduction of paddy bulk handling and their possible constraints are further examined.

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Current Practices

Harvesting

Harvesting is traditionally done manually, with the sickle as the most commonly used tool. Before the actual harvest, the farmer selects and gathers the best paddy for seed, using a sharp hand blade, the 'tuai'. The main crop is cut by sickle and tied into small bundles. 'Shields' are placed on three sides of the threshing tub to prevent the scattering of grains. Threshing is hard work as much force has to be used while beating the sheaves of paddy on the 'ladder' placed inside the threshing tub, which is a wooden box. For historic reasons, gangs of women usually cut the crop and it is left on the ground for the following gangs of men to collect and thresh. In Malaysia, many farmers report labour shortage at harvest and this has led to the two operations of cutting and threshing being separated as long as 4 hours. As most of the wet season harvesting takes place in wet fields, the act of putting cut crop on to the stubble causes an uptake of moisture of almost 6% by the time the crop is threshed (Calverley et al. 1976). The relatively high cost of manual harvesting has acted as an incentive for local agricultural equipment distributors to introduce small, powered reaper-binders, power threshers, etc. as has occurred in several other countries such as the Philippines, Indonesia, and Thailand. However, none of these machines has found acceptance in any part of Malaysia. This appears to be due to their low productivity, the fact that no great reduction in labour requirements is effected and, in some cases, their unsuitability to physical conditions in the major Malaysian rice areas. Power threshers, for instance, save some physical effort in threshing, but a considerable amount of labour is still required for reaping and carrying the rice sheaves to the thresher.

Owing to farm labour shortages and rising labour costs in Malaysia, harvesting has been considerably mechanised over the past few years (Embi 1986). For instance, about 95% of the Muda Irrigation Area is harvested by large, continental-type, self-propelled combine harvesters (Table 1). About 400 units of combine are used in the said Muda area with 90% owned by contractors providing a service to individual farmers.

Under wet field conditions, a large combine can harvest about one-third of a hectare per hour and about twice this area under dry conditions. This includes reaping, threshing, grain/straw separation, and loading threshed grain into a grain tank mounted on the combine itself. Small plot size, though lowering productivity, is never found to be a serious problem. Khairuddin (1986) has reported that it now costs about US$85 to harvest a hectare of paddy using a combine in the Muda Irrigation Area and twice as much if manual labour is used.

The apparent benefit of mechanised harvesting operations is most significant in terms of a reduction in farm labour requirements (Table 2). From a requirement of more than 600 man-hours/ha, it has now been reduced to about 255 for a transplanted crop and is further reduced to 129 when direct seeding is practised.

TABLE 1. Costs and levels of mechanisation in rice farming in Malaysia

	MADA[1]	KADA[2]	Barat Laut[3]
Transplanting cost*/h	1971 - 44		
(excluding nursery)	1976 - 112		
	1979 - 143	1979 - 145	1981 - 148
	1981 - 199	1982 - 190	1983 - 183
Tillage by tractors (%)	1966 - 32		1966 - 11.8
	1969 - 94	1975 - n.a.	1976 - 99
	1975 - 99	1980 - 99	1980 - 99
	1984 - 99	1981 - 99	1983 - 99
Manual harvesting cost*/ha	1966 - n.a.	1966 - n.a.	
(cutting and threshing)	1976 - 193	1977 - 178	1981 - 309
	1979 - 312	1980 - 304	1983 - 338
Combine harvesting (%)	1975 - n.a.	1980 - 1	1975 - n.a.
	1980 - 93	1983 - 3	1981 - 60
	1984 - 95		1985 - 80

Sources: 1. Muda Agricultural Development Agency 2. Karang Agricultural Development Agency 3. Barat Laut rice-growing district, Selangor; personal communications and unpublished reports
n.a. = not available
*Costs are in Malaysian ringgit ($M2.5 = US$1)

TABLE 2. Labour utilisation in paddy production in the Muda Irrigation Project, Malaysia

Type of activity	Transplanting technique 1974	Transplanting technique 1981	Direct seeding technique 1983
	(man-hours per hectare)		
Seed preparation	3.3	3.4	2.2
Nursery preparation	26.3	20.1	0.0
Land preparation	50.4	14.7	8.9
Planting–direct sowing	151.7	132.9	33.9
Fertiliser and insecticide application	12.2	14.4	14.3
Weeding	49.6	10.0	12.4
Water management	1.5	25.0	25.9
Harvesting	254.8	12.2	24.3
Paddy transportation	28.1	17.1	5.0
Postharvest activities	37.1	5.4	2.4
Total	615.0	255.2	129.3

Source: Muda Agricultural Development Agency

Complaints as to grain quality from combines, particularly the high incidence of immature grains and impurities, as well as grain breakage and partial dehusking, are reported by Rohani et al. (1984). Comparison between combine and hand harvested samples (Table 3) showed, among other things, an increase of 4.5% in brokens in the combine harvested samples. However, it is doubtful that such an increase in broken grains is caused solely by machine limitations. More generally, it is believed that the existing paddy grading system and pricing policy should be reviewed in order to bring about the general improvement in grain quality through greater care in crop handling.

The question of field and infrastructure damage is perhaps of greater concern at present. Efforts to introduce small, lightweight, head-feed type combines have not succeeded so far, due to their low rate of work, and lack of durability under contractor use. Small combines have also been reported to be more expensive in relation to output (Ahmad 1986).

TABLE 3. Comparison of quality of samples of combine and hand-harvested paddy

	Combine-harvested samples	Hand-harvested samples
Impurities (%)	5.50	4.20
Injured grains (%)	0.54	0.00
Cracked grains (%)	1.60	0.60
Immature grains(%)	7.40	5.50
Total milling yield (%)	66.70	67.30
Head rice (%)	87.60	92.10
Brokens (%)	12.40	7.90

Source: Rohani et al. (1984)

In-field Handling

Collection and transportation of paddy in jute or hessian sacks are still the most common practice, though in some instances, plastic woven bags are also being used. The present system invariably entails bagging of grain before it is transported, irrespective of whether it is manually or machine harvested. Each jute bag weighs about 80–90 kg when filled. Bagging is found to be cumbersome, time consuming, and uneconomical, and creates bottlenecks in the postharvest operations particularly in terms of grain sorting and grading at the receiving ends. Figure 1 illustrates the present options for collection of grain after harvesting. In the case of manual harvesting, threshed wet grain will be bagged in the middle of the field and carried to the farm road. The in-field transport can be accomplished in a number of ways, the most common being by bicycle, motor cycle, and buffalo sledge.

To load the bicycle or motor cycle, the jute sacks are carried from the field, often through mud and water, to the narrow bund where the machine is propped up on its stand. The bicycle usually has a load of one sack, whereas one to three sacks of paddy may be carried by a motor cycle, depending on the bund's condition. The bunds are generally not more than 300 mm wide and it is along these that much of the output of paddy must travel. Obviously, it is a difficult and arduous operation to transport paddy from

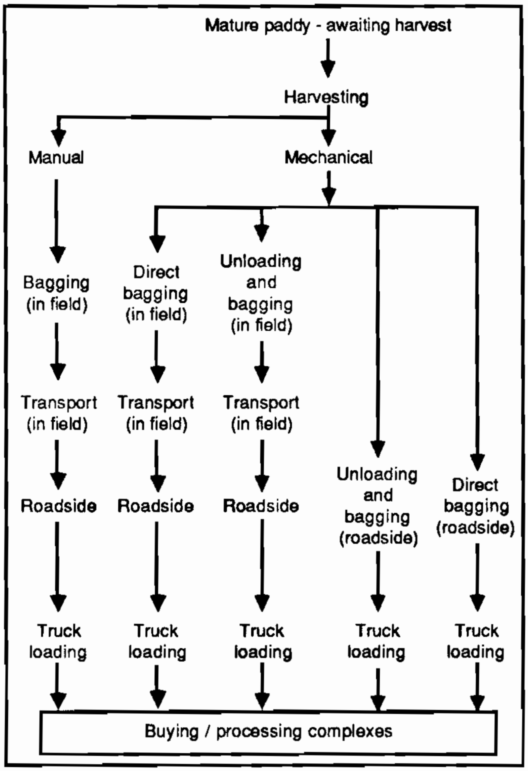

Fig. 1. Diagram showing steps in the existing postharvest system in Malaysia.

the field to a laterite or metalled road, from where it can then be carried by lorry to procurement centres.

A survey of Muda paddy fields carried out in 1976 (Calverley et al. 1976) indicated that 64% of the parcels of land were within 250 m of a laterite or metalled road. In some of the larger blocks, the distance was as much as 1250 m, but this was exceptional (Table 4). Apart from distance, the limited number of access bridges across irrigation waterways and drains imposes additional limitations on accessibility. Figures 2 and 3 give a schematic representation of a typical irrigation block in the North-West Selangor project area and the Muda Irrigation Area, respectively. In the former area, total paddy land within each block varies between 60 and 80 ha comprising 50–60 farmers, but in the latter area block sizes are larger. Examining the existing road system, the lack of in-field vehicular access is quite apparent, especially considering the size of fields involved. Few farmers have direct access to roads, this being determined purely by chance. New farm roads may be constructed as part of the long-term program to improve the physical infrastructure at the farm level. However, bearing in mind that a reasonable balance has to be struck between the intensity of the roads in the agricultural area and the need to conserve as much land as possible for food production, it is unlikely that future road development alone will have any significant impact on the basic character of the in-field transport problem.

When harvesting is mechanised and where the field is close to the farm road, the combine harvester can act as an in-field transporter by bringing newly threshed grain to the roadside. The wet grain can be off-loaded onto a large piece of plastic sheeting placed on the ground where bagging of paddy will be carried out manually by the farmers. Alternatively, paddy can also be bagged straight from the combine harvester. In order not to hold up the machine longer than necessary, more labour will be required for the latter procedure. Thereafter, sacks will be picked up by lorry for delivery to the procurement centres, as in the case of manual harvesting.

However, in cases where the field being harvested is some distance from the road, the

TABLE 4. Distance of parcels of paddy land in the Muda area of Malaysia from an access road

Distance (m)	0-250	250-500	500-750	750-1000	1000-1250	>1250
Cases	76	22	10	4	2	4
Percent	64.4	18.6	8.5	3.4	1.2	3.4
Cumulative %	64.4	83.0	91.5	94.9	96.6	100.0

Source: after Calverley et al. (1976)

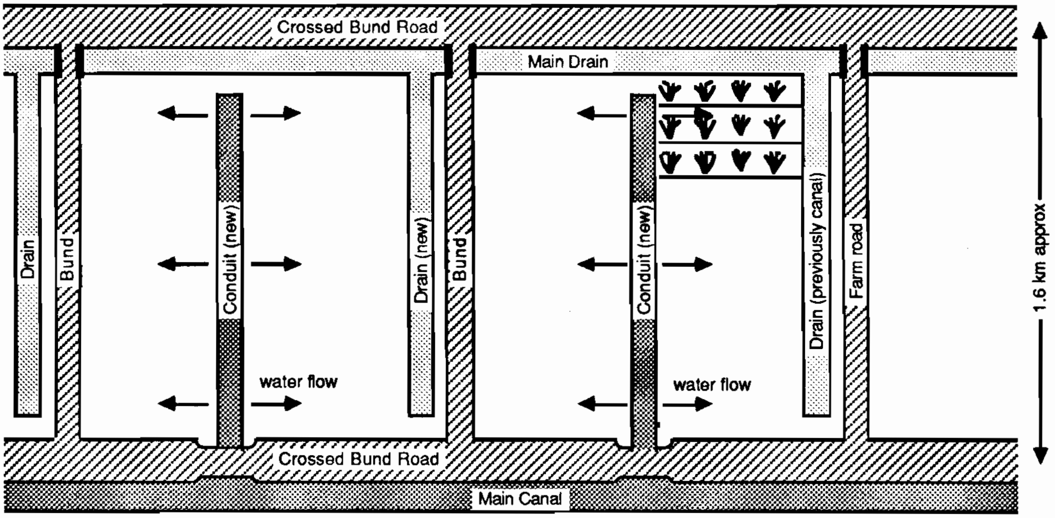

Fig. 2. Schematic representation of the layout of an irrigation unit in the paddy growing area of north-west Selangor, Malaysia.

combine harvester will drive up to the nearest bund where wet grain will be either bagged directly or dumped on the plastic sheeting placed on the ground. In the latter case, the bagging operation will be carried out as at the roadside. However, it can be more difficult as the bunds are often narrow and surrounded by wet and boggy fields. In addition, the sacks of grain still have to be carted to the road by in-field transport as described earlier. Owing to the physical difficulty of moving the harvested wet grain, the general shortage of labour during the harvesting season (not to mention its high cost), and the urgent need to move the crop to the market, the present system of manual or semi-manual in-field transport is often an expensive operation for the farmers and directly affects the farm income. In-field transport costs vary between $M1.00* and $M3.00 per sack, depending on location, weather, field conditions, distance involved, and type of transport used. This does not include bagging which adds another $M0.50 or $M1.00 per sack.

Moreover, delay experienced in the transport of grain of high moisture content as a result of in-field transport problems, will cause deterioration in grain quality and lead to lower

*During October 1987, 2.5 Malaysian ringgit ($M) = US$1.

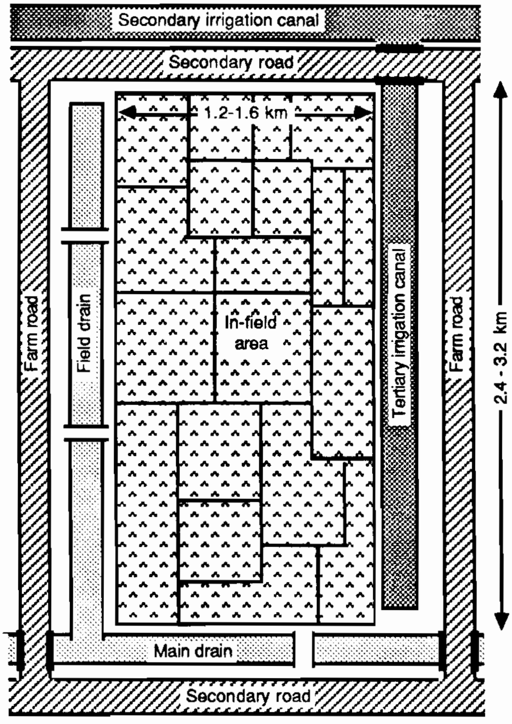

Fig. 3. Schematic representation of the layout of an irrigation unit in the Muda Agricultural Development Area in north-western Malaysia.

rice recovery at milling. Teter (1983) estimated a 21% loss in value of paddy consequent on a two day delay in drying of wet paddy held at a moisture content of 25%. Higher moisture contents will cause even more rapid grain deterioration.

Procurement

In Malaysia, harvested paddy is generally released fairly quickly into the marketing system by the farmers. This is mainly due to the introduction of a paddy price subsidy scheme, the payment of which is based on sales of paddy by farmers. The other reason is the lack of speculation in the local rice trade, as both paddy and milled rice are governed by floor and ceiling prices, respectively. Table 5 indicates the sources of paddy bought by mills. Large private mills and LPN complexes receive about equal proportions of their paddy from independent agents, who in turn buy their paddy directly from the producing farmers. On the other hand, LPN procures a greater amount of its paddy directly from the farmers than do large private mills.

Grain transport is almost entirely owned and operated by the private sector. A previous analysis (Calverley et al. 1976) showed that 61% of agents own or share ownership in vehicles. Of these, 53% have one or two vehicles but only 8% have more than two. The remaining 39% have to rely on hired transport. Examination of the type of transport used to deliver paddy to the mills shows that small lorries below 2 tonnes capacity are particularly popular because they can use the laterite farm roads and have reasonable penetration into the paddy area (Table 6). Though their number is relatively small, large lorries are also very significant in the paddy transportation system. As a group, they carry about 51% of the total grain.

TABLE 5. Sources of paddy bought by mills in the Muda area of Malaysia

Seller	% purchases Large private mills	LPN
Farmer	39.6	55.2
Independent agent	37.9	43.7
Mill employed agent	22.3	-
Farmers association	0.2	0.6

Source: Calverley et al. (1976)

TABLE 6. Type of transport used to deliver paddy to mills in the Muda area of Malaysia

	Large lorry (> 5 t)	Medium lorry (2-5 t)	Small lorry (< 2 t)	Tractor and trailer
Percentage of transactions	32	13	55	Negligible

Source: Calverley et al. (1976)

Owing to the stringent requirement for low ground-contact pressure, an in-field transporter will invariably be unsuitable for highway running and, at best, it performs as a shuttle service for moving grain from the combine harvester to secondary transport waiting at the edge of the farm. Hence, with the conversion to bulk handling in the future, these conventional lorries can still be utilised following body modifications to maximise their bulk grain carrying capacity.

Grading

Paddy received will be graded for moisture, presence of impurities, immature and damaged grains, variety mixture, and other quality defects, and appropriate deductions made from the payments to growers. This information also enables proper segregation of paddy before drying and storage. In most cases, deductions are made in respect of excess moisture and/or presence of impurities or immature grains. There are occasional cases where grain brought in by the growers has already been heat damaged. This grain attracts heavy deductions. Under the present paddy grading system, except in the cases of damaged grains, all deductions are calculated in terms of potential shrinkage or weight loss, without any reflection on the costs of their removal, which are supposed to be borne by the mills (Table 7). This policy, though it appears equitable, does not provide incentives for

TABLE 7. Schedule of deductions applying to paddy delivered by farmers to LPN, Malaysia

(i) Moisture content	Rate of deduction (kg) for every 100 kg of paddy
14% and less	nil
14–15%	1
15–16%	2
16–17%	4
17–18%	5
18–19%	6
19–20%	7
20–21%	8
21–22%	9
22–23%	10.5
23–24%	11.5
24–25%	13
25% and above	negotiable

(ii) Dirt
1 kg for every 1%

(iii) Unripe paddy
1 kg for every 1%

(iv) Damaged or red grain
1 kg for the first 1%
2 kg for every additional 1%

(v) Gunny sacks
1.2 kg for dry gunny
3 kg for wet gunny

the growers to deliver better and cleaner paddy. This leads to instances where little attention is paid to grain quality maintenance, because farmers are still paid for the nett content of grain delivered after deductions for moisture and impurities have been made.

Receival and Handling Practices

Up to this point, almost all grain handled is in jute bags, and its unloading and sorting are therefore done manually. Bags of paddy must be systematically stacked to facilitate subsequent handling. Wetter paddy, which requires immediate drying, is stacked near the existing intake hoppers. Care must be exercised to segregate the bagged grain according to variety and moisture content range.

Though aided by motorised portable bag escalators, the process of unloading bags of paddy from trucks can be quite time consuming and result in considerable queuing time and cost to lorry operators.

Role of Bulk Handling

From the foregoing discussions, it is clear that there is a need to adopt an appropriate paddy bulk handling system to efficiently and effectively move grain from the field to procurement centres or mills, thereby avoiding the high costs of handling and transportation associated with bag handling. There is also a need to introduce into the existing paddy grading system a premium for better and cleaner paddy. The premium system would also ensure that paddy moisture content is maintained at an optimum level through avoidance of moisture uptake from the wet field, exposure to rain, etc.

At the field level, paddy from the combine harvester should ideally be loaded directly into lorries. The costs and time involved in the process of bagging the paddy in jute sacks and manually carrying these to bunds and access roads would thereby be saved. However, with only an estimated 30% of the existing paddy land permitting direct access, additional farm roads will have to be constructed in order to make the entire area accessible by lorries. Alternatively, a successful bulk system will require the introduction of some form of mechanised in-field transport which could function as a shuttle in moving grain from the combine harvesters to lorries waiting on the farm road.

At the mill level, if paddy were delivered in bulk, the processes of grain sampling, grading, unloading, and subsequent drying and storage would be very much speedier, resulting in better grain quality maintenance and an overall improvement in handling and processing costs for paddy, as detailed in other papers presented at this workshop. In addition, less labour would be required to handle the same amount of crop.

To facilitate the bulk handling of paddy, a number of plant modifications would have to be carried out, particularly to receival, cleaning, drying, and storage facilities. The milling operation, however, would remain unchanged.

Constraints to Bulk Handling of Paddy

The major constraints to the successful introduction of bulk handling of paddy are summarised in the following subsections.

Small Farm Size

It has been recognised that the existence of many small farmers plots is responsible for large variations in the paddy quality and grades, as well as in grain maturity, making it difficult to implement a mechanised bulk handling system. Delivery of paddy harvested in small lots belonging to individual farmers could create logistic problems (Table 8).

Soil Conditions

Soil strength is partly determined by soil texture. Suhaimi et al. (1986) reviewed earlier studies which categorised the soil strength into three groups based on soil bearing capacity, measured as cone index (CI):

(i) soft, with mean CI of 2 kg/cm^2 (average 0–30 cm depth, yearly mean);

(ii) intermediate, with mean CI of 2–3 kg/cm^2; and

(iii) hard, with mean CI greater than 3 kg/cm^2.

TABLE 9. The extent of soft soil in the major rice areas of Malaysia

Locality	Total area (ha)	Area of soft soil (ha)
MADA	95 857	9 500
KADA	31 808	6 000
Tanjong Kerang and Sabak Bernam	19 830	17 800
Krian	23 453	10 700
Sg. Manik	9 715	3 000
Seberang Perak IV	5 141	283
Seberang Perai and Pulau Pinang	15 000	1 000
Total	200 804	48 283

Source: Ayob (1983)

Table 9 shows that soft soil is characteristic of about 24% of total major rice growing areas (Ayob 1983). Machine mobility problems under soft soil conditions limit the introduction of in-field transporters for grain handling. Soil strength increases with drainage (surface and sub-surface) or on drying, and it reduces with wetting. The minimum soil bearing strengths required for easy trafficability of the various types of in-field grain transport machinery have been calculated by Chan and Azizul (1986).

TABLE 8. Paddy farm size distribution in the various states of Malaysia in 1976

State	Farm size (acres*)					
	< 1.0	1.0–2.5	2.5–5.0	5.0–7.5	> 7.5	Average
Perlis	12.0	38.8	35.0	9.7	4.5	1.6
Kedah	18.9	43.2	26.1	7.5	4.3	2.7
Pulau Pinang	21.1	46.4	26.7	4.8	1.0	2.0
Perak	18.6	46.4	25.1	8.7	1.2	2.0
Selangor	3.8	30.6	50.0	12.2	3.4	3.1
Negeri Sembilan	29.2	61.8	8.5	0.5	–	1.3
Melaka	33.2	53.4	11.2	1.3	0.9	1.4
Johor	16.3	69.0	11.2	3.5	–	1.6
Pahang	14.2	58.1	22.1	4.5	1.1	2.0
Trengganu	14.7	61.8	19.3	3.5	0.7	1.9
Kelantan	20.6	57.8	18.8	2.4	0.4	1.7
Peninsular Malaysia	18.7	50.2	23.4	5.7	2.0	2.2

*1 acre = 0.40 ha

Source : Statistics Department, Agricultural Census 1977—Main Report, Tables 6.1 and 6.2, P. 99-100

They varied from a cone index of 1 kg/cm^2 for a special tractor, to 4 kg/cm^2 for a tractor-trailer combination.

The essential technical feature of an efficient in-field transporter is an ability to manoeuvre under soft and sticky soil conditions, in order to receive wet crop from the combine harvesters and transport it to waiting lorries at the edge of farm roads. Particularly during the wet season harvest, it must have a high level of mobility and manoeuvrability. To accomplish these, a high level of flotation with low ground contact pressure and high soft soil trafficability are essential to prevent sinking or bogging in waterlogged fields. On the other hand, it must also be able to move at reasonable speeds on deep, moist clay with no or little surface water. Experiments have shown that in-field transporters can be seriously impeded under such conditions, because the tyre lugs fill with mud, causing the wheels to spin and sink and eventually bog.

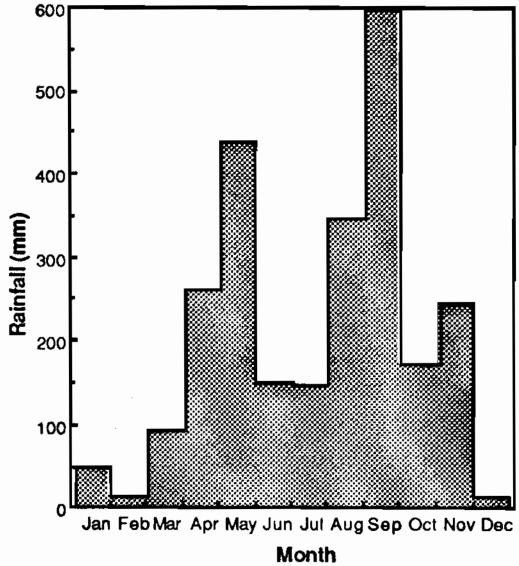

Fig. 4. Annual distribution of rainfall at Alor Setar, north-western Malaysia. (Source: Malaysian Meteorological Service.)

Conclusion

Existing and impending farm labour shortages in Malaysia call for total mechanisation. However, the tempo and state of mechanised activities between different phases of paddy production are not in complete harmony. Land preparation, tillage, and harvesting are more easily mechanised than in-field handling of harvested crop. Some of these difficulties could be partially overcome through larger scale production.

The adoption of paddy bulk handling is to a large extent dependent on the successful introduction of in-field handling. Because paddy is grown in both dry and wet seasons, only a few machines are versatile enough for use in wet and dry conditions. A possible alternative is to improve the accessibility of fields by constructing more farm roads, but this process would be time consuming and costly.

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Current Drying Practices and Needs in ASEAN

J.A. Tumambing*

Abstract

In Southeast Asia, improved grain production technology and expanded irrigation infrastructures have led to double cropping and increased grain yields. However, one crop is harvested during the rainy season, when grain is reaped at high moisture contents (24–28% for paddy; over 35% for maize). This condition necessitates the immediate threshing and drying of the grain to prevent serious quality deterioration and associated economic losses.

In this paper, the existing drying practices and their problems, and requirements of grain drying systems in ASEAN are described. Current drying technologies are categorised according to the needs of the individual farmers, farmer cooperatives, commercial millers, and government marketing agencies. The potential and constraints of adopting bulk handling and storage in conjunction with the drying technology at each level of operation are briefly presented. Priority areas concerning drying of grains in ASEAN that need further attention are also presented.

THE introduction of improved grain production technology coupled with expansion of irrigation infrastructures in the past two decades in Southeast Asia have led to the introduction of double-cropping systems and to increased grain yields. However, an increasing proportion of the crop is harvested during the wet season, when the delivery of grain reaped at high moisture contents (24–28% for paddy; over 35% for maize) has placed strains on the existing drying and handling capabilities.

The present on-farm handling practice of leaving the fresh harvest in windrows or field stacks causes delays in threshing and drying of the wet grain. The mechanical threshers in use perform well for the summer crop but have trouble working on the wet season crop due to choking and clogging with wet straw. These conditions have brought about delays in stabilising the product which lead to grain quality deterioration (de Padua 1986). Quality deterioration is manifested in general discoloration, yellowing, germination, decrease in head rice and milling yield, a high percentage of dry matter loss, and aflatoxin contamination in maize.

The only practical means of preventing grain quality deterioration is immediate threshing and drying of the high moisture harvest. Once the wet grain is threshed, drying becomes essential. In spite of the many drying technologies available as a result of the past 20 years of research and development, there is still much work to be done, especially in designing drying systems compatible with specific drying requirements at the various levels of operation, such as individual farmers, farmer cooperatives, commercial millers, and government grain handling authorities.

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Current Drying Practices, Problems, and Requirements

Sun Drying

Sun drying is still the most widely used method of drying high moisture grain whenever the sun shines. The drying process is accomplished by a combination of radiative, convective, and conductive heat transfer. Some grain in unthreshed form is pre-dried in the field by laying the stalked grain in either conical or rectangular field stacks. Other unthreshed grain is pre-dried in the field by bundling and placing in shocks or hanging in bamboo poles. However, the new high-yielding varieties are not handled as stalked grain since they shatter easily and grain kernels are alternately subjected to drying during the daytime and rewetting at night (Esmay et al. 1979).

Threshed paddy is sun dried by spreading it on a flat, smooth surface in the sunshine and occasionally stirring it. Drying floors used vary, and can be straw mats, hard soil, concrete floors, or some other hard surface. The depth of the grain on the sun-drying floor is maintained at 3 to 5 cm and hourly stirring is practiced for uniform drying. In the Philippines, it is common during the peak harvest season to observe wet grain being dried covering half the width of highways, for stretches extending up to several kilometres. This practice is a nuisance to motorists and exposes the grain to great risk of kernel breakage every time it is run over by passing vehicles.

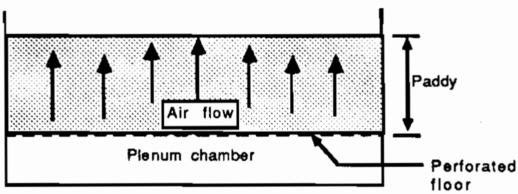
The temperature of the sun-drying floor surface and the grain may rise to as high as 60 to 70°C. This uncontrolled heating induces severe temperature and moisture gradients within the grain kernels resulting in a rapid drying rate and the induction of stress checks and cracks. Grain checking resulting from sun drying is a common and too often, unfortunately, accepted form of loss of grain quality. Sun drying is undoubtedly a low-cost method, but it is labour intensive and subjects the grain to considerable quality deterioration (Tumambing 1984).

Mechanical Drying

The commercial grain dryers most common in Southeast Asia function by forcing heated air through a layer of grain. The air is the convective medium that supplies heat for evaporating moisture from the grain kernels and then carries the water vapour out of the grain mass. Basically, dryers are either of batch type with shallow or deep beds, either static or recirculated for mixing purposes, or they may be large, expensive, and sophisticated continuous-flow devices intended for multi-stage drying. Systems based on continuous-flow drying should incorporate tempering bins.

Batch (Fixed Bed) Dryers

Figure 1 illustrates the two basic approaches to convective drying. The grain is held stationary in either a horizontal (flat bed dryer) or a rectangular or circular bin (upright dryer) throughout the drying process. The grain depth is normally in the range of 30 to 50 cm to keep the resistance to airflow at less than 250 Pa (2.54 cm water gauge) static pressure and reduce the fan power requirement. Air at a rate of over 10 m^3 per minute per square metre of drying floor area is forced into the plenum chamber



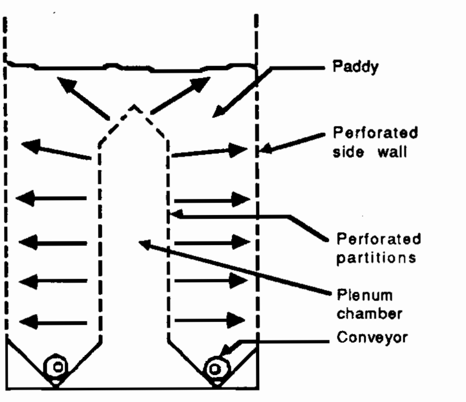


Fig. 1. Conformation of fixed-bed dryers.

below or beside the perforated false floor by an axial fan powered by a small engine or motor. Heat derived from burning fossil fuels or agricultural wastes is supplied to the air before or after it goes through the fan. The drying air temperature is kept below 43°C to prevent fissuring of the paddy. Under normal humid tropical conditions, about eight hours are required to dry wet grain from 26% moisture content down to a safe storage level of 13%.

The most widely used batch dryer in the region evolved from the UPLB (University of the Philippines at Los Banos) 2-tonne flat-bed dryer which had been adapted to suit various needs. Lembaga Padi dan Beras Negara (LPN) of Malaysia has modified this to accommodate 30 tonnes. Likewise, modified versions have also been made by the Thai Agricultural Engineering Division, the Badan Urusan Logistik (BULOG) of Indonesia, and the International Rice Research Institute (IRRI) in the Philippines. Other types of batch dryers finding some use in Southeast Asia are the Danish Kongskilde vertical batch dryer (12 tonnes/batch) and the Japanese recirculating batch dryer (2.4 tonnes/hour).

Continuous-flow Dryers

This type of dryer has a holding bin on top, below which is a tall drying section. Under that is a flow control section, in the form of metering rollers or oscillating rockers, that regulates the flow through the dryer and discharges the grain. An air heater and blower forces or sucks hot air through the grain in the drying column (Wimberly 1983). In terms of capacity, continuous-flow dryers offer the largest drying capacity per unit (1–5 tonnes/hour) and are therefore used to dry large volumes of wet grain quickly. This type of dryer is used only with conveying equipment, and is usually therefore associated with a bulk handling and storage system. Continuous-flow dryers are usually classified as non-mixing and mixing types.

Figure 2 shows a schematic diagram of the drying section in a non-mixing type continuous-flow dryer. Drying takes place as the grain descends between two parallel screens 15–25 cm apart. Relatively high air velocities of 125–250 m^3 per minute per tonne are used, permitting a faster movement of the grain from the top to the bottom of the dryer. A drying air temperature of 54°C is used and the grain is exposed to this condition for about 15 minutes, the time it takes to pass through the column. No mixing occurs in the column, which the grain passes straight through. A limited amount of mixing occurs when grain is discharged and conveyed from the dryer.

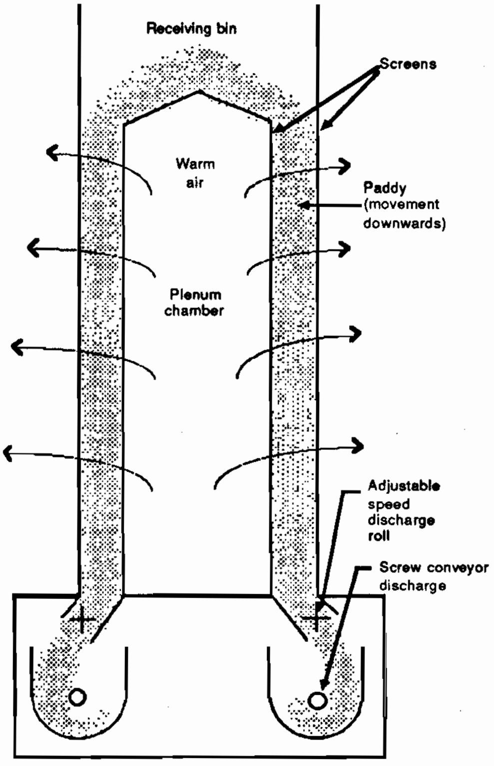


Fig. 2. Schematic drawing of air and paddy flow in a non-mixing columnar dryer.

As shown in Figure 3, the baffle-type mixing dryer is similar in design to the vertical non-mixing dryer. Alternate baffles are arranged so as to cause grain mixing as it descends in a zigzag path. Lower air velocities of 50–95 m^3 per minute per tonne and a higher drying temperature (66°C) are used than those for non-mixing types.

The Louisiana State University (LSU) mixing-type dryer shown in Figure 4 is the continuous-flow dryer in most common use in Southeast Asia. It consists of a large drying column in which layers of inverted V-shaped channels are installed. The layers alternate between hot air intake and exhaust air outlets and are staggered to provide mixing.

Continuous-flow dryers must be used with a multi-pass drying procedure to obtain higher drying capacity and good quality grain. The systems involved incorporate tempering bins and conveying equipment (Fig. 5). Grain is exposed to the heated air for 15–30 minutes during each pass, with 1–3% of the moisture being removed. Between drying passes, the grain is stored in a tempering bin for 4 to 24 hours to allow the moisture content at the centre and the surface of the grain to equalise. Figure 6 shows the reduction in the moisture content of the grain in multi-pass drying as compared with continuous drying. It can be observed that the moisture content is reduced from 20% to 14% in 1.5 hours of actual drying (plus tempering time) for the multi-pass system versus 6 hours of actual drying for a continuous drying system. The actual reduction in moisture per pass depends on the initial moisture content. In the case shown in Figure 6, it is 3% for the first pass, 2% for the second pass, and 1% for the final pass.

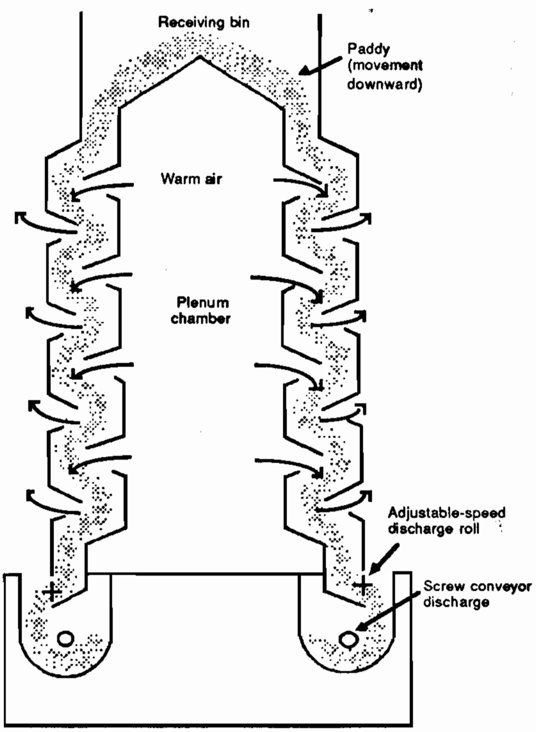


Fig. 3. Schematic drawing of air and paddy flow in a baffle-type mixing dryer.

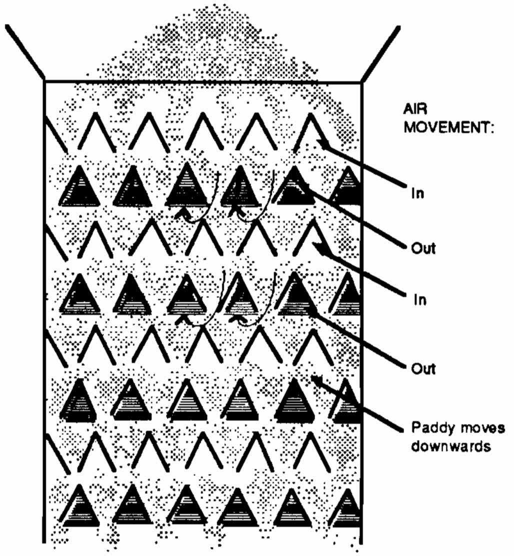


Fig. 4. Schematic drawing of air and paddy flow in the Louisiana State University (LSU) dryer.

Experimental Dryers

Research and development work in the past 10 years has come up with several experimental dryer prototypes of varying designs and capacities. These prototypes are being tested for appropriateness at the farm level, and at cooperatives, commercial millers, and government grains complexes. These are briefly described in the following sections:

1. Warehouse type dryer. This dryer was developed by Dr Jeon at IRRI. Non-conventional sources of energy are used (rice hull furnace and solar collector as heat sources and vortex wind machine as drying air circulator). Drying capacity is up to 8 tonnes per batch, making it suitable for cooperative or village level operation, or by a group of farmers or rice mill operators (Halos et al. 1983). This dryer is acceptable as an intermediate technology but its application will differ widely between areas due to differences in weather conditions and agronomic practices.

2. African (KSU–Brooks) dryer. Utzurrum and Vilar (1986) describe this natural convection

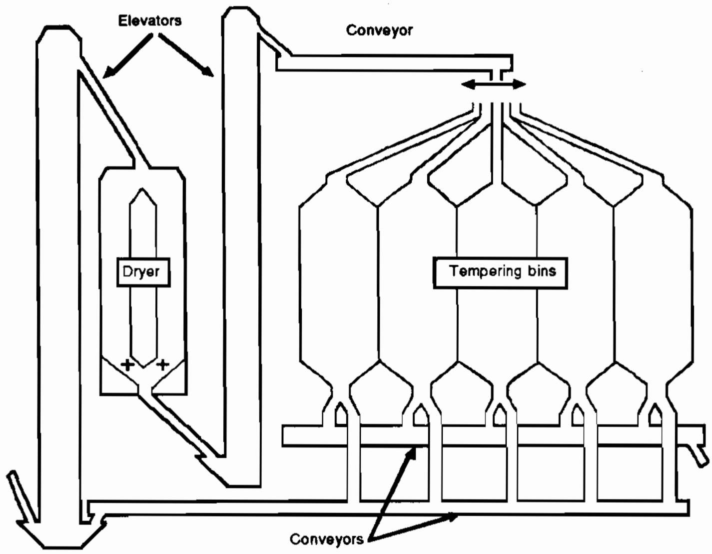


Fig. 5. Schematic drawing of continuous-flow dryer with conveying equipment and tempering bins.

dryer developed in Silliman University College of Agriculture. The dryer is made from indigenous materials and uses firewood as fuel for the oil drum heat exchanger. At 25.3 cm depth of grain, the dryer can dry about a tonne of shelled corn from 23% to 14% moisture content in 5 hours. Apparently, this dryer is widely accepted by small-scale corn farmers in Negros Oriental, Philippines.

3. DA–IRRI paddy dryer with rice hull gasifier. The Philippine Department of Agriculture (DA) and IRRI have collaborated in the development of a paddy dryer for small- and medium-scale rice millers, traders, and farmer cooperatives in typhoon prone areas. Stickney et al. (1987) report the prototype dryer has a capacity of 0.8–1.3 tonnes/hour, pre-drying the wet paddy from 23–31% initial moisture content to around 16–18%. A high drying temperature of 80–95°C is used with a 100 second exposure time without detrimental effect on the milling properties of paddy. Combustible gases from the rice-hull gasifier are completely burned to provide hot air for heating the rotary drum. The pre-dried paddy is then briefly sun dried to about 14% during favourable weather conditions.

4. Integrated paddy drying and storage solar hut. Soponronnarit et al. (1985) describe an integrated paddy drying/storage solar hut consisting of an 18.6 m^3 flat plate type solar air heater, two drying/storage rooms, a fan, and an air duct system. The solar hut is suitable for storing about 10 tonnes of paddy and for drying 15 tonnes of paddy per month. Head yield of paddy after milling varies from 45–50% and germination is greater than 92%. The farmers in Thailand who participated in this project showed interest in the solar hut for drying their wet paddy during the wet season and for storing paddy and selling it when prices are high.

5. Solar rice dryer. A low-cost solar rice dryer was developed by Exell and Kornsakoo (1977) at

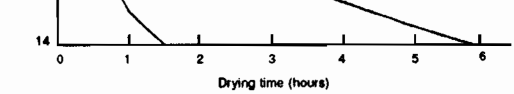


Fig. 6. Reduction in moisture content over time (drying curve) for continuous and multipass drying systems.

the Asian Institute of Technology (AIT). The dryer is constructed from bamboo poles and transparent plastic sheets. An induced draft from the chimney causes air to be naturally circulated above an absorber made of burnt rice hulls, then through a paddy layer 10 cm thick. About one tonne of paddy can be dried on a sunny day and the same amount every three to four days during wet season. This dryer was implemented in rural areas but was not accepted by Thai farmers because of its low drying capacity, its flimsy construction, and the lack of an economic incentive to dry grain.

6. Two-stage or 'combination drying' system. Research on a two-stage, or 'combination drying' system, in which a fast-drying stage is followed by unheated or minimally heated air drying in storage, has been conducted in the Philippines, Malaysia, and Thailand under the Australian Centre for International Agricultural Research (ACIAR) Grain Storage Research Program. The high moisture grain is dried rapidly to about 18% using a continuous-flow dryer or other high-speed dryer in the first stage. Final drying is done gently in storage using ambient air or supplementally heated air.

Results of a pilot plant study in the Philippines showed two-stage drying to be a highly feasible drying strategy, especially for wet season drying. Among the benefits of this drying system are: (1) flexibility in meeting drying requirements, particularly during the peak harvest period, (2) substantially lower energy costs than conventional heated-air drying, and (3) high quality dried grain (Tumambing 1987). A commercial-scale trial of this drying system has also been conducted in the Philippines, using one of the National Food Authority (NFA) grain drying and storage complexes. However, further large-scale trials are needed to confirm its technical and economic soundness. This particular two-stage drying system will work well when coupled with bulk handling and storage facilities.

The drying technologies in varying degrees of development and use at the different levels of operation in Southeast Asia are summarised in the box at the top of the next column.

Drying Technologies in Use in Southeast Asia

Individual Farmer

1. Rotary drum dryer
2. AIT solar dryer
3. African bush dryer

Farmer Cooperative/Small-scale Miller

1. UPLB flat bed dryer
2. IRRI vertical bin dryer
3. Japanese recirculating batch dryer
4. Warehouse type dryer
5. DA–IRRI paddy dryer with rice hull gasifier
6. BULOG batch dryer
7. Thailand Department of Agriculture batch dryer
8. Lister type in-sack dryer

Government Grains Complex/Large Private Miller

1. UPLB flat bed dryer
2. Moisture extraction unit (MEU)
3. Kongskilde vertical batch dryer
4. Japanese recirculating batch dryer
5. LPN 30–tonne batch dryer
6. Reversible airflow batch dryer
7. LSU mixing type continuous-flow dryer
8. Cimbria continuous-flow dryer
9. Woodland continuous-flow dryer
10. Shanzer continuous-flow dryer

Drying Problems and Requirements

The most common and pressing problem in handling wet grain in the region is delay in drying caused by unfavourable weather conditions, antiquated postharvest handling practices, and insufficient drying capacity of existing dryers. This accounts for considerable grain quality deterioration and subsequent postharvest losses in storage and milling. In Malaysia, serious drying problems have been reported during the wet season, when delays in transport to grain drying complexes are common and inadequate drying facilities are strained by heavy deliveries of wet grain. In the

Philippines, Mendoza and Quitco (1984) pointed out that various postharvest drying practices led to a reduction in monetary value of grain of 5 to 58% due to quality deterioration. An AFHB study noted a similar magnitude of losses in Thailand when storage losses are correlated with drying practices (AFHB 1984). In Indonesia, a JICA study on paddy losses at farm level showed 10% quantitative and 4.4% qualitative losses (Fredericks and Mercader 1986).

In spite of the recognised need, minimal use has been made of drying technology to prevent grain deterioration and toxin formation. Sun drying of grain in the region is still the predominant practice whenever the sun shines, even if mechanical dryers are available. The most common arguments given are that sun drying is cheaper, or that the milling quality is better with sun drying, or that their mechanical dryers do not have the necessary capacity. These arguments may or may not be valid, but with the existing double-cropping system in the region, it is imperative to use mechanical dryers to maximise the value of the wet season crop.

It can be observed, however, that the investment in mechanical dryers has been made mainly by government grain handling authorities. In the Philippines, Villaroel and Cardino (1984) reported that only 12% of production can be handled by mechanical dryers. NFA owned 90% of the dryers in the country, but handles only about 15% of production. Needless to say, the balance must be sun dried, and that this is so is clear from the poor quality of milled rice from the wet season being sold in the marketplace.

Large millers in the private sector have also invested in grain dryers, but the performance of this equipment has been less than satisfactory.

Where mechanical dryers are used, there is a lack of technical know-how in their operation. It has been observed that continuous-flow dryers designed to dry the grain in stages and therefore requiring tempering bins, are used improperly in the engineering sense. They are often installed without tempering bins and operated at higher drying temperatures for one-pass drying (de Padua 1977). This inevitably leads to a high percentage of broken grains. A common justification for the practice is that at the peak of harvest season, capacity is required to save the crop, and that the procedure is more economic. It is further presumed that the local market does not pay premiums for high head grain and that the grain industry is not producing for export. This argument is, of course, quite fallacious. A continuous-flow dryer operated as designed to dry in stages has about one-quarter to one-third net drying time as compared with continuous drying in one-pass, and hence, has three to four times more drying capacity. A high percentage of brokens means a low milling recovery. Therefore, the net result is uneconomic.

The same lack of technical knowledge on drying holds true for users of batch dryers. Farmers and millers who lack understanding of the technical aspects of mechanical drying have blamed the dryer for yielding poor quality processed grain. However, the poor quality may have been due to: (i) drying of grain that was already spoiled, and (ii) improper adjustment of temperature, airflow, and other drying conditions.

One of the most serious constraints to investment in mechanical dryers is the incompatibility of the drying system capacities with those actually required. In spite of the many drying technologies available, there is no particular drying technology suited to the specific requirements of the users (i.e. individual farmer, farmer cooperative, commercial miller, government handling authority). Experience has shown that 2–tonne batch dryers introduced to farmers who work on less than 3 hectares of land are too large for their needs and thus uneconomic. However, the 2–tonne batch dryer which can easily dry about two loads (4 tonnes) per day is too small for a commercial miller. At the government grains complexes, existing drying capacities cannot cope with the heavy deliveries of wet grain during the wet season peak harvest, but these same dryers remain idle or are underused during the dry and off-season harvests.

Some key factors therefore have to be considered for the successful design and operation of a drying plant. These factors were enumerated by de Padua (1986) as follows:

1. The drying facility should be integrated with the milling process, and considered a supportive facility. The cost of drying should be analysed as part of the integrated processing system.

2. The drying plant capacity should be compatible with the market (consumer) demands and milling requirements.

3. The operators of the dryer must possess technical skills. This means not only the 'how to', but also the 'why of things', to cope with changing product characteristics and the environment.

4. Peculiar to Southeast Asia, due to low harvest volume per farmer and traditional handling practices, the drying plant should be able to handle:

- extremely wet and dirty grain, especially during the wet season
- two varieties, and at least two grades, of incoming wet paddy
- batches of wet grain delivered to the plant with varying initial moisture contents, without mixing

Drying Strategy

Considering the high moisture content of the harvested grain and the unfavourable weather conditions, especially during the wet season, it has been suggested that wet grain handling can properly be done by drying the grain in two stages (Tumambing 1984). Two-stage drying can be done in various ways, depending upon the drying technology available, final grain quality desired, weather conditions in the area, and level of operation. The idea of two-stage drying is to rapidly dry the high moisture content grain down to more manageable levels (say 18%) using a high speed dryer (e.g. batch dryer, continuous-flow dryer, rotary dryer), or by sun drying if the weather is favourable. The final drying to 14% can be done in the drying plant using a continuous-flow dryer or by gentle drying in storage. Where sun drying can be done properly, mechanical drying in combination with sun drying is an alternative two-stage drying system. A high degree of cost sensitivity is associated with the different options of two-stage drying, especially at the farmer-cooperative and commercial miller levels. Decision in choosing a particular option should primarily consider its cost/benefit implications.

Potential and Constraints of Bulk Handling and Storage in Solving Grain Drying Problems

Delay in drying wet grain in the region is the major cause of quality deterioriation losses. Hence, measures should be taken to accelerate delivery of the wet grain to the drying facilities. In principle, the introduction of a bulk handling system is one of the best means of avoiding drying delays. A bulk handling system can be expected to reduce wet handling time and at the same time significantly reduce labour and bag costs and also result in more uniform grain quality (Wahab and Nour 1984). However, there are some factors to consider before a bulk handling system can be successfully adopted at any of the levels of operation. Some of these factors are the following:

- it should not entail extra cost to farmers or commercial millers;
- facilities necessary for bulk handling should already be available in the area (e.g. combine harvester, bulk truck);
- farmers and other handlers should be able to participate in the bulk handling system;
- individual farmers should be organised to produce the right type and quality of grain and at the same time consolidate their harvest to obtain the minimum volume for bulk handling;
- bulk handling should be able to be incorporated into the present marketing channels without creating a major change;
- the displaced labour force should be provided with alternative employment related to present skills and way of life, in order to prevent any social problems that may arise; and
- improvement in the design and management of existing bulk storage facilities is required due to problems of caking, condensation, and mould growth.

Priorities for Further Research

There is no particular drying technology available at present that seems to suit the specific drying requirements at each level of operation. Research and development on grain drying should focus more on designing drying technology appropriate to the needs of the private commercial millers, since they handle the majority of the harvested grain. The approach to grain drying research should concentrate more on engineering system analysis, than on particular aspects of the drying phenomenon. Drying load parameters should first be established before designing a system that is compatible with drying requirements, is technically efficient, and is cost effective. Guidelines for determining the drying load parameters are clearly drawn in the proceedings of the August 1986 IDRC crop drying workshop held at SEARCA, Los Banos, Laguna, Philippines.

Since a two-stage drying system appears to be the appropriate drying strategy for handling high moisture grain in the region, more effort needs to be expended on the development of an appropriate partial drying technology for farm, private mill, and government grains complex levels. At the farm level, a suitable partial dryer is one that is mobile, uses high temperature heat from agricultural waste, with very short exposure and residence time of the grain, and provides mixing of the grain. It can be made cost effective when operated on a custom basis, as in the case of the mobile paddy thresher. Further work is also needed to develop methods of accelerating delivery of wet harvest (e.g. tractor-mounted bulk/bag transport) to the drying plant, applicable to those areas where on-farm partial drying is impractical.

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Drying Systems for the Humid Tropics

R.H. Driscoll and T. Adamczak*

Abstract

A wide variety of technologies exists for drying grain in the tropics, ranging from small-scale sun drying to large-scale, fluidised-bed dryers. Choosing the appropriate method for a given situation depends on detailed knowledge of scale of operations, weather patterns, appropriate and acceptable technology, available heat sources, and economic or political factors. Some of the major dryer types are analysed in this paper and simple models appropriate for economic assessment are presented. Modifications to existing equipment are suggested, and strategies for optimising the drying system are outlined.

THE problems of the grains postharvest subsector in Southeast Asia are well documented. Yet many farmers remain unaware of the extent or significance of postharvest losses (Soepani 1983). In Indonesia, for example, losses are about 25% of the harvested crop (Mears 1981), made up of losses incurred during harvesting and threshing (8%), transportation (5.5%), drying (2%), storage (5%), and milling (4.5%). When reporting the drying losses as here, the figure quoted does not include the effects of reduced grain quality or milling yields due to inadequate, inefficient, or incorrect drying techniques.

The central Thailand area recognises the need for improved drying methods in order to increase the head rice yields of paddy, especially during the wet season (Kruawan 1983), when harvesting delays due to rain cause quality losses.

A study in the Tanjang Karang area in Malaysia (Rohani et al. 1982) indicated that the main losses arose during harvesting (0.9–1.8%) and threshing (2.4–6%), from spillage (3.5–7.4%), and as a result of quality deterioration since the paddy is sold as high moisture (22–30%), uncleaned grain. The total losses may range between 15% and 40% before storage. A major portion of this is clearly due to drying delays and excessively high grain moisture levels.

In the Philippines, concern at the high levels of postharvest losses prompted studies on the effects of threshing and drying delays. Quitco (1983) found that drying delays of several weeks caused discoloration at 20–22% moisture content (m.c.) wet basis, and that several months delay caused discoloration at 17–18% m.c. (wet basis). Mendoza et al. (1983) investigated several field storage methods coupled with threshing and drying delays. They made recommendations on maximum permissible delays and suggested methods for storing paddy in the field to reduce deterioration.

Much of this problem has resulted from the introduction of high-yielding rice varieties and double cropping (de Padua 1986). The objective, to preserve grain quality, can be accomplished

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either by drying or cooling the product. Both will reduce the rate of biological activity tending to degrade the grain, but whereas cooling is effective only in the short term, drying can prolong the useful life of the grain almost indefinitely. The second crop is harvested during the wet season when sun drying is inadequate to guarantee high quality, and the existing mechanical drying facilities have become overloaded. Thus to reduce postharvest losses in Southeast Asia, a new system of postharvest management needs to be developed. The basic objective of this system is to minimise the delay between harvest and drying, at the minimum cost. This paper is directed at the drying methodology itself.

The particular drying strategy used is very closely related to the allowable time before the onset of excessive deterioration. For example, cooling during transport can extend the allowable time, as can partial drying. As a rough rule of thumb, very high moisture paddy (such as paddy harvested and then exposed to rain) must receive drying or cooling treatment within a day, whereas paddy at 18% m.c. at harvest may be held for up to three weeks in tropical climates at this moisture content before excessive deterioration occurs. A more quantitative measure of the maximum allowable holding time is provided by the dry matter loss indicator of Seib et al. (1980). This indicator has been used in developing strategies for the region (Mochtar et al. 1985; Teter 1982).

The drying strategy must then be related to the required overall system design (Wimberly 1983) or, for an existing system, interfaced in such a way as to make maximum use of the facilities in place. Examples of both are discussed below.

Drying Technology Options for Southeast Asia

A wide choice of technologies is available for drying grain. Each has specific advantages and disadvantages which allow the engineer to choose a dryer for a particular situation. Each (including sun drying) has an operational cost, a capital cost, a quality cost, and a social cost. The operational cost is the cost of running the dryer, measured in dollars per tonne per hour. Even when the tonnage is related to rate of moisture extraction, this is still a function of both the dryer and the moisture content of the grain, because it is easier to remove moisture from wet paddy than from dry. The capital cost is related to the cost of the dryer, its capacity, lifetime, installation costs, and additional equipment required to operate it. The quality cost is a measure of the loss in value of the grain consequent on the drying operation. For example, if paddy is dried too quickly and then exposed to a moist environment, its head rice recovery decreases, which in many countries represents a loss in value of the paddy. However, the most important and difficult cost to calculate is the social cost. The effect of a new technology in disrupting social structures, displacing labour, and redistributing wealth is well known. The resistance of farmers to new dryer technologies is a common theme at technological conferences in Southeast Asia (de Padua 1985; Fredericks and Mercader 1986; Mangaoang 1984; Lorenzana and Pableo 1983; Vilar 1986; Habito 1986; Cardino et al. 1986), and there are many large-scale drying complexes in the region which are no longer fully utilised.

Sun Drying

Sun drying requires little capital cost (concrete and rakes) but a high labour cost to keep the grain turned regularly and protect it from wet weather. It has a high quality cost in the wet season. However, since it is the traditional method and has become culturally settled, it has little social cost. Because of the difficulties of sun drying in the wet season, this method has no future for complete drying in humid tropical countries.

Management of sun drying, despite its centuries of use, is still not good. For example, in hot weather certain precautions should be taken to ensure good quality: it has been demonstrated that midday shading is beneficial in increasing milling yields (Stickney and Belonio 1986) in tropical climates. Frequent raking (every 15 minutes) prevents over-exposure of one side of the grain, reducing the moisture differential which may crack the grain on subsequent mixing. The colour of the drying surface makes little difference, as the heat is either reflected back into the grain (radiation) or stored in the surface and reaches the grain by conduction. Thus a sealed road is about as effective as a concrete surface. However, wind speed has a major effect on the effectiveness. Higher wind speeds reduce the drying rate by convecting the heat away, while lower wind speeds allow an insulating vapour haze to reduce the heat flow to the grain. Similarly grain depth is crucial. Too thin a layer allows excessively fast drying and wastage of heat between the grains; too deep a layer leads to excessive drying times.

Dry season losses may also occur through livestock, rodents, birds, insects, traffic on roads, spillage, and rain, but the wet season losses for tropical countries are far greater because of limited drying time, rain damage, and higher initial moisture contents.

Bag Drying

Drying of grains in bags has so far proved to be unsuccessful, even as a temporary maintenance measure. The method currently used in Malaysia is based on Lister diesel-powered moisture extraction units (MEU), in which the bags are arranged to form a tunnel blocked at one end, and the fan/burner is used to pump high temperature air through the tunnel. The use of MEU has caused major quality problems. They overdry the grain directly exposed to the heated air to the extent that almost black grain results. The remainder of the grain tends to be underdried or not dried at all, possibly due to channeling effects between the bags. The resulting grain gives poor head rice recovery after milling. In the absence of a feasible alternative, the method continues to be used for poor quality high moisture received paddy. Some work has been done at the University of New South Wales to develop an efficient mobile bag dryer and concomitant management technique. Results at this stage are promising. The mobile bag dryer is designed to partially dry close to the point of harvesting, with a capacity of about half a tonne per hour. This would be a part of a system to maintain quality in the period between harvesting and transport to the mill.

Flat Bed Drying

There are considerable advantages in gathering the grain into a bulk of one or two metre thickness and then drying using high temperature, low humidity air. It is an energy efficient system, because a high percentage of the energy put into the air is used to remove moisture. The compression energy of the fan is released as heat energy, the waste fan energy is useful heat, and the exit kinetic energy of the air is very small. Heat losses are minimised by the low depth to floor area ratio. However, due to the shallowness of the bed, the drying front reaches the top of the bed too quickly, reducing the drying efficiency (Driscoll 1986).

The flat bed dryer is also difficult to load and unload. It is thus too slow and has too small a capacity for a first-stage dryer and too cumbersome and inefficient for a second-stage dryer. Its best role is for smaller amounts of paddy at intermediate moisture contents, such as the crops of individual farmers able to harvest at below 21% m.c. (wet basis). Even then the flat bed dryer is prone to large top-to-bottom moisture differences, and mixing the grain after drying is not a good solution to this problem if high head yields are sought. The basic concept has been utilised more successfully in two other ways: the inclined bed dryer (IBD) and the in-store dryer. The IBD reduces the unloading difficulties of a flat bed dryer by tilting the bed at an angle equal to the angle of repose of the grain. The bed can then be unloaded by gravity. A particular problem of the IBD is the occurrence of a dead spot near the top of the bed, where the grain does not receive enough air to dry completely.

In-bin Drying

In-bin drying is a technique for slow-drying low moisture content paddy in bulk, coupled with the ability, using occasional aeration, to store paddy in the drying bin until it is required by the mill. This method assumes a fast drying first-stage in which the paddy is reduced in moisture to about 18% m.c. (wet basis). The technique originated in the United States of America, was adopted in Australia, and is presently used in many temperate climates throughout the world for a variety of crop types. Figure 1 gives a basic design for an in-store dryer, and Figure 2 shows a typical configuration in the Australian rice industry.

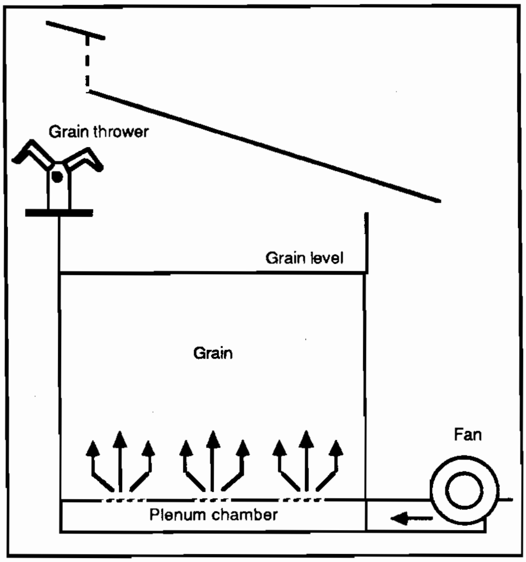

Fig. 1. Diagram showing principles of in-store drying.

There is wide variety in the methods used for in-bin drying (Brooker et al. 1974). The simplest is full bin drying, where the grain is dried, cooled, aerated,and stored in the one bin (also called in-store drying).

The bin may be fitted with grain stirrers to give more uniform drying by mixing the grain. This has several potential advantages. It promotes more uniform drying, so that the final moisture distribution across the bed does not have the large top-to-bottom differences usually associated with deep-bed drying. It allows higher air temperatures to be used, since the bottom layer is no longer subject to overdrying, and so reduces the overall drying time. It breaks up any wet or trashy areas in the bed, which would otherwise cause air channeling. Finally, it helps to increase the airflow (by up to 10%) through the grain by preventing the bottom layers from being compacted by the drying.

Despite these merits, the economics of grain

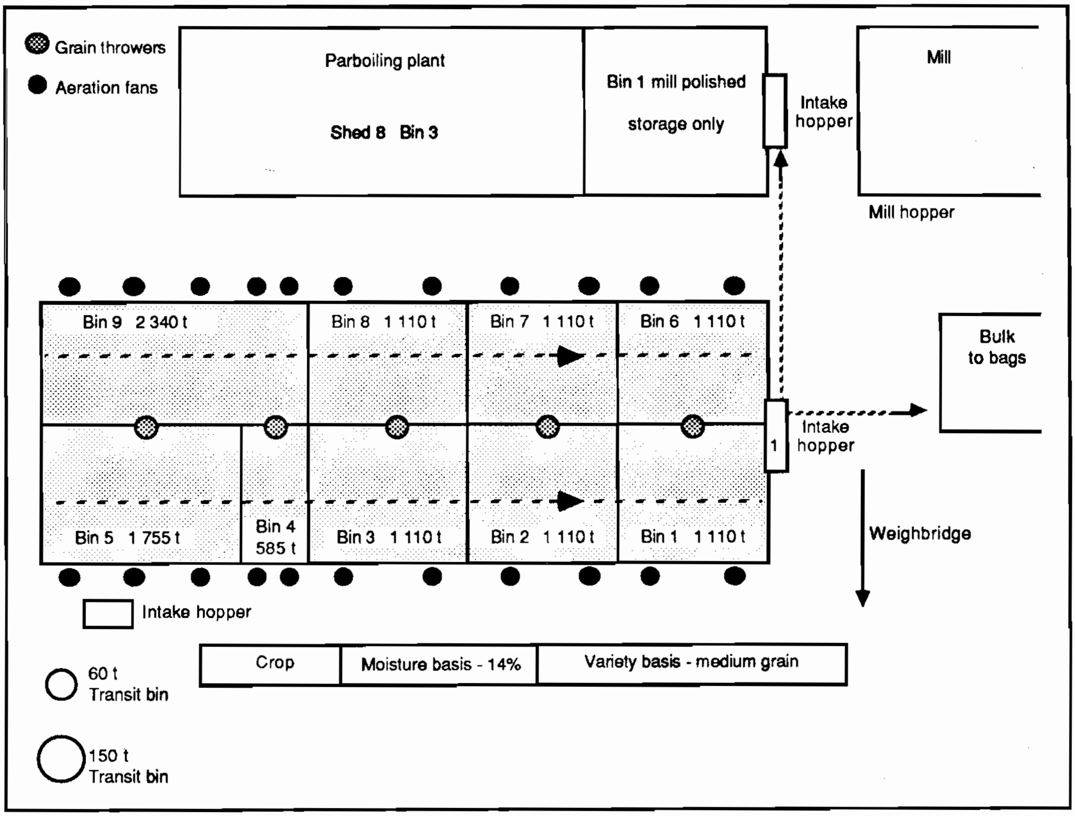

Fig. 2. Typical grain shed arrangement for in-store drying of paddy in Australia.

stirrers make them an expensive luxury for Southeast Asia. Loewer et al. (1984), studying the American corn industry, found stirrers to be economical for layer drying (see below) but not for near-ambient drying except with very large bin diameters, due to their high capital and maintenance costs.

The bin may also be fitted with a grain recirculation device, which takes dried paddy from the bottom layer (nearest the inlet air) and redistributes it on the top layer of the bed. Again the grain is dried more uniformly. It is doubtful whether the additional capital or maintenance costs are warranted for Southeast Asian conditions.

A further modification of full bin drying is layer drying, where the wet paddy is added in layers. After the first layer has been added to the bin, the fans are switched on and a drying front generated which moves upwards through the grain. As the drying front reaches the top of the first layer, the second layer is added, and so on. This system requires more careful management than direct filling, but has significant advantages in maximising flow rate and minimising the time before the paddy dries to a safe level.

The best strategy for Southeast Asia is partial layer filling, that is, filling the first bulk bin with medium moisture grain to a depth of about one metre, then commencing drying, and spreading the drying load over as many bins as the requirements of grain segregation and available electric power will allow at the site. Thus, all bins would fill and dry slowly at the same time. Once dry, the bins would revert to storage/aeration bins.

If one bin is fitted with a greater heating capacity than the others in a particular shed, then a variant of the above method may be used, called half-bin drying. In this technique (employed in the Australian rice industry), the high drying capacity bin is half-filled. The grain in it is dried and then transferred to the lower drying capacity bins for final drying and storage aeration. Half filling reduces the fan electric energy requirements for the same degree of drying, at the expense of gas energy which is cheaper.

In-bin storage works best with some sort of computer control over the input air, as discussed by Driscoll et al. (1987). This reduces the running costs, optimises the drying time, gives greater grain uniformity in moisture content, and reduces inlet layer moisture cycling in the bed.

Continuous Drying

All of the dryer types discussed so far are batch dryers. Many designs exist for dryers which move the grain continuously through the dryer. Two of them are illustrated in Figure 3. Most continuous dryers are based on the design developed at the Louisiana State University in the mid-1950s, called the LSU dryer. This design was developed specifically for rice, to ensure gentle treatment, good grain mixing, and good air-to-grain contact. Wet grain is passed through the dryer, removing the surface moisture, and then stored in an array of tempering bins to allow moisture diffusion processes to transport the moisture inside the grain to the outside surface again. The grain is then passed through the dryer a second time. Many passes may be necessary to bring the grain from a high moisture content to a safe storage level. Since the LSU-type dryer is most efficient at high moisture contents, Adamczak et al. (1986) have suggested a method of increasing drying throughput at a mill by combining a continuous-flow column dryer with in-store drying facilities.

The LSU dryer has become the most widely accepted mechanical paddy dryer in the world. However, there are many new techniques that are steadily gaining acceptance in the field of continuous dryers. Three of them will be described here: the fluidised-bed dryer, the spouted-bed dryer, and the rotary dryer. Space prohibits more than mention of other dryer designs and features: concurrent flow (for example, the LSU dryer), countercurrent, cross-current, mixing, non-mixing, and different cooling stages.

Commercial designs for fluidised-bed paddy dryers now exist. The principle of operation is to provide sufficient air pressure to fluidise a thin bed of grain, giving excellent air/grain contact. Above a certain pressure, related to the weight per unit area of the paddy bed, the pressure drop across the bed becomes constant with volume flow rate, so that fast drying can occur. By combining high air temperatures and

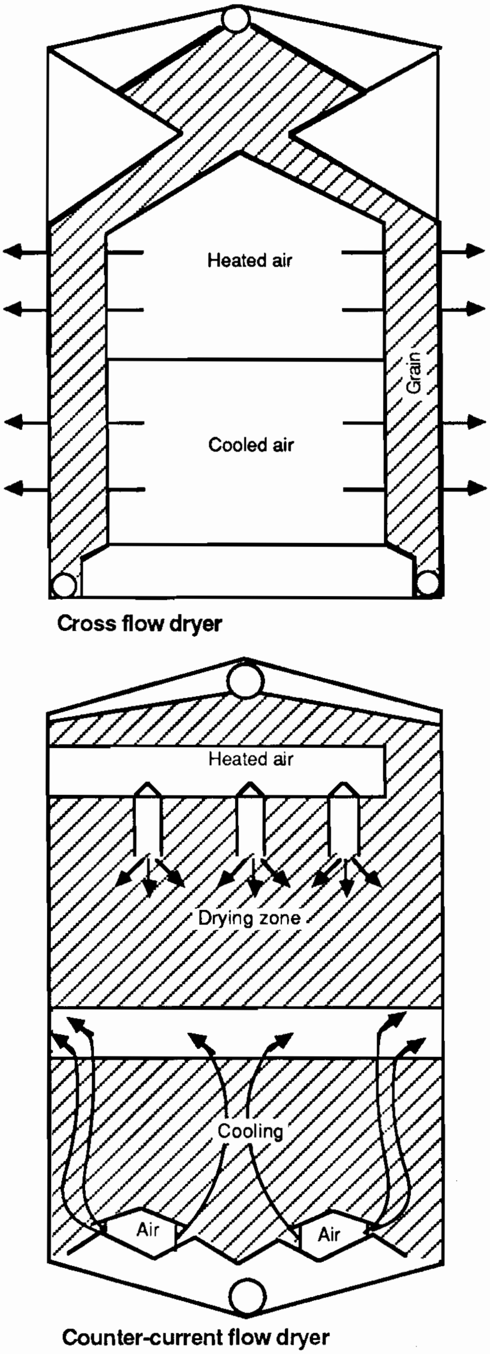

Fig. 3. Principles of the cross-flow dryer (a) and the countercurrent-flow dryer (b), two configurations for continuous grain drying.

suitable grain tempering, the fluidised bed offers better economy, gentler grain handling, and reduced drying times over the LSU dryer. It has been demonstrated that paddy can take far higher air drying temperatures than was previously thought possible, without loss of milling yield, provided the grain is cooled and protected from a moist environment directly after drying. For both fluidised and spouted beds, the drying rates can be described using thin-layer drying curves for the material (Kitic and Viollaz 1984).

A similar but less developed principle is the spouted-bed dryer. Instead of fluidising the whole bed, a jet of air is spouted upwards through a section of the bed, the paddy being entrained in the jet and falling out of the spout in a fountain onto the annular region of grain surrounding the spout. The whole bed of grain is continually being heated and dried, so the process is again very energy-efficient and uniform in treatment. The grain is automatically tempered while it is drying.

A more conventional approach is that of the rotary dryer (Suhargo and Jindal 1983; Jindal and Obaldo 1986). Present designs are partly based on scaled-down versions of the commercial rotary dryers developed for granular materials. The grain flows downwards through a rotating drum and is periodically lifted by inclined flights, then dropped, ensuring good air/grain contact. However, whereas in commercial practice the main method of heating is convective heating from the drying air, in the small-scale designs heating is by conduction through the walls of the drum. The walls are heated by direct contact with the flue gases of a combustor, preferably biomass fired.

Dryer Performance Estimates

Methods for estimating the costs of running in-store, flat-bed or inclined-bed, and LSU-type dryers are dealt with in this section. Further analyses are currently being developed.

Flat-bed or Inclined-bed Dryers

The flat-bed dryer may be modelled for air temperatures below about 50°C by a temperature-equilibrium model (also called a partial-equilibrium model). Such models give reasonably accurate predictions of drying time, but are too complex to be included directly in an economic model. The limitations of the near-equilibrium model in this range are governed by the accuracy of the data, especially factors such as the cleanness of the grain, the actual air speed, the drying rate of the grain, and the thermophysical grain data. The last two factors are variety dependent. In the laboratory situation, these data may be obtained with sufficient precision to give moisture front predictions to within 10%. In field situations of course, it is generally impossible to obtain data to this level of precision, so in trying to construct a simple model, our objective is to predict drying times to within about 10% of the accuracy of the temperature-equilibrium model.

Consequently, a linear model was fitted to the computer predictions of the drying time. It was assumed that the flat-bed dryer is operated within the following ranges of variables:

air speed (superficial) 10–20 m/min
ambient temperature 25–35°C
burner temperature rise 5–15°C
ambient relative humidity 60–90%
initial grain moisture 18–26% (wet basis)
bed depth 0.5–1.5 m

where the values refer to the average conditions over the period of drying. The final moisture content was taken as 16% wet basis, as it was assumed that the final two percent could be removed by ambient aeration in the warehouse, during transport, or by some other means before milling. The increase in time if the grain is dried to 14% is about 30%. The resulting model was:

$$t = \frac{0.086h}{v(Tb + 4.64)} (111 - Ta)(M - 15.8)(RH - 6)$$

where t is the drying time required to bring the average bed moisture content to 16.0%, h is the bed height in metres, Ta is the ambient temperature, Tb is the air temperature rise across the burner, M is the moisture content (percentage, wet basis), RH is the ambient air relative humidity (%), and v is the superficial air speed in metres per minute.

This model does not take into account non-uniformity in the grain or the effect of unclean grain. Fluctuations in ambient conditions about the average, however, should not have a major effect on the accuracy of the predictions.

Once the drying time has been estimated (and preferably confirmed for the particular conditions of interest), the running costs can be estimated as follows:

cost = t × (motor × \$/kWh electric + burner × \$/kWh gas)

where cost is the cost in dollars of running the dryer, motor is the fan motor size in kW, \$/kWh electric is the cost per kilowatt hour for electricity, burner is the burner size in kW, and \$/kWh gas is the cost per kilowatt hour for the fuel source for the burner. Other forms of this equation may be used, but the above is the simplest. To find the cost per unit of moisture extracted, divide by the tonnes dried per batch and by the fractional dry basis moisture difference between the initial grain and the final grain average moisture contents. Dry basis is a more accurate estimate here, because 1% dry basis is a fixed amount of moisture irrespective of the moisture content of the grain, whereas 1% wet basis relates to different amounts of moisture at different moisture contents.

As an example, consider paddy being dried from 24% to 18% m.c. (wet basis) in a 1.2 m flat-bed, using average conditions for the west coast of Malaysia. Then the average ambient temperature is about 28°C and the average relative humidity about 75%. The bed is 12 m by 6 m, and is aerated with a 40 kW fan coupled to a 91 kW burner. The airflow will be approximately 12 m/min for clean grain, and the total air temperature rise across the fan and the burner will be about 8.7°C (using basic formulae for pressure drops across rice and heat balances). Thus, the time of drying formula predicts 32.8 hours for drying. The total cost will be:

cost = 32.8(40 × 0.08 + 91 × 0.03) = \$194.50

The bin holds about 55 dry tonnes and the grain has lost 12.5% dry basis moisture, so the cost of moisture removal is \$28.3 per tonne moisture or 2.8 cents per kilogram moisture removed.

The inclined-bed dryer can be analysed in the same way, except that the bed depth must be taken perpendicular to the grain surface, and the drying will be less uniform.

In-store Dryer Model

For a deep bed of grain at an initial uniform temperature and moisture content, being aerated/dried by low speed air, it is possible to calculate the speed of the drying front through the grain simply by using the principle of mass balance (Driscoll and Bowrey 1985). For constant inlet conditions, this method gives the same result as the moisture equilibrium models of Sutherland et al. (1971), Ingram (1979), Bloome and Shove (1971), and others. The resulting formula is:

$$vs = v \times 0.2 \times \frac{(Hb - Ha)}{(Mo - Me)}$$

where vs is the moisture front speed (m/min), v is the superficial air speed (m/min), Hb is the outlet air absolute humidity (kg/kg), Ha is the inlet air absolute humidity (kg/kg), Mo is the initial grain moisture content (%, dry basis), and Me is the inlet air equilibrium moisture content (%, dry basis).

Although this model gives very accurate predictions for in-store drying times, the variables Hb and Me are difficult to measure directly, so again it was necessary to derive an approximate linear model in order to obtain the simplest possible formula for estimating drying times. The range of variables chosen was:

air speed (superficial)	4–10 m/min
ambient temperature	25–35°C
burner temperature rise	3–9°C
ambient relative humidity	50–80%
initial grain moisture	17–19% (wet basis)
bed depth	3–5 m

The final moisture content was set at 14% and the method of least squares again used to fit a linear equation to each variable. The variables were assumed to be interdependent, as for the flat-bed dryer. Note that the ambient relative humidity values chosen were lower than for the equivalent flat-bed dryer situation, as it is assumed that some weather selection by controller is possible. With these assumptions, the full temperature-equilibrium model was used to derive the following formula:

$$t = \frac{0.15 \times h}{v(Tb + 5.5)} (90 - Ta)(M - 13.2)(RH - 18)$$

Both linear models were found to agree with the temperature equilibrium model to within 5% over the given range of variables. Figures 4 and 5 compare the progress of the drying front for a 4 m bed, with the linear model predictions given above. In both cases, the mid-point of the drying front roughly coincides with the predicted value for drying the grain to an average of 14% m.c. (wet basis). Thus, the equation tends to slightly overestimate the drying time, an error on the safe side.

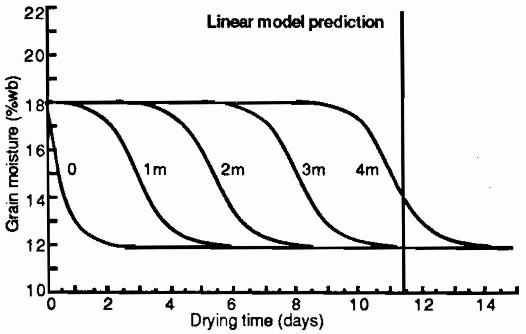

Fig. 4. Drying front profiles during high-speed drying.

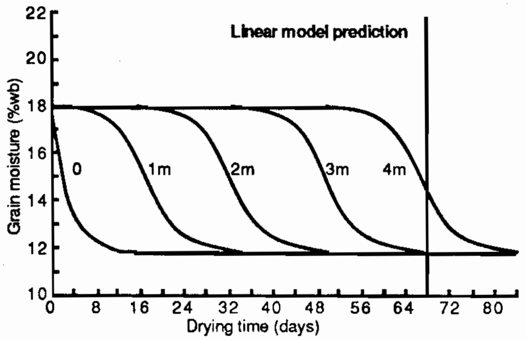

Fig. 5. Drying front profiles during low-speed drying.

Analysis of a Typical Continuous-Flow Dryer

The continuous-flow dryers manufactured for grain drying are versatile. They are modular in construction, so that any number of heating and cooling stages may be combined, dependent on the needs of the customer. The modular stages in turn come in several different types.

Therefore, in the following introductory analysis, it is not proposed to develop a complete model of a counter-current flow, continuous grain dryer, but to look in detail at a particular configuration in common use. It is intended, by further research, to develop this model into a more general one.

The configuration chosen is a typical one for Southeast Asian conditions. The dryer has three heating stages and one cooling stage. Data from a manufacturer's leaflet is used. The following assumptions were made:

- the flow rate per stage is 13 600 m^3/h
- average ambient conditions are 28°C and 75% RH
- the dryer is operated at 70°C
- the dryer volume per section is 8.3 m^3, giving a grain weight per section of 4.8 tonnes (t)
- it takes 1.5 h to dry from 20% to 15% m.c. (wet basis) at 70°C
- the dryer requires 3.8 kW/t/h

The dryer throughput for 20% m.c. to 15% (wet basis) is then 14.4 t/1.5, or 9.6 t/h. The required fan size per section is:

$$\text{fan size} = 1/3 \times 9.6 \times 5.1 \times 0.75 = 12.2 \text{ kW}$$

$$\text{burner size} = \frac{13\,600 \times 1\,050 \times (70 - 28)}{3600 \times 0.88} = 189 \text{ kW}$$

Thus, to remove 1 kg of moisture, 7.68 t (dry basis) of grain pass through the dryer per hour, losing 7.35% dry basis moisture. Therefore, 564.5 kg of moisture are removed per hour, which is 0.157 kg/s. The cost of removing this moisture can be calculated as:

$$\text{cost} = 0.086 \times \$/\text{kWh electric} + 1.00 \times \$/\text{kWh gas}$$

using the same notation as for the flat-bed dryer. For a situation comparable to that analysed for the deep-bed dryer in the previous section, this gives a drying cost of 3.7c/kg moisture, which is 30% more expensive.

A continuous-flow dryer is justified despite its higher capital and running costs because it can partially dry large amounts of grain over short periods, thus preserving grain quality. However, at lower moisture contents, where there is no such urgency to dry the grain, the cost becomes prohibitive. This can be seen in the following approximate formula for paddy:

$$\text{moisture reduction/pass} = 0.13 \times \text{initial paddy moisture}$$

where the moisture contents are expressed on a wet basis. Thus, to remove moisture at 27% requires 50% more energy than drying the same grain at 18%. This is due to two factors: the drop in air moisture capacity at lower moisture contents, and the internal moisture diffusion barrier to moisture transfer.

Conclusions

In this paper, brief descriptions have been given of various types of grain dryers. Many other designs exist. The dryers covered here represent the main options available for drying paddy in Southeast Asia, although many specific designs are presently being developed.

Approximate performance analyses of several of the dryers were presented. While this is one objective of a continuing ACIAR-funded project, it was possible to make estimates for some of the existing dryers that have already been studied. Simple linear models of flat-bed, deep-bed, and continuous-flow dryers over limited variable ranges were presented. Future research will be directed at constructing similar models for other dryer options, as well as at improving and developing the existing models.

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Storage and Ancillary Equipment for Bulk Handling of Grain

C.J.E. Newman*

Abstract

An overview is given of the state of the art in bulk storage of grain. As well as describing the various types of storages available, the paper also covers conveying systems, aeration, pesticide application techniques and equipment, sealing, fumigation, weighing and sampling equipment, dust control, fire protection, and automation and control systems. It is pointed out that simple solutions and procedures are still very often the best option, particularly where transition from bag to bulk handling is under way.

THE aim of this paper is to give a broad overview of the types of facilities available for bulk storage of grain, and their relevance to various levels of operation and other circumstances. The paper draws heavily on experience in Australia in general and the State of Queensland in particular.

Storages

An enormously wide selection of different structures is available for the storage of grain. Many offer particular advantages, but the selection of the most appropriate storage type for a specific need can be a difficult process.

Temporary Storages

A grain storage should suit the purpose for which it is intended. For on-farm storage of small quantities of grain, small, light-gauge steel silos are commonly used. However, they are generally suitable only for short-term storage since they are not usually sealed to exclude insects or to allow proper fumigation.

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The use of larger, gastight storage containers, made from high quality impervious plastic materials has been suggested as a low-cost storage medium for farmers in third-world countries but likely to prove unsuitable for high moisture grain storage. The method is already widely used in scaled-up form in Australia, for long-term storage of large volumes of grain. 'Pad' or 'bunker' storage, as it is called, has proved highly successful as a means of storing grain safely and economically (Fig. 1). Successful storage does, however, depend on control of insects and of grain moisture levels, since losses through moisture migration can otherwise become significant. By exercising strict controls, Australian Bulk Handling Authorities have been able to reduce loss rates during pad storage to much less than 0.1%.

Debate continues in Australia as to the cost-effectiveness of pad storage. The current trend of thought is that low-cost permanent storage (costing less than $A60 per tonne) is a better long-term investment in situations where regular utilisation can be assured (one filling and emptying four years out of every five). Where storage is to be provided for more marginal yields and for production peaks, there is little

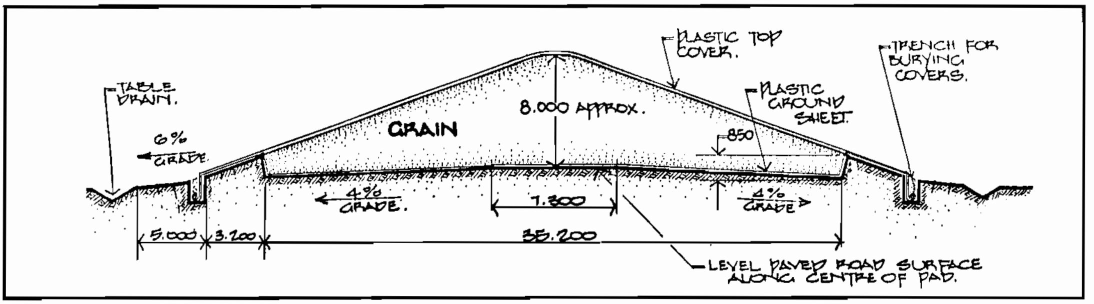


Fig. 1. Diagram giving details of construction of a bunker storage for grain.

doubt that pad storage is the most economical system for Australian conditions.

Regardless of the arguments in this debate, however, any centralised storage system requires a core of high quality permanent storage to give it the operational flexibility to be able to store and handle grain efficiently.

Permanent Storages — General Comments

As for any storage system, a permanent storage should be selected to suit its intended purpose. The centralised storage and handling organisation responsible for the safekeeping of stored grains, should select storages on the basis of quality ahead of cost considerations. The value of the stored products over the life of the storage will far exceed the value of the storage container, and high loss rates may quickly erode any capital cost savings made in the selection of poor quality storage.

High quality storage may be defined as being:

- structurally adequate
- durable
- hygienic, i.e. easily kept clean
- gas sealable for fumigation

These qualities are not difficult to achieve and need not result in high costs. In fact, good quality storage need not be expensive or difficult to build. In Australia, good quality storage can be built for as little as $A25 per tonne, although costs as low as this can only be achieved with large volumes.

Various forms of storage have been built by Bulk Handling Authorities in Australia which adequately satisfy the above requirements. They are, however, not all equal in quality or price. In addition, some types of storage are better suited to particular applications than others.

Storage Volumes

Before looking at different storage types, it is worth considering storage volumes appropriate to particular requirements.

It is a generally accepted principle that the larger the volume of a particular storage, the lower its unit cost. This is because the ratio of surface area to volume decreases as volume increases and it is the structure forming the surface area that costs money.

It is important to select a unit storage size that is not too large for foreseeable needs. A unit storage should be of a size that can be assured of regular filling, and which can be filled and emptied in manageable time periods. A few years ago in Queensland, Australia a 60 000 tonne shed (Fig. 2) was constructed with 400 tonne per hour conveying equipment in a rapidly expanding grain growing area. It was constructed at the then very low cost of $45* per tonne and was expected to meet foreseeable future storage requirements in the area. Technically, the storage was a success, but in practice it proved difficult to manage, because there is often less than 60 000 tonnes of any one classification of grain to be stored. As segregation needs to be provided, it is necessary to separate grains into different piles, thereby reducing the effective storage capacity. Furthermore, there is seldom a requirement to ship 60 000 tonnes of grain from one location in one movement. Often the emptying process is prolonged to such an extent

*All costs given in this paper are in Australian dollars. During October 1987, approx. $A1.40 = US$1.

Fig. 2. A typical 60 000 tonne grain shed in Queensland, Australia.

that the grain is left in the storage in a relatively unprotected state. The cost of fumigating such a large volume is very high, more so if the shed is only part full.

In retrospect, three separate storage units of 20 000 tonnes each would have been a better option. This is now the unit volume that has been adopted as a maximum for future construction in similar circumstances.

As will be discussed later, there has been no cost penalty attached to this change in policy. As a general rule, it is suggested that storage volume should be selected so that filling and emptying will take no longer than two or three weeks under normal circumstances.

Storage Types — Comparison of Geometric Shapes

Sheds

Traditionally, horizontal sheds have been used to provide low-cost, large-volume storage. Very large sheds have been constructed for grain storage, amongst the largest of which would be the 300 000 tonne shed at Kwinana in Western Australia.

Sheds in Australia are usually of steel construction with flat concrete or bitumen sealed floors requiring the use of portable sweep conveyors or end-loaders for grain outloading.

Equipment is available for automatic sweeping of flat shed floors as, for instance, the suspended drag-chain conveyors (Fig. 3) incorporated in the 60 000 tonne shed mentioned previously. These conveyors are suspended from motorised monorail trolleys which enable them to travel the length of the shed above the grain surface. They operate by being lowered onto the static grain surface to drag the grain to the centre of the shed floor where it drops onto an outloading conveyor in a tunnel below. The costs of these conveyors are extremely high and, in the above case, amounted to $8 per tonne or approximately $250 000 each, including wiring, catenary cabling, and automated control system.

Because of their shape, sheds are relatively inefficient structures for grain storage. Grain

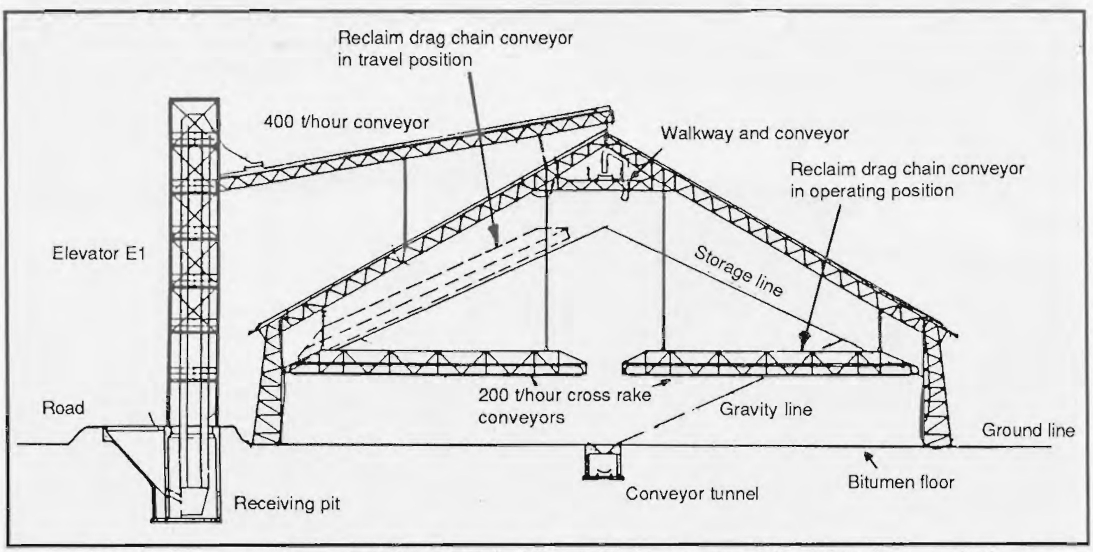


Fig. 3. Diagram of suspended travelling drag-chains for grain reclamation from a shed.

loads on the walls have to be supported by girts and by heavy vertical buttresses designed to resist their loads in bending. Roofs have to be supported on a network of purlins and rafters, also requiring bending stiffness to provide structural strength.

Costs of sheds depend upon their size and other factors. As a guide, however, indicative costs in Australia are between $25 and $40 per tonne, excluding mechanical equipment, for storages of between 60 000 and 100 000 tonnes capacity.

'Squat' Silos

Squat silos compete with sheds in the market for low-cost, 'quality' storages. Because of their greater structural efficiency, they can be built from lighter materials and costs are generally lower for a given storage volume. Structural efficiency is achieved by the walls carrying their loads principally in tension and by the conical roof carrying its loads principally 'in plane', i.e. in tension, compression, and shear.

Typically, a squat silo will have a wall height to diameter ratio of 0.5 or even less. Large storages are thus of large diameter and unsuited for full gravity discharge. 'Built-in' sweep conveyors are simpler than those required for a large shed storage since (a) they need only to operate radially, sweeping grain to the silo centre and (b), because no segregations of grain can be stored, the conveyors do not have to be able to be travelled over the grain stack. They can remain on the floor and be buried in grain.

Both drag-chain and auger sweep conveyors are available as proprietary designs for sweeping large diameter flat silo floors. They are, however, expensive (over $5 per tonne) and, unless a storage is to be filled and emptied regularly, the use of portable equipment (such as an end-loader) for outloading may be a very much more economical alternative.

The largest squat silos currently being built in Australia are 200 000 tonne units with post-tensioned precast concrete panel walls and stressed skin roofs made from light gauge galvanised high-strength steel members. The silos are 48 metres diameter, have 10.5 metre high walls, and are 25 metres high at the roof apex. The storage cost (excluding machinery) will be around $25 per tonne.

The design is based on a proprietary Australian design called the 'Safeway Silo' (Fig. 4). This

Fig. 4. The 'Safeway' silo, a type of 'squat' grain silo.

design features the use of high-strength steel framing and folded steel plate in the wall construction. Silos of this type range in price from $25 to $50 per tonne for storage capacities of less than 1000 to up to 20 000 tonnes.

Vertical Silos

Vertical silos can be circular, hexagonal, square, or rectangular. They tend to be more expensive than squat silos and sheds, ranging in price from around $50 to $150 per tonne depending on type, size, and foundation conditions.

The extra cost is, nevertheless, justifiable where high throughputs demand the provision of full gravity discharge, or where space limitations preclude the use of large floor areas.

Where gravity discharge is required, it is achieved by the provision of sloping floors with either single or multiple discharge points. In most cases, a single central discharge point is to be recommended to reduce risks of eccentric discharge patterns and to minimise complexities and costs.

Floor slopes should be adequate to minimise material 'hang-up'. In Australia, slope angles of 30° are 35° are common and generally give satisfactory results provided the surface is smooth. With very dusty or moist grains, however, even slopes of 40° will not guarantee full discharge.

Both steel and concrete can be used for conical floor construction and very often a combination of both is used: concrete upper section and steel lower section. Where concrete is used it is important to achieve a smooth finish and this can be difficult when pouring in-site on a steeply sloping surface. The use of 'top-forming', render finishing, or pre-casting are more likely to assure good quality finishes. Alternatively, special coatings can be applied after construction to improve grain flow properties if problems arise. High-build epoxy-mastic paints have been successfully used for this purpose.

With square or rectangular self-emptying silos, the hopper slopes have to be steeper to prevent grain lodging in the 'valleys' at the interface between the hopper sides.

In situations where silos are used as buffer storage in a continuous throughput situation, the avoidance of 'static' product in the bottom may be critical to avoid segregation and/or deterioration. The design of a silo floor to ensure reliable 'first-in-first-out' flow requires laboratory testing of the stored product to determine a number of critical properties such as its unconfined compressive strength after consolidation, internal friction angle, and wall friction angle. Hopper slope angles of 60° or 70° are usually necessary to achieve reliable mass-flow. With normal hoppers slopes of 30° to 40°, pipe flow or funnel flow are more likely to occur in which the bottom layers of material remain static until the upper material has been discharged (Fig. 5).

Where gravity discharge is not an essential requirement, flat 'on-ground' floors offer very significant cost savings, particularly when

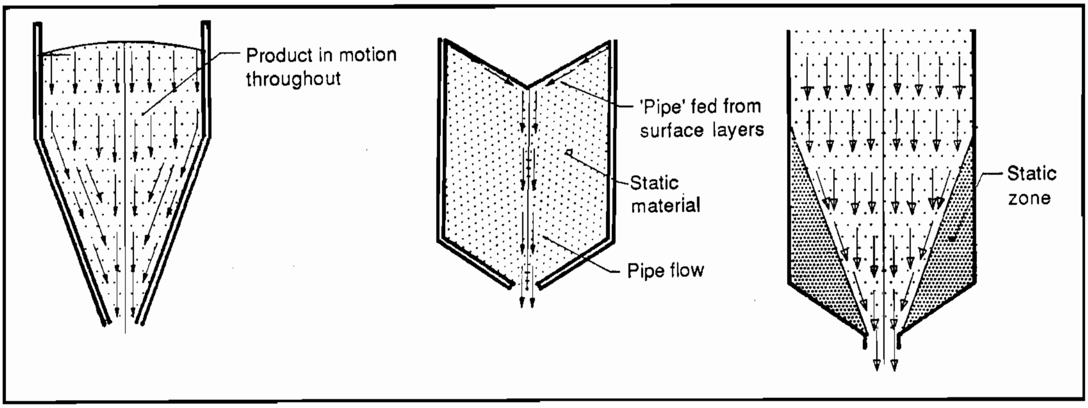


Fig. 5. Diagram showing different types of flow possible when emptying a vertical grain silo.

coupled with the use of portable conveyors for outloading as discussed later.

It may be mentioned that a 'ventilation' system has been developed in France for cleaning out flat bottom storages (Fig. 6). The system uses trapezoidal-shaped metal ducts with vertical louvres cut in the sides, which are fixed to the floor of the silo. Static grain is moved across the storage floor by high pressure air inside the ducts being exhausted through the louvres. The system is reportedly successful. It appears to have found use primarily in square, flat-bottom silos with small floor areas. The cost is high, but may be justifiable in certain situations especially where in-storage aeration or drying of grain is required since the floor ducts can be used for these purposes.

Storage Types — Comparison of Construction Materials

Basically, the choice of construction materials for modern permanent storages is between steel and concrete, although it is noted that masonry brick is also used in some countries (e.g. China).

The selection process between steel and concrete can involve a wide range of considerations.

It should be recalled that two of the requirements for 'quality' storage are durability and gastightness.

The choice of construction material should take these requirements into account. A corollary is that once a construction material is chosen, these two considerations (in particular gastightness) should influence the structural design.

Durability

On the question of durability, a few points are worthy of note.

• Concrete silos are not maintenance-free. If their design is inadequate, they may crack, allowing water ingress and/or fumigant loss. Crack repair can be an expensive process. Concrete is also a chemically reactive material. One chemical compound that it reacts readily with is carbon dioxide, the gas reacting with calcium hydroxide molecules in the cement matrix to form calcium carbonate. Calcium hydroxide is a highly alkaline substance which gives chemical protection against corrosion of the reinforcing steel. Carbonation removes the alkalinity and the protection.

Carbonation takes place in all concrete as a

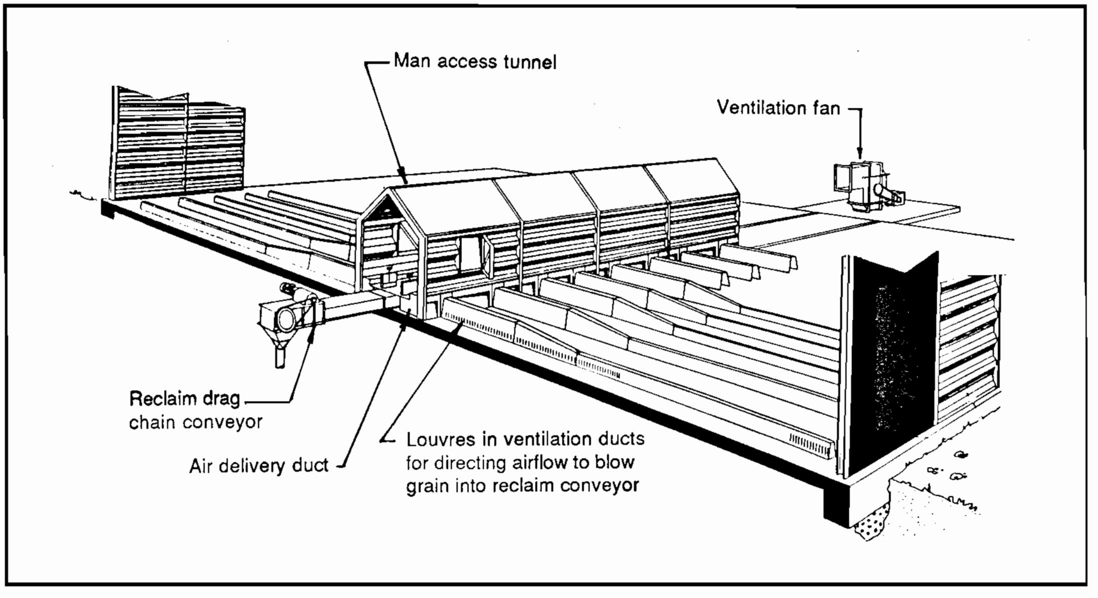


Fig. 6. Ventilation system for reclaiming grain from flat-bottomed storages.

result of reaction with carbon dioxide (CO_2) in the atmosphere. The CO_2 concentration is, however, very low (0.03%) and the reaction very slow. Typically, carbonation may penetrate at less than 1 mm per year in a chemically clean rural atmosphere.

Grain produces CO_2 as a natural by-product of metabolic activity. Storage of grain in concrete silos thus produces an accelerated rate of carbonation such that it is possible that in a 50-year life a 200 mm thick silo wall may become fully carbonated.

Current considerations relating to the use of CO_2 gas to disinfest grain change the picture somewhat. At 'controlled atmosphere' concentration of 60% CO_2, the reaction is extremely vigorous and carbonation depths of 20 or 30 mm can be expected to result from a single 4-week disinfestation period. Thus, the chemical protection against corrosion of reinforcing steel may be lost in a very short time.

Physical corrosion protection may, however, prove adequate if concrete compaction is good, if strength is high, and if cracks are controlled. These factors depend upon the quality of design and construction.

It may be noted that the use of fly-ash as a cement replacement in concrete for silo construction should be avoided due to the greater rate of carbonation that can be expected to occur.

The rate of carbonation can be dramatically reduced by the application of certain high build paints. These add both to capital and maintenance costs of a concrete silo and need to be formulated to resist abrasion from grain movement.

• In steel silos, zinc galvanising should not be relied upon to give long-term corrosion protection in marine or chemically aggressive environments. In such conditions, galvanised surfaces should be overcoated with an appropriate paint system.

• Paint systems can add significantly to the cost of steel constructions, thus care should be taken not to overspecify. Equally, paint-system maintenance costs can be very high if a system is underspecified or if application is inadequate.

Paint systems most commonly employed these days for structural works where high corrosion protection is required are:

- high quality sand-blast of steel surfaces to 'near white' conditions (class 2 1/2).
- inorganic zinc rich primers (minimum zinc content should be specified).
- chlorinated rubber solvent-based coatings: these are extremely impermeable coatings, highly resistant to chemicals other than mineral oils, and being solvent based they are readily overcoated for maintenance purposes. They are, however, relatively soft and are easily damaged when handling and erecting pre-painted steel.
- high solids epoxies: these can be applied in very high film builds and provide excellent corrosion protection. Their main problems are colour fade due to chalking, and difficulty in overcoating. They are extremely hard and will suffer minimal damage in handling and erection.
- polyurethane coatings: these are only justifiable where aesthetic considerations are prevalent. Whilst giving good protection, they are expensive and cannot be applied in thick coatings. Their advantages are high gloss retention and high colour retention.
- as will be discussed later, steel storages should be painted white. In low-corrosive environments, a coating of water-based acrylic paint applied over galvanised steel or zinc-primer-coated black steel will provide a low-cost, easily applied coating with good durability.

Gastightness

Just as the misconception commonly exists that concrete silos are maintenance-free, another equally commonly held misconception is that they cannot be made gastight. In fact they can be made gastight without major difficulty or expense. For instance, in Queensland, Australia 80% of all storages built since 1972 totalling 500 000 tonnes have been vertical concrete silos. All achieved gastightness standards when built and most have retained them with little deterioration in usage. Concrete silos are no more difficult to make gastight than steel silos, provided certain simple rules are followed.

Further reference to gas-sealing is found in a later section on sealing of storages.

Condensation

It is sometimes suggested that steel silos cause moisture migration and/or moisture condensation, resulting in mould development and grain spoilage.

Whilst this may be the case with unsealed steel silos, there are grounds for suggesting that steel silos do not cause such problems, if they are gas-sealed. Once moisture migration processes have begun, however, steel silos are likely to accelerate the process more quickly than would occur with concrete silos, because of the higher rate of heat loss that will occur from the walls and roof of a steel silo.

Damaging moisture migration should occur in an airtight storage only if high moisture grain is stored or if insect activity develops. Insect-free grain stored at less than the critical moisture content for mould growth (say 12 or 13%) should not experience damage from moisture migration in either concrete or steel silos which are effectively sealed.

Aeration/Drying

The question of aeration is covered briefly later in this paper. It is noted here, however, that the choice of storage may be influenced by the need for in-store aeration and/or drying.

Squat (large floor area, low height) storages offer advantages in reducing energy requirements and at the same time speeding up cooling and/or drying processes.

For instance, the fan power requirement for a given aeration rate and for a given quantity of grain approximately doubles with every 50% increase in grain depth.

New Storage Development

The emphasis in new storage technology in Australia is currently towards the development of low-cost permanent storage to take the place of pad or bunker storage, or at least to reduce current levels of dependence on it.

Apart from squat silos, another form of storage structure currently being developed is that of a free spanning arch roof structure formed from deeply corrugated light-gauge galvanised steel sheet (Fig. 7). Spans of over 40 metres are expected to be achieved, such that a 20 000 tonne storage may be built with dimensions of around 120 x 40 metres.

Current cost predictions of between $16 and $21 per tonne for storage only (excluding earthworks or floor preparation) make the system attractive, but only where annual usage is likely to be achieved.

Conveyors

This section of the paper gives a brief review of conveying systems in common use in the grain industry.

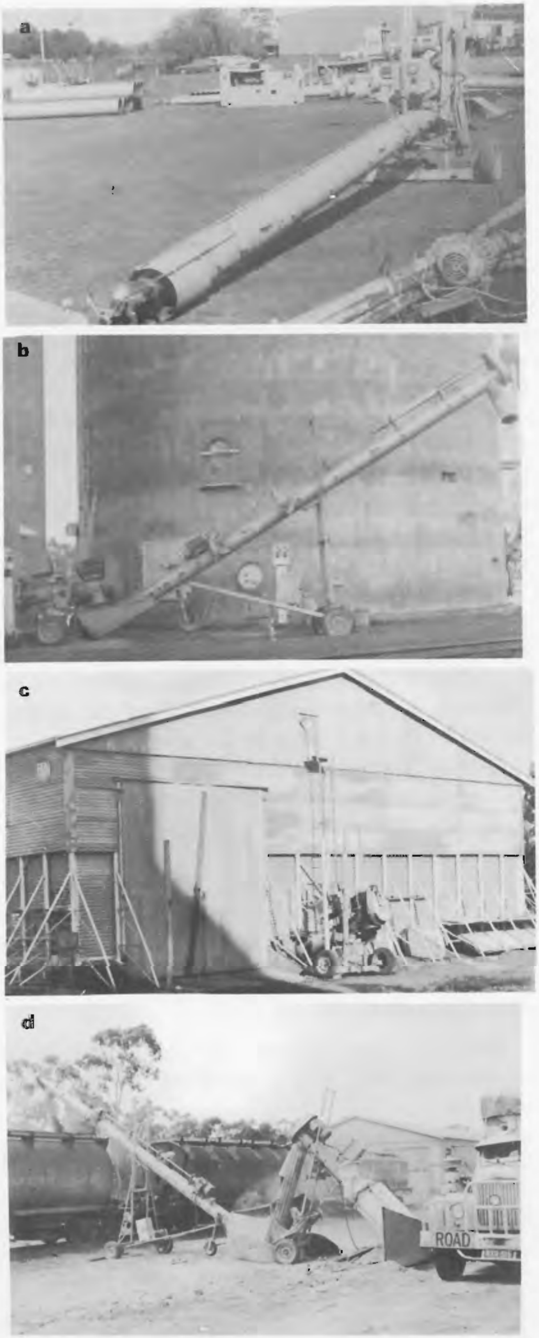
Portable Conveyors

Portable conveyors can play an enormously important role in a modern bulk handling system and their use can allow major cost savings to be achieved.

Augers (Screw Conveyors)

In Queensland, Australia 55% or 800 000 tonnes of permanent country storages (including both silos and sheds) have no permanent outload conveying system and rely totally on the use of portable equipment for emptying. A fleet of 50 portable auger sets, costing $20 000 per set

Fig. 7. An arch shed for grain storage, made from deeply corrugated, light-gauge, galvanised steel sheeting.



(representing an investment cost of $1 000 000), performs the task of emptying these storages and loading grain onto rail wagons and/or road trucks. Allowing for fixed equipment and electrical wiring necessary to operate the portable conveyors, an all-up cost of between $2 and $3 per tonne for high capacity (200 tonne per hour) outloading equipment represents a very low cost investment. The effective cost is lowered even further since the same equipment is used for other purposes, such as extracting grain from road hoppers (dump pits) and for loading grain into non-permanent storage.

An auger 'set' consists of two augers: an 'extractor' auger (Fig. 8) for extracting grain from a storage and an 'elevating' auger for loading it into transport.

Augers are often regarded as second-rate conveying systems, suitable only for farm use. Properly designed, however, they are cheap to build, robust, easily transported, and easily maintained.

A disadvantage of augers is that they rely on friction between the auger flight and the grain for their operation. As a result they are relatively high power consumers. For instance, a 10 metre long 200 tonne per hour auger running at elevations of up to 40° requires a 22 kW motor.

Grain breakage can be minimised by allowing sufficient clearance between flight and barrel, which should exceed the largest size grain to be handled.

Tube Conveyors

Whilst augers will inevitably have an on-going role as portable conveyors, a relatively

Fig. 8. Various views and uses of the grain auger (screw conveyor): (a) rear view of extractor auger; (b) extractor auger used to outload grain from silo and elevating auger to load it into rail wagons; (c) extractor auger as used for outloading grain from a shed; (d) extractor and elevating augers filling rail wagon from temporary (portable) road dump pit; (e) extractor auger used for feeding grain to belt slinger for pad storage filling.

new form of conveyor which is becoming popular incorporates many of the advantages of augers and avoids some of their disadvantages. This is the tube conveyor.

The tube conveyor (Fig. 9) is simply a belt conveyor which is run inside a cylindrical tube between its end pulleys, requiring no idlers except to support the return of the belt.

Perceived advantages of the tube conveyor for portable use include low cost, lower power requirements, and high capacity to weight ratio.

Recently introduced 200 mm diameter conveyors, 19 metres long, and capable of carrying 180 tonnes per hour horizontally and 120 tonnes per hour at a 25° incline use 11 kW motors and weigh about 0.75 tonnes.

Fixed Conveyors

Whilst portable conveying equipment has a diversity of potential uses, for many situations there is no alternative to fixed conveyors.

Bucket Elevators

In high throughput facilities, such as grain export terminals, there is a trend to minimise or avoid the use of bucket elevators because of their relatively low reliability (compared with belt conveyors) and the higher risk of fire and explosion associated with them. Nevertheless, because of economic considerations elevators are likely to remain the most common means of in-loading large storages in the foreseeable future.

Recent developments in elevator technology have been aimed at improving performance and reliability and most relate to bucket design.

'Bottomless' and low profile 'cup' buckets have been developed for upgrading the capacity of existing elevators. They can be placed at much closer intervals than normal deep profile buckets and, combined with an increase in the elevator belt speed and drive power and improvements in discharge geometry, the handling capacity of an elevator can be increased by as much as 100%. Both systems have been trialled with reasonable success in Australia. However, the 'cup' buckets appear to perform more reliably than the bottomless bucket.

Various forms of plastic buckets have also been developed, primarily aimed at achieving either longer life or lower cost than conventional steel buckets. Polyurethane buckets are claimed to have extremely high wear resistance and to be capable of resisting shock loading by elastic deformation. They are extremely expensive and experience with them in Queensland has not been wholly successful. Problems with bucket breakage appear to have been due more to faulty manufacture rather than design errors.

Polyethylene buckets are more rigid and brittle than polyurethane and offer an advantage only where their price is significantly lower than steel buckets.

Recent developments in America have been towards the use of low-speed elevators with belt speeds of around 1.6 to 2.4 m/sec, rather than, say, 3.5 m/sec. Advantages claimed include longer bucket life, better discharge pattern, and reduced fire risk.

Fire-resistant, antistatic belting should always be specified. Belt carcass should be Kuralon-Nylon or Polyester-Nylon to minimise belt stretch. Nylon-Nylon carcass belting should, however, be used for butt-strapping due to the extra flexibility it gives to the jointed length.

Gravity 'take-ups' are almost universally used in new elevators for maintaining belt tensions. A recent introduction has been the 'floating boot' where the boot casing is fixed to the tail shaft such that it floats up and down as the belt stretches. Its advantage is in the fixed clearance between the boot and tail pulley, minimising the accumulation of grain in the boot casing.

Belt Conveyors

Recent innovations in belt conveyor technology for grain handling in Australia include:

Fig. 9. A portable tube conveyor for grain.

• use of higher belt speeds (up to 4.5 m/sec)
• use of steeper troughing angles (up to 45°)
• use of inclined belts to elevate grain, thereby eliminating the need for bucket elevators.

Bulk Grains Queensland's new grain export terminal at Fisherman Islands near Brisbane (Fig. 10), incorporates the highest capacity belt conveyor in the grain industry in Australia and introduced to Australia the American concept of using inclined belts in place of elevators. The Fisherman Islands conveyors are of 2200 tonnes per hour capacity, 1500 mm wide, and have a 45° troughing angle. Belt speed is approximately 3.5 m/sec and the longest of the conveyors is approximately 200 metres between pulleys. Inclined conveyors have a maximum feed-on angle of 10° and conveying angle of 12°.

Because of the very high reliability associated with belt conveyors, the unusual step was taken of constructing the terminal with no back-up conveying system thereby saving very significant costs.

It may be noted that further costs were saved by constructing the conveyors with weather covers rather than enclosing them in galleries. Not only is dust accumulation minimised but wind-loadings on elevated gantries are also reduced, resulting in savings in structural costs.

Drag Chain Conveyors

Drag chain conveyors offer advantages of:

• relatively high capacity (capacities of up to 400 tonnes per hour are common) within a compact size
• relatively low maintenance
• relatively low power consumption (compared with augers)
• high reliability
• in-built weather protection
• ability to discharge at multiple points along a single conveyor
• can be constructed to elevate grain at steep angles (over 45°)
• no dust emissions

Experience in Queensland suggests that:

• for horizontal conveyors or inclines up to 15°, single chain drags are preferable to double chain conveyors. Not only are they cheaper, but there are fewer problems with grain 'carry- over'. Single chain conveyors have also proven more reliable. Blade distortion on double chain conveyors can cause chain misalignment which can result in the chain riding off the head or tail sprocket.
• chain speeds of 1 metre per second perform quite satisfactorily. Traditionally, 0.5 metres per second has been regarded as the maximum design speed.
• the problem of grain carryover from intermediate discharge points can be overcome by fitting a hinged brush over the chain or by welding a number of 'cups' to the drag-chain blades at intervals along its length (Fig. 11). These pick up carryover grain and return it to the tail pulley, minimising accumulation at the head pulley.

Other Conveyors

Various new conveying systems have been developed in recent years. Whilst these have

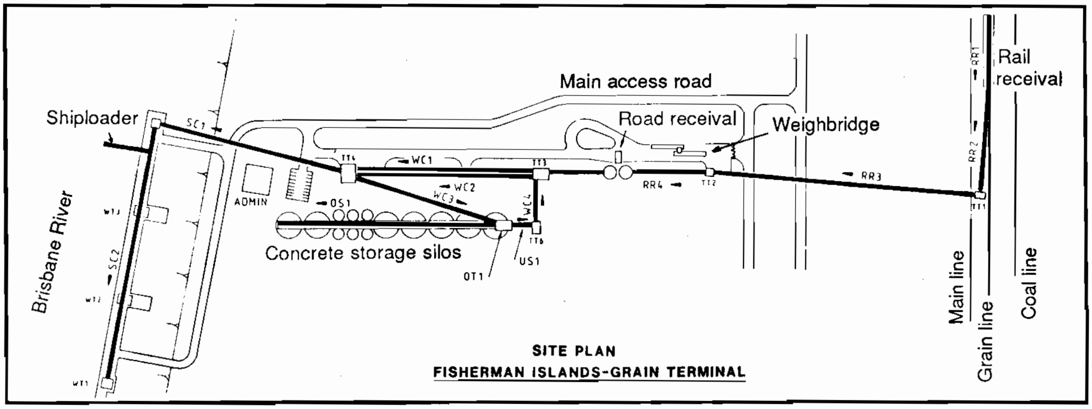


Fig. 10. Grain flow diagram for Fisherman Islands grain terminal, Brisbane, Australia.

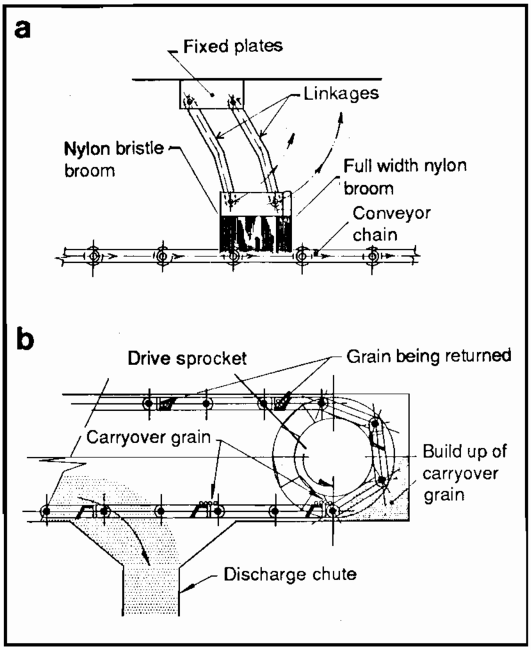


Fig. 11. Diagram of (a) chain sweeper and (b) 'cups' for handling grain carryover on belt conveyors.

found use in the minerals and mining industries, little use has yet been found for them in the grain industry in Australia. Such conveyors include the 'Simlofter' sandwich belt and deep-ribbed belts, all of which are aimed at combining the advantages of belt conveyors with steep angles of incline. The first deep-ribbed belt to be used in the Australian grain industry is expected to be installed at the Mackay export terminal in Queensland shortly.

The jet belt (Fig. 12) is a European concept which aims to reduce power needs and wear rates on conventional conveyor belts. Idle rollers are replaced by a continuous light gauge steel trough which supports the belt when stationary. Low pressure air is fed through small openings in the bottom of the trough when the conveyor is running to effectively provide an air cushion for the belt to run on.

The tube conveyor referred to earlier is, however, a stronger candidate for future use in the Australian grain industry, although it may be developed to incorporate the air-support system utilised in the jet belt.

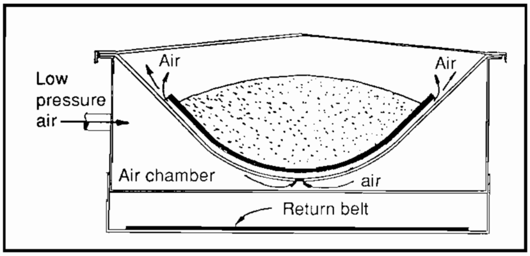


Fig. 12. Diagram giving operating principle of the jet belt grain conveyor.

Advantages of the tube conveyor for fixed installations are seen to be:

- low cost
- relatively low power requirement
- probable low maintenance costs
- ability to run at steeper angles than belt conveyors or shallow blade drag chains
- capable of free-spanning several metres without support and easily stiffened to span 20 metres or more
- the conveyor is weatherproof
- the conveyor can be made dust-proof
- it has no intermediate mechanical components requiring regular servicing or maintenance.

For small capacity conveyors, 'Flow-veyors' and flexible augers have been developed. The Flow-veyor (Fig. 13) consists of a series of plastic discs mounted on a steel cable which runs inside a tubular enclosure through which grain is conveyed. Bends are readily incorporated and the conveyor will operate at any angle or inclination. Conveyors of up to 80 tonnes per hour capacity are available as proprietary designs.

General Comment—Conservative Design

Whilst current practice indicates that high efficiency can be built into new conveyors by adopting high conveyor speeds, steep troughing angles, special buckets, etc., experience has shown that conservative design may pay off in the long run.

Bulk handling of grain did not commence in Queensland until the mid–1950s and during the first 15 years of its implementation handling rates of 100 tonnes per hour were regarded as more than sufficient for new facilities. Between 1970 and 1980, 200 tonnes per hour conveying systems became the norm for country receival facilities. In the 1980s, however, the need for even higher intake rates has prompted the upgrading of a number of these older facilities to increase their handling rates by as much as 100%.

Conservatism in their original design made the process of upgrading relatively cheap and easy in many cases. For instance, drag chains designed with oversized drives and head shafts and with chain speeds of 0.5 m/sec, have been modified to run at 1.0 m/sec by simply changing the gearing ratio of the drive to increase capacity by 100%. Elevators have been increased in capacity by 100% by increasing the belt speed and by increasing motor and gearbox horsepower and by fitting low-profile buckets. Belt conveyors have also had their capacity increased by 100% by increasing speed and troughing angle. If conservatism had not been adopted in the initial designs, such upgrades would not have been possible without major re-design and significantly higher costs.

Power Consumption

As indicated, screw conveyors suffer relatively high power consumption compared with drag chains and belts. Figure 14 gives an indication of relative power requirements for different conveyor types. A length of 200 metres of horizontal conveyor is assumed.

In comparing power usage, the relative cost of power consumed by different conveyors should not be considered in isolation. For instance, Queensland's 200 tonne per hour portable screw conveyors require a 22 kW drive. This power is only required for start-up conditions and around 12 kW is required for continuous operation.

At, say, 15 cents per kilowatt hour, this represents $1.80 per hour running cost, or under one cent per tonne of product conveyed.

Whilst such costs should not be ignored, they may be justifiable where significant capital cost savings are achieved.

Aeration Equipment

Aeration can provide three major benefits in the storage of grain:

- it cools the grain and slows down insect activity

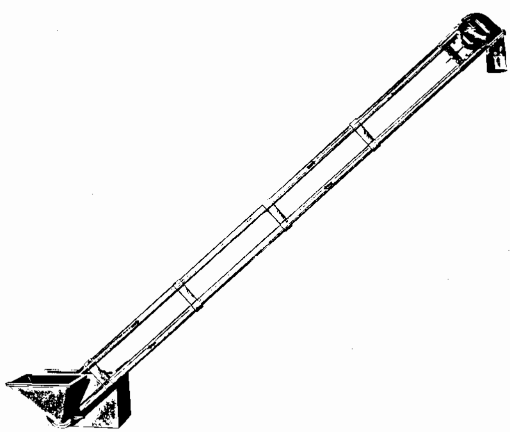


Fig. 13. Drawing of a grain 'Flow-veyor.'

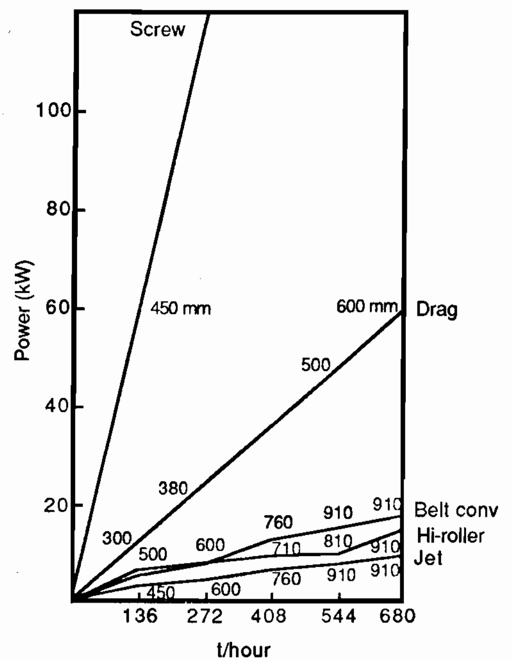


Fig. 14. Relative power requirements of different types of grain conveying systems.

- by cooling the grain, it prolongs the effectiveness of pesticides
- it can provide an appreciable drying function

Aeration systems are installed in both horizontal and vertical storages in Queensland. Most were installed during the 1970s and were designed in accordance with recommendations of the US Department of Agriculture*. These set the following basic design parameters suitable for cooling aeration of dry grain.

Airflow rate: silos 0.8 litres/sec/tonne
sheds 1.6 litres/sec/tonne
Maximum duct velocity: 10 m/sec
Maximum entry velocity
of air into grain: 0.15 m/sec

From these parameters, fan output, duct size, and duct surface area can be determined. The actual fan characteristics are determined from graphs relating pressure loss against airflow rate and grain depth (Fig. 15).

Axial fans are universally used for shed aeration. Non-overloading centrifugal fans should be used for vertical storages because of the higher pressures required. When overloading fans are used it is recommended that a manually adjustable throttle valve be fitted to the inlet duct to cut back the airflow when aerating partly filled silos. In such cases, an ammeter should be fitted to the fan to allow the valve to be adjusted to optimise the airflow rate.

Aeration systems in Queensland all use upward airflow and blower fans because of the belief that air drawn into the top of the storage would undergo a rise in its temperature from solar radiation on the storage roof during daytime aeration.

Nevertheless, there are strong arguments against this approach:

- most aeration is done at night when the head-space is cold
- downward airflow follows the natural movement of cold air in warm grain
- suction fans do not impose any extra heat load on the storage

*L.E. Holman. Aeration of grain in commercial storages. United States Department of Agriculture Marketing Research Report No. 178.

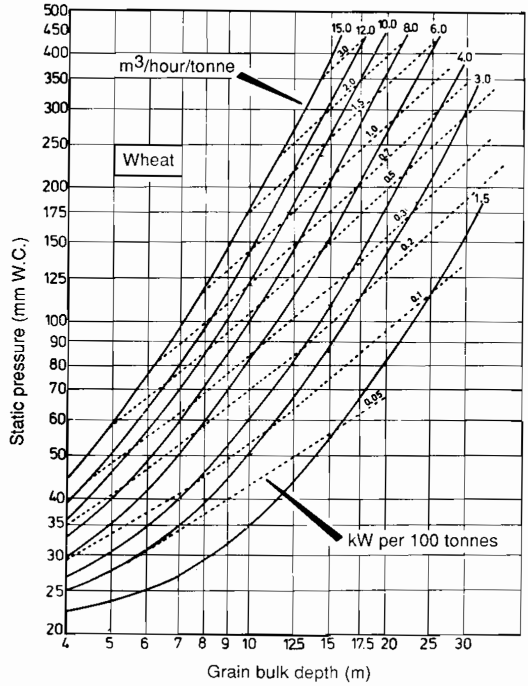


Fig. 15. Graph showing the relationship between pressure loss, airflow rate, and grain depth in bulk wheat.

Various configurations of ducting can be used for air distribution inside the grain mass. Where on-floor ducting is used, it is often important to allow for its removal to facilitate floor sweeping. For this reason, full-round ducting is usually used in sheds where grain loads are moderate. In such cases, duct anchorages are usually in the form of light metal hoops or straps. Screw threaded sockets recessed into the floor avoid problems with sweeps or end-loaders when ducts and fixings are removed.

Both longitudinal and cross-floor ducting can be used in sheds, the cross-floor ducting being preferred since only the fans connected to ducting buried in grain need be operated when the shed is part-filled.

Generally, ducting is made from galvanised steel sheet with 2.5 mm perforations at 6 mm centres. On-floor ducting is normally corrugated and curved for rigidity.

Ducting in silos is normally exposed to considerably higher grain pressures. Half-round ducts anchored to the floor and/or fitted with internal stiffeners are frequently used. However, on flat floors requiring sweeping they can be difficult to remove. In-floor ducting avoids this problem but requires the use of flat perforated sheet requiring a structural support frame below it. Costs are thus significantly higher. An alternative is perimeter ducting formed from quarter round corrugated ducting (Fig. 16).

Any design of floor-mounted ducting should incorporate provision for clearing out dust and broken grain, i.e. ducts should be hinged or removable.

Aeration systems can be readily fitted to sealable storages. An adequate sized bird-proof exhaust vent needs to be fitted to the roof with a flanged end to allow sealing with a cover plate. Aeration fans should also be fitted with fully sealed casings requiring blanking-off of only the inlet to effect a seal.

Watts and CSIRO aeration controllers are widely used in Australia and perform satisfactorily for cooling aeration purposes. Temperature differential settings on the Watts Controller (dry-bulb grain versus wet-bulb air) of 10°C are normally used to control fan operation when cooling dry grain. A lower differential is used for cooling high moisture grain, e.g. 5°C for 15% moisture.

Pesticide Application Equipment

Whilst the majority of pesticides are still applied in highly diluted form, some ULV (ultra-low-volume) systems are now in service in Australia. For instance, in South Australia trials

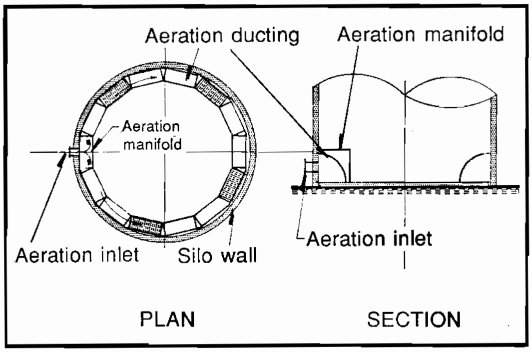


Fig. 16. Details of perimeter ducting for aeration of a grain silo.

using neat pesticide, drip-fed directly onto the grain stream have resulted in reasonably satisfactory distributions, while in Queensland very low dilutions are being spray applied to grain at two export terminals. The reason for using ULV systems at these locations was because of the very high grain handling rates (1200 and 2200 tonnes per hour) which would have required very large volumes of fluid to be handled at normal dilution levels.

With ULV spray systems, nozzle performance is critical. To perform properly a constant flow rate of liquid needs to be applied through the nozzle independently of both grain flow rate and the application rate of the concentrate. This is achieved by varying the dilution of the concentrate such that a constant volume of fluid is sprayed onto the grain per second.

Pesticide concentrate is metered by means of a positive displacement, variable-frequency pump, the pesticide being pumped into a constant pressure water mixing chamber where it is diluted. Under constant pressure, the flow rate of the diluted chemical out of the chamber is maintained constant, regulated to suit the design of the atomising nozzle. A fully automated control system monitors the grain flow rate on a belt weigher and adjusts the pump frequency such that the rate of concentrate flowing into the mixing chamber is adjusted to suit the required application rate (Fig. 17).

In country receival facilities, pesticides are applied in very much more diluted form at a flow rate of 1 litre of solution per tonne of grain, through small centrifugal pumps.

A by-pass line is used to pass excess liquid back to the mixing vat where it is returned through a venturi agitator to provide a continuous mixing action. Suction lines are connected to the base of the vats to minimise priming problems.

Delivery lines are connected across a 'tapered stem' type flowmeter to provide visual indication of the flow rate from the pump. Flow rate can be adjusted by appropriate setting of the nozzles on the delivery and by-pass lines.

Insecticide flow is controlled by means of a hinged flap in the grain stream which is deflected by the passage of grain. The shaft of the hinged flap is fitted with a cam that operates an on-off valve to start and stop the flow (Fig. 18).

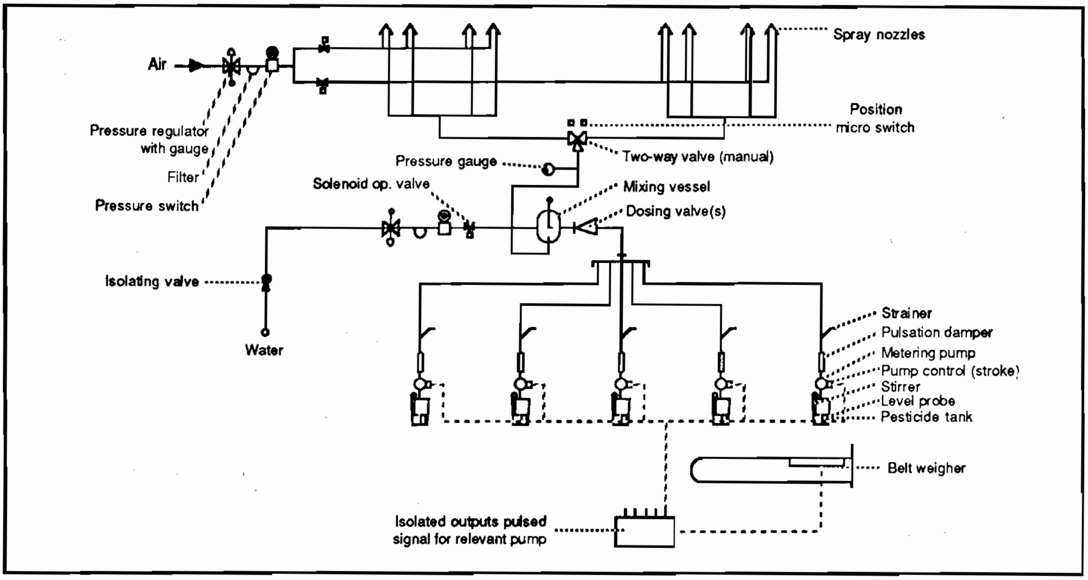


Fig. 17. Flow diagram for the low-volume pesticide application system used at the grain export terminal at Gladstone, Australia.

Because the liquid flow rate does not automatically adjust to suit the grain flow rate, it is important to calibrate the delivery rate of the chemical to suit the maximum flow rate of the grain intake system. It is thus also important to ensure that this grain flow rate is maintained so that the pesticide is applied at the correct dosage.

Regular calibration checks of pumps and delivery systems are important to ensure that each spray unit is operating correctly.

Because of the relatively high dilution rates

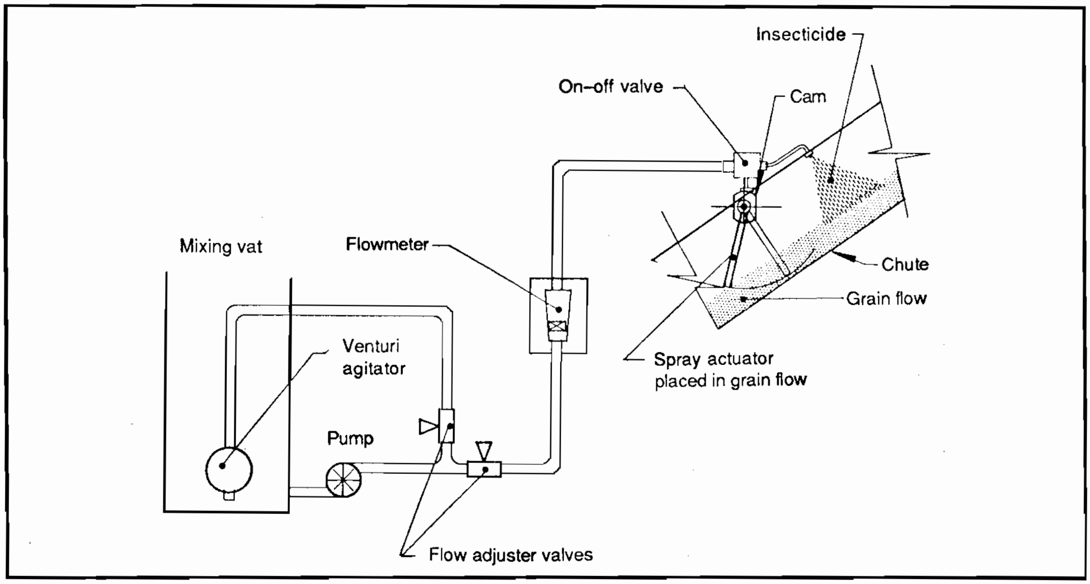


Fig. 18. Diagram of principles of high-dilution, constant-flow pesticide application system as used at country grain terminals in Queensland, Australia.

used, spray application often creates grain flow problems due to buildup of dust and grain dampened by the spray. Application points in chutes etc. have to be provided with an access opening nearby to allow cleaning out to be carried out quickly and regularly.

Major reliability problems with both pumps and spray systems have been largely overcome in recent years by careful selection of appropriate materials and equipment. For instance pumps have been fitted with three-phase motors which have greatly increased reliability. Impellors and platings are now specially made using gun-metal in place of aluminium, to reduce corrosive attack from the pesticide chemicals.

Hoses, seals, O-rings, etc. must be chosen to suit the chemicals being applied. Many will deteriorate quickly: for instance, hoses may swell, reducing their capacity. Similarly, seals can swell or disintegrate and become ineffective. Viton rubber has been found to be effective in resisting chemical attack.

The location for any spray application of pesticide must be carefully chosen to ensure that good mixing takes place and that spray loss is minimised. Preferred application points are inside chutes or enclosed conveyors and away from dust collection points.

Sealing of Storages

A relatively high proportion of storages in Australia can be sealed to high standards of gastightness, the proportion being higher in some states than others. Enormous importance is placed on the concept in Western Australia, where over 50% of all permanent storage is now sealable and where major expenditure is committed each year to sealing of existing storages, most of which are in the form of horizontal sheds.

In Queensland, all storages built since 1975 have been built to gastightness standards and several others have been retrosealed. Whilst retrosealing of old storages is sometimes expensive and difficult to achieve, there should be no difficulty in constructing new gastight storages if reasonable care and attention is paid to design details and to supervision of construction. Few extra costs need be involved in sealing a storage such as concrete silo or welded steel bin. Proprietary light-gauge bolted bins are, however, difficult to seal.

Extra costs are incurred in sealing any steel storage because of the necessity to apply a coat of white paint to reduce heat absorption in the daytime and heat loss by radiation at night. This is important since it minimises internal temperature fluctuations which will cause gas losses to occur. A white-painted roof can reduce head-space temperature by more than 10°C and will reduce skin temperature to within 2° or 3°C of ambient air temperature.

Sealing Concrete Silos

Provided it is well-designed and constructed, a concrete silo should not require any special treatment to be made gastight.

Some suggestions drawn from experience are:

- use independent (unconnected) circular bins
- avoid eccentric discharge especially in large bins
- keep reinforcing steel design stresses below 135 MPa
- use high yield-strength reinforcing steel
- use good quality concrete with adequate cement content, controlled water/cement ratio, and good compaction
- double layer wall reinforcement is to be recommended but is not essential in smaller silos

Independent circular concrete bins can be designed and built with minimum likelihood of wall cracks developing from grain pressures. In addition, if cracks should occur, they are readily accessible for sealing, which is not necessarily the case with interconnected bins.

Also any gas leaks that occur in an independent silo are vented harmlessly to atmosphere instead of finding their way into adjacent storages and thence possibly into a work area.

Interconnected and rectangular bins are, by their nature, subjected to significant bending stresses which are likely to cause cracking unless carefully designed and properly constructed. Even then, the risk of crack development is significant.

Sufficient reinforcing steel should be

incorporated to provide a rigid joint between walls and foundations, and where appropriate, between walls and roof. The increased rigidity imparted to the walls in this way can significantly reduce any tendency to distortion through uneven grain loading (e.g. through eccentric discharge).

Where it is inappropriate to have a rigid connection between wall and roof, judicious use of an appropriate flexible sealant can readily render the joint gastight. Where the joint is exposed to ultraviolet radiation and significant joint movement, silicone or polysulphide type sealants should be used. Bitumen-based or mastic sealants should be used only where joint movements are small, or where the sealant is maintained under compression.

Sealing Welded-steel Silos

Welded steel silos require no special sealing provisions except at the joint between floor and wall. Some designs allow for horizontal wall movement at the joint, requiring careful seal detailing. Since joint movement from grain pressure seldom occurs in practice, it is probably safer to design the walls with a rigid base making allowance for the resulting bending stresses, but simplifying joint sealing.

Sealing Light-gauge Bolted Silos

Light-gauge, bolted steel silos, as sold by numerous proprietary companies, have not proven easy to make gastight, due to their light flexible construction and multiple screw fixings. Roofs are also usually extremely light and flexible and the roof-to-wall joint is often difficult to seal.

Whilst bins of this type have been successfully sealed, the cost of doing so is normally high and reduces the cost competitiveness of this type of silo. Long-term maintenance of the gas seal may also be difficult.

Sealing Steel Sheds and Similar Structures

Steel-framed sheds and silos can be designed and detailed to facilitate sealing by careful attention to joints so as to minimise relative movements and widths of joints to be sealed.

Large gaps can be bridged with metal flashings, and smaller gaps (up to approximately 25 mm) can be filled with polyurethane foam. This should, however, be overcoated with an appropriate high-build flexible (elastomeric) acrylic paint. Small gaps (up to around 6 mm) can be sealed with silicone-type sealants and gaps of around 1 mm can be filled and bridged with high build, flexible acrylic paint.

Corrugated cladding, e.g. roof sheeting, has to be sealed at each fixing and at lap joints. A heavy coating (say 400 microns) of flexible, high-build acrylic paint over the surface of such joints usually suffices.

Especial care must, however, be taken to seal between edge laps of roof sheeting where they cross the roof-to-wall joint to ensure continuity of seal (Fig. 19).

Temporary Sealing of Openings

Providing for sealing of openings need not be difficult or expensive. In country storages with low throughput, insertion plates sealed with rubber gaskets or silicone sealant are often used for sealing grain inlets and outlets (Fig. 20). Access manholes can usually be sealed by screwing them shut against flexible gasket seals.

Where gravity discharge grain outlets are used, more complex sealing systems are required since very high grain pressures act on the discharge valve. Various sealing arrangements have been

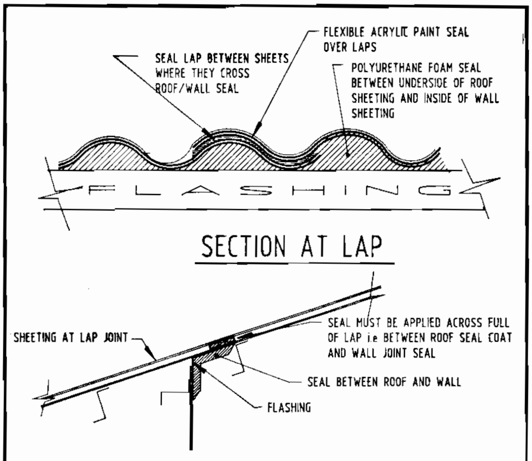


Fig. 19. Detail of lap joint sealing for a grain store.

devised, some involving jacking of the valve plate upwards against the grain pressure, others based on the use of a perimeter sealing gasket (Fig. 21).

Gastightness Testing

Testing of sealing effectiveness should be done by means of recognised pressure-decay testing procedures as, for example, those recommended by CSIRO Australia.

Testing for air leaks under pressure can be done in a number of ways. However, spraying the structure with a soap solution is probably the quickest and most effective method, since leaks are quickly signalled by the appearance of soap bubbles.

Test pressure should be selected to suit the structural capacity of the storage. It is common to apply an initial pressure of 1.5 KPa to silos and 0.5 to 0.75 KPa to sheds. It is important to protect structures against inadvertent applications of excess pressures (either during testing or in service) by fitting of a suitable pressure-relief valve. A simple oil bath type valve is very effective and relatively easy to manufacture. Alternatively, proprietary diaphragm valves can be purchased. Either way, the effective vent area should be sufficiently large to allow air to enter or escape fast enough to prevent structural damage from high or low pressures.

Costs of Sealing

Indicative costs of sealing work range from a few cents per tonne for a welded steel or concrete silo, to around $2 per tonne for a new shed, including white painting. Retro-sealing of sheds can cost between $4 and $8 per tonne depending on the shed size and the difficulty of effecting a seal.

Fumigation Equipment

Sealed storages can be easily and effectively fumigated, using methyl bromide or phosphine.

Methyl bromide

Methyl bromide can be used at port facilities to ensure quick and effective results so as to minimise delays should insects be detected either before or during shiploading. It can also be used to fumigate sealed vertical up-country storages when a quick kill is required, for instance prior to outloading.

Methyl bromide fumigation requires the use of fans and ducting to recirculate the gas in the storage. At both port facilities and country silos in Queensland, permanent internal radial ducting is provided at floor level to feed in the gas. (In aerated silos, the aeration ducting is used.) A typical country silo inlet ducting is illustrated in Figure 22 whereby the tube that is used to house a portable auger for extracting the grain is used also as a gas entry duct for fumigation.

Methyl bromide fumigation duct dimensions are selected using the same criteria as for aeration, except the airflow rate used is lower at around 0.45 litres per second per tonne.

Fumigation of up-country storages is carried

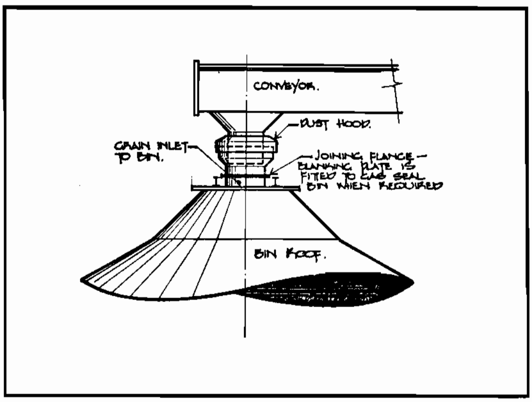


Fig. 20. Detail of gas sealing of grain bin inlet.

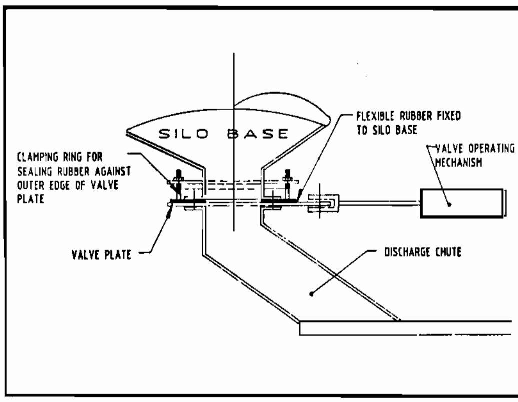


Fig. 21. Detail of gas sealing of grain bin outlet.

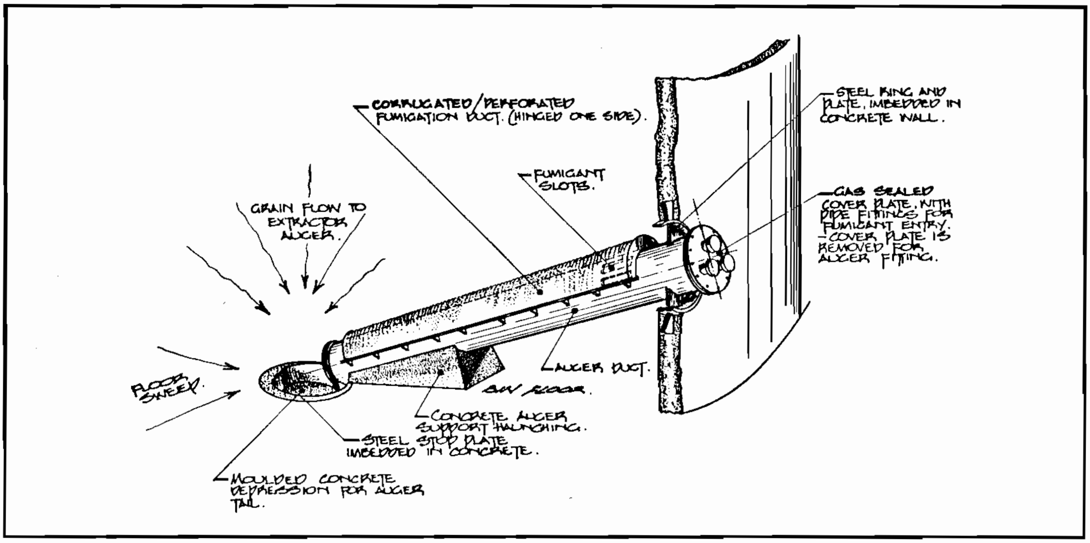


Fig. 22. Detail of typical grain silo inlet duct used both to house portable auger and as a gas entry duct for fumigation.

out using portable (flexible) external ducting and a portable axial fan for gas recirculation. The ducting is connected between the access manhole on the silo roof and the fan inlet. The fan itself is mounted on the air inlet in the silo wall.

At port facilities permanent fans and ductwork are used, fitted with associated valves for directing the airflow. Normally, recirculation fans are also used for venting the gas after fumigation. At the recently constructed Fisherman Islands Terminal, however, separate fans and ductwork are used for recirculation and ventilation, thus allowing independent operation. Even in a highly automated terminal such as Fisherman Islands, manual operation of the entire fumigation system has been adopted for safety purposes.

Gas is supplied in liquefied form in pressurised containers. Gas usage is measured by weighing the cylinders as they are discharged. An application rate of 35 g per cubic metre of grain is normally applied. With a target Ct (concentration × time) product of 180 mg hours per litre. The liquefied gas is passed through a heat exchanger consisting of copper coils in a heated water jacket thermostatically set to around 85°C. From these the vaporised gas is bled into the airstream on the outlet side of the fan. The rate of gas feed is controlled such that the total gas dosage is applied during one air cycle of recirculation system. In other words, the aim is to achieve the required gas concentration of 10 to 15 mg per litre at the top of the silo at the same time as the last of the gas is fed in at the bottom. Fan sizes and heat exchanger capacities are also governed by the requirement to fumigate quickly and a maximum air cycle time of 1 hour is normally adopted.

The cost of methyl bromide is currently around $2.50 per kilogram. The cost of gas for fumigation is around 15 cents per tonne.

Phosphine

Traditional methods of phosphine fumigation, involving placement of pellets into the grain stream while turning the grain, have now largely been superseded by the use of phosphine in blanket form.

In squat storages, blankets each containing 1132 g of phosphine are placed on the grain surface and natural convection is relied upon to distribute the gas through the grain mass. Application rates of between 0.5 g and 1.0 g phosphine per cubic metre of storage volume are used for fumigating such sealed storages.

Phosphine is also used for treating grain in tall sealed silos (height:diameter ratio greater than one). Natural convection currents cannot be relied upon to distribute the gas evenly throughout such storages and it is thus necessary to use forced recirculation. Fan induced recirculation has to be undertaken with caution due to the explosiveness of the gas when exposed to low pressures, as occurs on the inlet side of a fan.

Typical equipment requirements for such a recirculatory system are a 0.3 kW blower fan and 75 mm flexible plastic recirculatory ducting connecting the fan between the silo roof and the inlet duct on the silo floor.

The cost of phosphine in blanket form at around $150 per kg represents a fumigation cost (for gas) of around 15 cents per tonne at dosage rates of 1 g per tonne. Fumigation storages with large head space volumes will be more expensive due to the need to apply phosphine at a rate related to the volume of the storage rather than the amount of grain within it.

Flow-through Phosphine Fumigation

An important new development recently introduced by the CSIRO Stored Grain Research Laboratory in Australia is the use of phosphine in gaseous form. Phosphine is supplied in pressurised cylinders mixed with carbon dioxide (CO_2) which acts as a carrier. The gas is introduced in low concentrations through a low pressure air stream generated by a small fan, the fan speed being adjusted such that a very slight positive pressure is maintained throughout the grain mass. In this way all leakage is outwards from the storage and inward air leakage such as could dilute the gas concentration is prevented.

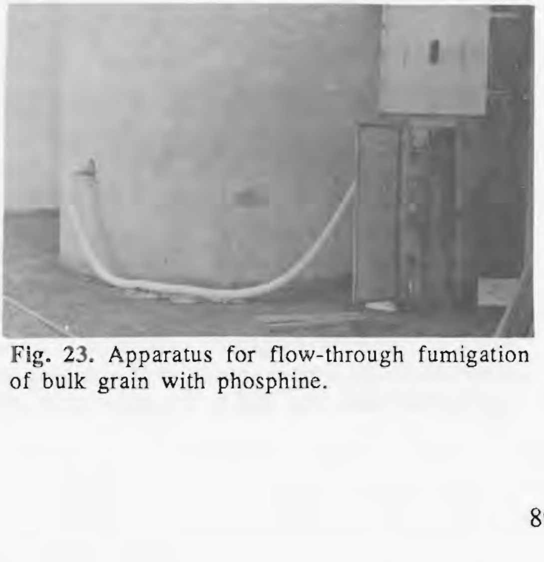


Fig. 23. Apparatus for flow-through fumigation of bulk grain with phosphine.

The importance of this development in fumigation techniques is the ability to safely and effectively fumigate a relatively leaky storage. Also, the equipment required (Fig. 23) is relatively simple and inexpensive and very little distribution ducting is required in the grain mass.

Trials recently conducted in Queensland involved the use of 2000 tonne open-top cells in which the grain surface was simply covered by a plastic sheet.

Weighing Equipment

Accurate weighing of grain is essential for commercial transactions. Weighing accuracies of ± 0.05% are the accepted standard in Australia for both receival of grain over road weighbridges and for export through in-line batch weighing systems.

Some form of weighing or measuring function is also frequently required for grain movements within the system, for instance for internal stock control purposes. In such instances, lower accuracy levels will often suffice allowing lower cost weighing systems to be used.

Electronic systems are rapidly supplanting mechanical weighing systems.

Weighbridges

Almost all new weighbridges being build in Australia are 'pitless' bridges.

Pitless bridges are normally constructed above ground and incorporate a concrete or steel platform supported on a number of load cells. Typically, spans between load cells are between 8 and 12 metres. The largest bridges in Australia are 33 metres long and are supported on eight load cells (Fig. 24).

Construction costs of pitless bridges are somewhat lower than for equivalent pit bridges due to the simplified construction of the foundation and the absence of complex lever mechanisms. This is largely offset, however, by the cost of load cells (around $2500 each) and electronic components.

Typical costs for new weighbridges, including foundations, deck structure, and electronics are:

Fig. 24. A pitless weighbridge, 33 m long and of 100 tonnes capacity.

12 metre, 4 load cell	$A40 000
18 metre, 6 load cell	$A55 000
24 metre, 6 load cell	$A60 000
33 metre, 8 load cell	$A80 000

The principal advantages of electronic weighing systems are:

- no operator involvement required
- high accuracy
- high reliability
- low maintenance
- ability to interface with automatic ticket printers and electronic security systems for fraud prevention
- ability to interface with data handling systems

High reliability and low maintenance are, however, only achieved by good design using high quality equipment and by great care being taken in the initial installation.

The following points should be noted. Avoid using site generated power. Electronic equipment can be damaged by spikes, wave distortion, and even frequency fluctuations. If a high quality power supply is not available, battery power through an a.c. inverter should be used.

Even where a good power source is available, the electronic equipment should be protected by a suitable power regulator. Electronic line conditioners perform better than ferro-magnetic transformers in protecting against wave distortion and frequency changes.

Wiring connections, particularly load-cell cable terminations, must be well insulated and kept dry. External connections should be housed in weatherproof junction boxes.

Electronic weighing equipment should be of good quality and proven reliability. Potential suppliers should be expected to demonstrate their ability to fault-find and service their equipment quickly and effectively in the event of breakdown.

Whilst almost all new weighbridges in Australia are of the electronic pitless type, a number of older mechanical bridges are also being converted to electronic operation. This is achieved by the simple expedient of attaching an appropriate size load cell to the pull-rod below the headworks and connecting it to a digital indicator. The headworks can either be retained as 'back-up' weighing system, in case of electronic problems, or they can be removed altogether.

A typical load cell required for such a conversion would be a tension type with a capacity of between 0.5 and 2.0 tonnes costing around $1200. Total cost of conversion including weight indicator is normally around $4000. The justification for such expenditure is primarily associated with the increased weighing capacity that can be achieved. 20 tonne capacity bridges are often upgraded to 30 tonne capacity, while 40 and 50 tonne bridges are upgraded to 60 tonne.

Electronic systems are also used for extending the length of existing weighbridges by coupling two bridges together in 'tandem' (Fig. 25). Two mechanical bridges can be placed end-to-end with a load cell fitted to the end of each transfer lever avoiding the need for a complex mechanical linkage mechanism. In the last year a system of extending old mechanical bridges with a 'pitless' deck extension has been devised with consequential savings in cost.

Batch Weighers

The principle of operation of a batch weigher is similar to that of a weighbridge in relation to the weighing equipment itself, since it is required to measure static weights. Electronic weighing systems are, however, particularly suited to batch weighing since they can be readily integrated into an electronic control system for operations of the hopper gates. In this way, 'intelligent' systems can be designed which will automatically deliver exact weights, or deliver pre-determined blends. They can also control the discharge gate opening, to balance the grain outflow rate with the inflow rate to give a continuous and uniform downstream flow. This is achieved by incorporating inflow weighers (e.g. belt weighers) on the inbound and outbound grains streams to provide the control system with flow rate information to control the gate opening. High level alarm switches are fitted to both upper and lower garner bins to prevent choking in the event of a system malfunction.

Conversion of mechanical batch weighing systems to electronic operation is relatively simple, requiring the fitting of a tension load cell on the pull-rod at the end of the lever system.

Provision of adequate air balance ducting is an important feature in any batch weigher, as is the design of dust seals in the chutes between the three bins. It is important that seals be flexible enough to avoid the transfer of load across them. Without air balancing, it is easy for positive or negative air pressures to develop across the connecting dust seals such that tension forces

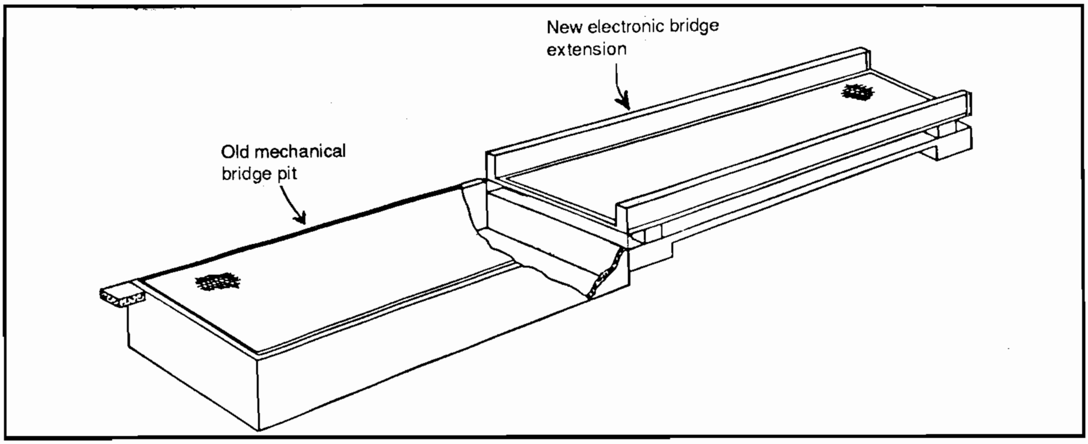


Fig. 25. Diagram of a 'tandemised' weigbridge, with a pitless electronic weighbridge extension.

created in them will upset the weight indication.

Operating systems for electronic batch weighers can be stand-alone controllers dedicated to the system or, where a larger plant control system is incorporated, the weigher operation and gate sequencing should be incorporated into its software. Whilst such systems can be readily set up to store individual batch weights in digital form and to maintain a running total of weighings, it is usually imperative to ensure that a continuous printout of individual weights is maintained, so that information is not lost in the event of a power supply failure or system breakdown.

The cost of electronic batch weighing systems is dependent largely on the mechanical items such as bins and gates, and the structure required to support them. The electronic components may cost only $3000 or $4000 for an electronic conversion (excluding the control system) and $15 000 for a three load cell, full electronic system.

Belt Weighers

Accuracies achievable by belt weighers are adequate for stock control purposes but do not approach those of static weighing devices such as weighbridges and batch weighers.

The complexities associated with mechanically operated belt weighers previously made them rare and expensive devices. However, the development of electronic weighing systems readily suited to the mathematical integration of a variable load with respect to time, has enabled accurate and reliable belt weighers to be developed and marketed at much lower costs.

The cost of a belt weigher is governed largely by the size of the weigh-frame, which in turn is governed largely by the belt width and the accuracy of weight recording required. Electronic components for large or small belts remain similar in price. Typical costs range between $15 000 and $30 000 for accuracies between 0.5% and 1.0%. However, units around $7000 are currently being developed to give accuracies between 1.0% and 2.0%.

Other 'In-flow' Weighers

Most other in-flow weighers differ from the belt weigher in that they do not make actual weight readings, but rely on indirect means, such as volumetric measurement. Some, however, can achieve levels of accuracy close to that of the belt weigher.

Chute weighers: these consist of a hinged plate placed in a chute. The plate measures the weight of grain passing over it by means of a small load cell. No commercially successful weighers of this sort are believed to have been developed to date.

Impact weighers: similar to the chute weigher, these involve the placement of a hinged plate at the end of a chute. Commercial devices of this sort are claimed to operate successfully, but most are designed for measuring very small flows.

Kyoat meter: this is a proprietary volumetric measuring device which can be sized to suit any flow rate. It consists of a cylindrical chamber into which grain is fed. Inside is a rotating inner chamber with radial blades dividing it into segments.

An electronic control system counts the rotations of the inner chamber and calculates the volume of grain that has passed through. The control devices can be designed to give a direct indication of weight by allowing the operator to key in the grain density. The devices can achieve better than 1% accuracy. A 200 tonne per hour unit costs around $10 000.

These units are particularly suited to installation in gravity chutes. A portable version is also being developed.

Ultrasonic level detectors: these are also volumetric devices which measure the height of grain on a belt or in a bin. Accuracies of between 2% and 3% can be reasonably expected where grain of known density is being handled.

Mass sensors: these involve a radioactive emitter and sensor normally mounted one above and below a conveyor belt. They measure the rate of absorption of radioactivity by the product on the belt and relate this to its mass, from which the flow rate is determined. Very high accuracies (below 1%) are believed to be achievable.

To date these devices have not gained acceptance in the grain industry in Australia.

Strain gauges fitted to the support legs of storage bins can provide a reasonably accurate indication of the weight of the contents.

Grain Sampling Equipment

Strict sampling procedures are essential for grain quality control and insect detection.

In Australia, for example, every truck load of grain delivered from farm is sampled for classification and insect detection before being admitted into the central storage system. Grain is sampled again on outloading from country storage. Export grain is sampled on arrival at port and is finally sampled as it is loaded onto ship. The final sample inspection is carried out by Government Inspectors who ensure that Australia's nil tolerance standard for live insects in export grain is strictly observed.

Until 1985, almost all sampling was carried out manually. This is still the case in country receival depots, but there has been a major shift into automated sampling systems at export terminals.

Sampling in Country Depots

Sampling of grain receivals is almost universally carried out with manual probes which have to be pushed into the grain mass. The probe has an inner and outer tube, both with slotted holes along one side (Fig. 26). The inner tube can be rotated such that after the spear has been placed in the grain, the slots are brought into alignment allowing grain to flow into the inner tube along its full length. A reasonably representative sample is thus obtained from the depth of penetration of the spear. Note that the slots in the inner tube are progressively offset, such that as the tube is rotated, the slots at the bottom of the tube come into alignment first, followed by the ones above, and so on.

At least five samples are collected from each truck, more being collected from large vehicles. Care is taken to take samples from each corner of the truck body and from the centre.

The sample once taken is then subjected to inspection and classification procedures. Part of the sample is sieved and a visual inspection carried out to check for foreign seeds, insects, etc. A portion is then tested for moisture content (usually with a Marconi meter using a ground sample) and visually classified prior to binning. Laboratory analysis is subsequently carried out where necessary, to back up the visual classification.

'Trebor' whole grain protein testing machines have been installed at every receival point in Queensland, for testing of wheat and barley. These are near infrared analysers which evaluate grain quality and moisture content by measurement of infrared light reflection off the grain surfaces. With very thorough calibration, using hundreds of samples of grain of known quality, these machines have proven to be able to produce extremely accurate results in both protein and moisture determinations, accuracies of around 0.1% being typically achieved. Testing requires no sample preparation and takes around 15 seconds.

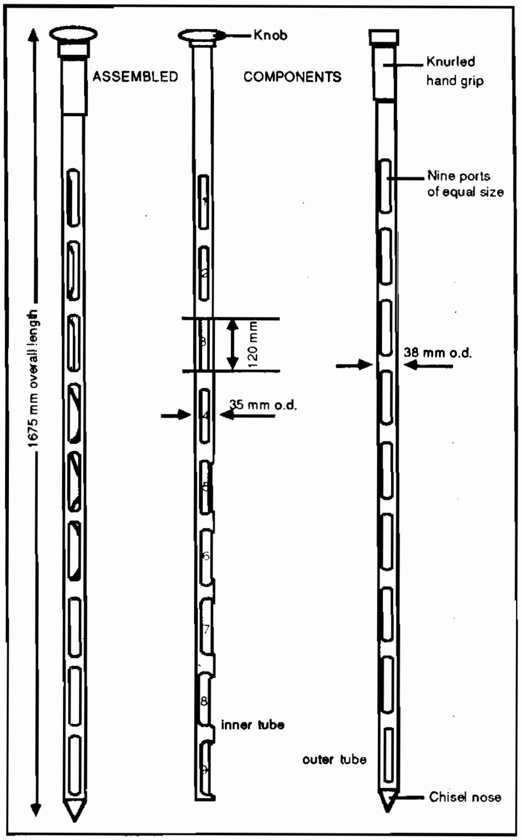


Fig. 26. Probes for manual sampling of grain.

Introduction of these machines has revolutionised storage strategies and has allowed very precise segregations of different protein wheats to be achieved.

Despite the introduction of such sophisticated equipment for classification of samples, there appears to be little likelihood of improvements to the sample collection procedures. Various automatic sample collection devices have been trialled in Australia (mostly imported from the USA) but generally they have proved difficult to operate and slow compared to the simple manual probe.

Automated Sampling at Export Terminals

As indicated earlier, grain is sampled on arrival at the export terminal and again as it is loaded onto ship.

The inbound sample is taken to check for insect and grain quality. The outbound sample is taken primarily to check for presence of insects. However, a small quantity is retained as a representative sample of the shipment.

Automation of both inbound and outbound sampling systems has recently been introduced in a number of export terminals in Queensland and similar systems are being installed or planned in other parts of Australia.

The automated systems include:

- sample collectors
- sample dividers
- delivery systems
- inspection equipment.

Brief descriptions of the systems used in Queensland follow.

Sample Collectors

Two types of collectors have been successfully used: cross-cut collectors (Fig. 27) and rotating tube collectors (Fig. 28).

The cross-cut collectors used are of American origin and consist of a cutting head which is mechanically driven across the grain stream at the head pulley of a conveyor, or inside a gravity chute. The cutting head consists simply of a narrow hopper with a slotted opening in the top through which the sample is collected. The slot

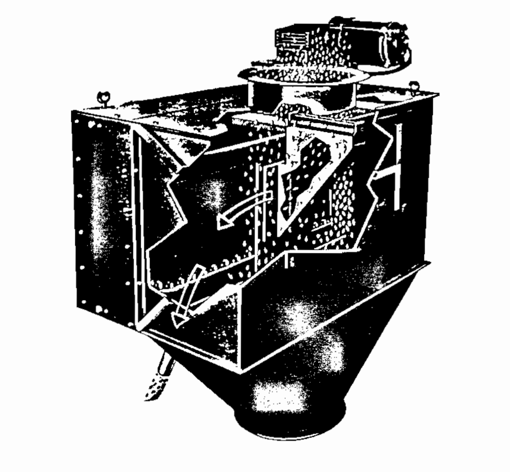


Fig. 27. Automatic cross-cut grain sample collector.

is of sufficient length to collect a sample from the full depth of the grain stream. The cutting head moves across the full width of the grain stream, thus the collected sample is representative of the full cross-section of the grain flow.

A cutting frequency of between 30 and 60 seconds is normally used but this can be readily adjusted through the control system.

Such cutting devices are both expensive and bulky, and they can be difficult to fit into existing plants. An alternative device which can be used in almost any situation is the rotating tube. This consists of a hollow tube with a slot cut in one side, which can be fitted into an elevator head, conveyor head or chute, i.e. wherever grain is free falling. Rotation of the tube can be readily automated and a timing sequence set up to adjust the quantity of sample collected.

Sample Dividers

The width of opening necessary in the cross-cut sample collection head to prevent blockages occurring makes it inevitable that the size of sample collected is larger than that required for inspection purposes. The sample must thus be reduced in size, but must at the same time retain its representativeness. Rotary dividers can be used to achieve this purpose, the

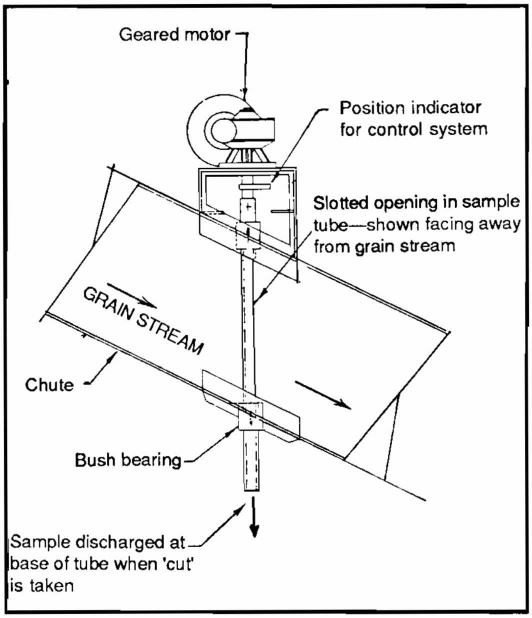


Fig. 28. Principle of the rotating tube grain sample collector.

unwanted portion of the sample being returned to the grain stream.

Rotary dividers can also be used for proportioning a given sample size such that a required quantity is retained for analysis or reference purposes while the remainder is presented for inspection.

Delivery/Transport Systems

Gravity sample delivery systems are by far the cheapest and most effective. However, they are not always possible where centralised sample inspection and collection is required.

Pneumatic conveying systems are an ideal option since grain quantities are small. Pneumatic conveying also allows grain to be conveyed horizontally, vertically, and around bends without transfer points or separate drives.

The major problem with pneumatic conveying is that it is very effective in killing insects, and can thus be quite unsuited for delivery of samples required for live insect inspections. 'Lean phase' pneumatic conveyors can result in over 50% insect mortality, particularly where multiple bends have to be negotiated. 'Dense phase' conveyors have proven less damaging. They nevertheless require careful design and commissioning.

Inspection Equipment

With grain flow rates of more than 400 tonnes per hour, manual sample collection, sieving, and inspection becomes impracticable if a satisfactory rate of sampling is to be maintained. In Australia, export grain is sampled at a rate of 2.25 litre sample size per 33 tonnes of grain. At 400 tonnes per hour this represents a sampling rate of 27 litres per hour or 2.25 litres every 5 minutes. In Queensland's new export facilities with a 2200 tonnes per hour export grain stream, around 150 litres per hour of sample has to be collected, sieved, and inspected.

To facilitate this, samples are collected and transported to a central inspection room where they are dropped onto a vibrating screen which divides the fine from the coarse particles. These are then presented separately on either side of a slowly moving flat conveyor belt for visual inspection to be carried out.

The belt is white and is well illuminated to assist in insect detection. A 600 mm wide 2 metre long belt with variable speed drive (0 to 0.7 m/sec) has been found quite adequate for visual inspection purposes.

Dust Control Equipment

A few recent developments in Australia relating to dust control are:

- the replacement of cyclone collectors with bag filter units in dust sensitive areas
- dust suppression at dump pits
- dust suppression during grain loading
- the use of mineral oil to reduce dust generation

Bag Filters Versus Cyclones

Cyclone collectors are notoriously inefficient and are largely ineffective in collecting particles smaller than 10 microns. Larger cyclones are significantly less efficient than small ones. Almost all new facilities requiring dust collection equipment now use reverse pulse bag filter units.

The various bag filter options fall into two general categories: those with vertically aligned filter elements and those with horizontal elements. Both appear to work effectively and the choice between them is usually based on price.

The main performance difference between units is in the design of the dust collection hopper, pyramoidal and conical hoppers blocking up much more readily than trough-shaped hoppers with vertical end faces.

Cloth filters are almost invariably used (in preference to paper filters) and dust collector size is based on having sufficient filter cloth area such that the average air velocity through it is kept below 2.5 m per minute.

Dust Suppression at Dump Pits

Total dust suppression at dump pits for either rail wagons or road vehicles is very difficult to achieve and seldom warranted. A relatively new device has, however, been successfully tested at several locations in Australia. The amount of dust reduction that can be achieved is to a large extent dependent on the effectiveness of the dump pit enclosure in preventing wind currents from removing the dust before it is captured by the collection system.

The dump pit dust suppression system involves the fitting of hinged baffle plates immediately below the hopper grillage. These deflect to allow grain to flow into the hopper but otherwise limit the open area through which dust can escape.

By fitting a dust extraction system to the hopper itself, dust can be contained within it. The capacity of the system must, however, be sufficient to extract air displaced by the inflowing grain while maintaining a negative pressure at the hopper grillage level. Ideally, it should be able to maintain an inward air movement through the gaps between the baffles while the pit is being filled.

The system will not trap dust which escapes as the grain free-falls above the grillage, but generally this represents only a small proportion of the dust generated when dumping grain.

Dust Suppression when Grain Loading

Devices for suppressing dust during grain loading operations are based on the principle of arresting the flow of the grain and controlling the height of free fall below the loading spout. In many cases, dust is extracted from the surface of the arrested grain inside a 'dead-box' at the end of the loading spout.

Such systems have recently been installed for the first time in Australia on new shiploaders in Queensland's Gladstone and Fisherman Islands terminals.

Mineral Oil Applications

A white mineral oil formulation which is spray applied to grain is reportedly in widespread use in America. Trials in Australia have confirmed that the material can be effective in reducing dust emissions from moving grain. The effectiveness of the material appears to be long lasting, and is not diminished by repeated handling of the grain.

Whilst very limited use of the material has so far been made in Australia due to uncertainties of market response, health authority approval has been given for its use at rates of up to 200 ppm.

At a cost of around $1.50 per litre (representing 30 cents per tonne), the potential benefits of its use include reductions in cleaning and hygiene costs, running of dust plants, sizes of new dust plants, emissions from cyclone collectors, and fire and explosion risks.

Minimising Dust Emissions

In large handling facilities requiring extensive use of belt conveyors, the use of dust collection equipment with its associated high capital and operating costs, may be an unavoidable necessity.

In smaller plants, the need for dust extraction can be reduced or eliminated by appropriate design (Fig. 29). Silos should have sealed roofs to contain dust inside. Breather vents will emit dust but where permissible these can be vented to atmosphere. Enclose augers, drag chains, elevators, etc, and fit all connections with dust seals. Belt conveyors can be made dust-tight by the use of continuously skirted, full-length covers. Mount conveyors externally, thereby

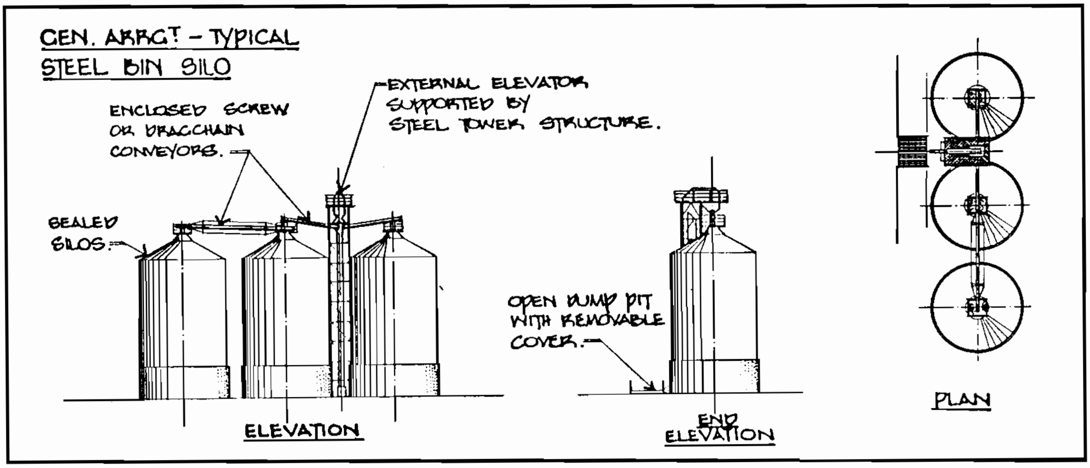


Fig. 29. Steel silo design features to minimise grain dust problems.

avoiding enclosed conveyor galleries, elevator towers, etc. where dust can collect.

Storage facilities requiring no dust extraction systems can be built in this way.

Fire and Dust Explosion Protection Equipment

Methods of reducing risks of fire and of dust explosion fall into two categories:

- primary measures aimed at preventing fire or explosion
- secondary measures aimed at minimising the effects of fire or explosion should either occur

Primary Methods of Risk Reduction

Primary methods of risk reduction encompass removal of combustible material, e.g. by dust extraction or regular manual cleaning, and removal of potential heat and spark sources.

Various means for removing or reducing the risk of heat or spark sources are commonly incorporated in modern high throughput facilities. Many are omitted from low throughput country facilities where reliance is maintained primarily on minimising accumulations of combustible materials (dust, etc.) and/or operator vigilance to guard against mishap.

Means of risk reduction include the following.

• Establishing strict safety procedures for cutting and welding operations and use of a written permit system to allow such work to be carried out in hazardous areas.

• Use of dust ignition proof (DIP) electrical equipment. This is a mandatory requirement for new installations in Australia, wherever electrical equipment has to be placed in dust hazardous areas.

• Monitoring of bearings, which can now be carried out routinely using portable electronic sensors that measure vibrations or 'noise' in each bearing. The condition of bearings can thus be monitored and replacement carried out before failure occurs, thereby reducing risk of overheating. The system is called 'shock-pulse monitoring'. Continuous temperature monitoring of bearings may be warranted only in rare instances, e.g. high-speed bearings in inaccessible hazardous locations.

• Belt mistrack switches can be used to guard against friction generated fires caused by mistracking of an elevator or conveyor belt. These are normally linked into the control system in such a way that the belt will be stopped if a mistrack lasts for more than a few seconds.

• Belt conveyor speed monitoring is used to prevent friction generated fires at the drive pulley. The speed of the tail pulley is monitored electronically and if it falls below a preset value, automatic conveyor shut-down occurs. This type of protection is particularly useful in protecting against fires in elevators.

Secondary Methods of Protection

Options for minimising the effects of fire or explosion which should be considered, especially for high throughput facilities, include the following.

• Fire detection and alarm systems. These can take the form of smoke detectors, ultraviolet and infrared radiation detectors and, more recently, spark detectors.

Smoke detectors particularly suited to dusty environments are 'Unipolar' ionisation detectors which have proven reliable in service. Cleaning is required at only two or three yearly intervals.

Ultraviolet and infrared sensors on the other hand are less suited to dusty conditions, requiring regular cleaning of their optical lenses for reliable operation.

Spark detection equipment produced in Europe for the timber milling industry has recently been used for the first time in the grain industry in Australia for monitoring the inlet ducting to dust plants at the Gladstone Export Terminal in Queensland.

The decision to install these devices followed a disastrous fire in a dust plant in 1985 believed to have been caused by welding sparks setting fire to a small dust accumulation which subsequently found its way into the dust collection system.

The system uses highly sensitive infrared detectors fitted into the walls of the ductwork on the inlet side of the collector. The system not only detects sparks in the dust flow but also extinguishes them by means of a pair of water spray nozzles located downstream of the detectors. These are activated by the alarm system whenever sparks are detected.

• Explosion relief vents can be fitted to high risk areas. Their purpose is to vent any explosion that occurs to minimise the pressure rise in an enclosure and thereby limit structural damage. Vents are commonly fitted to dust collectors and elevator trunkings. They are sometimes fitted to building enclosures such as conveyor galleries and workhouses.

There is evidence to suggest that any solid blow-out panel will have too great an inertia to effectively relieve the very high rate of pressure rise that occurs in a dust explosion. Light plastic sheeting (200 micron polyethylene film) to cover vent openings offers three advantages:

- it is cheap
- it bursts easily at low pressures
- in the event of a fire (rather than an explosion) in an enclosure such as a dust collector, the plastic will quickly melt to allow water to be sprayed inside the enclosure.

Explosion vents must be large enough to effectively relieve the pressure wave that accompanies an explosion. Suggested vent areas are:

1 m^2 per 25 m^3 of space for dusty buildings

1 m^2 per 6 m^3 of volume for dust plants

• Provision of fire isolation doors is not usually practicable in a grain handling facility where conveyors connect adjacent areas. Isolation of dust plants is, however, an option which should be considered to prevent fires travelling back through ductwork which can act as a chimney when suction fans are switched off.

• Whilst automatic sprinkler systems are not used in grain handling facilities in Australia, due to the risk of serious damage to the grain in the event of a false alarm, manually operated deluge systems are sometimes fitted in areas with difficult access for fire fighters, such as underground conveyor tunnels.

• Electrical switchgear, PLC control equipment, and computers are commonly protected by automatic Halon gas dispensers. The gas chemically reacts with the combustion process, halting its progress. The gas is safe to both humans and electronic equipment. It is, however, very expensive and thus suitable only for protection of limited areas.

• The use of fire-resistant antistatic belting for conveyors and elevators is both a primary and a secondary method of risk minimisation. Such belting should always be used, since it will minimise the risk of propagation of a fire along a belt. Test certification should be sought before purchase of any belting from an unknown source.

Automation and Control Equipment

Electrical control systems can offer very high levels of automation, plant monitoring, and data collection, minimising dependence on manpower and improving equipment safety, reliability, and performance. On the other hand, small, low cost Process Logic Control (PLC) systems are now commonly used for the control of small facilities and sometimes even single items of plant.

Integrated Control Systems for Large Plants

The selection of appropriate system architecture and equipment, particularly for large and complex facilities, is not easy and conflicting advice will be offered by experts, most of whom will hold different views.

The following points should be considered.

• A choice always has to be made between using equipment which has a proven record of reliability and performance and 'new generation' equipment. Inevitably, proven equipment is likely to be obsolescent. It is probably better not to be swayed by arguments against the use of new systems since they are usually based on previous models and incorporate improvements to them. Reliability of new equipment seems to be less of a problem these days.

• The option exists to replace complex 'mimic' panels with plant functions displayed on VDU screens. The trend in large facilities is towards the use of multiple screens (or 'paging') in place of mimic panels. Major advantages of screen displays are:

- vastly more information can be displayed, including flow rates, alarm conditions, flow paths, grain segregations, grain stock holdings
- changes to screens can be made quickly and easily for instance when plant is modified
- complex flow paths can be simplified on a screen with unnecessary information omitted for clarity
- 'prompts' can be used on the screen to assist the operator in making selections for plant operations
- alarm or fault situations can be instantly brought to the operator's attention by visual and audible means

• Equipment should be selected to suit the purpose intended. PLC controllers are designed specifically for controlling plants. Whilst they can be used for controlling VDU screens and for data collection, computers are much better suited to these functions.

Recent technological innovations now allow personal computers running appropriate software, to be coupled to a PLC controller such that PLC programming can be carried out through the computer and screen functions carried out by the computer. Programming of both PLC and screen functions can be carried out by an engineer with relatively little training in control system technology.

• Any contract for supply and installation of an automated control system should include requirements for:

- preparation of a functional specification spelling out in detail the requirements that the control system has to fulfil.

  Whilst the requirements should be covered in the contract specification in general terms, the functional specification written by the contractor forms the basis for the actual software preparation. The functional specification should provide for all the general requirements of the contract specification and should convert them into logical terminology. For instance, the general specification may require that conveyors be shut down in the event of an underspeed alarm showing. The functional specification needs to define this requirement for each separate conveyor, spelling out other consequences of conveyor shutdown, e.g. upstream conveyors, displaying of an appropriate alarm signal on the control room VDU screen, etc.

  The functional specification needs to be thoroughly reviewed by the client and approved before software preparation starts.
- the contractor should also be required to provide source-coding for all software, fully documented with descriptions and notations for easy comprehension.
- the contractor should provide an operator's manual and should also provide on-site

training for control-room operators and maintenance technicians.

- hard-wire drawings showing all junction connections and their locations should be provided.

There is almost no limit to the level of automation that can be achieved.

Small PLC Control Devices

High levels of sophistication such as described above are usually only warranted in very high throughput facilities. However, small, low-cost PLC units are routinely used in grain receival facilities in country areas. These may have only three or four conveyors, two or three motorised gates and valves, and a few choke and 'high-level' indicators. PLCs are used in such situations because:

- they can save significantly on switchboard wiring costs
- they can perform programmed logic functions which are difficult to 'hard wire'
- they are much more easily changed and expanded than hard-wired control systems

A typical country silo installation will retain a mimic panel with light indicators to show conveyors which are operating and for alarm indication. The operator, however, has only two thumb-wheel switches through which he dials up where the grain has to be taken from and where it has to go. The system automatically sets the correct 'path', automatically sequence starts the conveyors, and opens the correct valves.

Such systems can be readily designed, installed, and programmed by a trained electrical tradesman and may involve 200 or 300 I/O (input-outputs).

Even smaller PLCs are often used for controlling individual items of plant. For instance the Kyoat metering device mentioned earlier is controlled by a PLC with only 8 I/O, the use of a PLC being particularly suited because of the need to carry out mathematical computations to calculate grain volumes and tonnages.

Conclusion

A broad range of subject areas has been addressed describing various aspects associated with modern bulk handling facilities.

Whilst high levels of sophistication and complexity can be appropriate in certain situations, the intent of this paper has been to emphasise that even in the most modern and up-to-date systems, simple solutions and procedures are very often the best option. Many of these solutions may be appropriate in storage systems where the transition from bag to bulk is still progressing. Simple and cheap bulk storage structures are appropriate in all countries for long-term grain storages yet they can and should be built to incorporate all the requirements for good quality storages.

Similarly, low-cost conveying systems can offer good reliability and low running costs. In addition, simple, portable conveyors such as augers, can provide great versatility whilst offering considerable savings on capital cost.

High capital costs and sophisticated storage and handling systems can normally be cost justified only in high throughput situations.

Integrated Pest Management in Grain Storage Practice

M. Bengston*

Abstract

While bulk handling provides an opportunity to improve standards of pest control, it also creates conditions conducive to greater damage through contamination, heating, and moisture migration if pest infestations are not controlled. The requirements of pest control must be considered in both storage design and management. Most active pest control procedures currently involve the application of either fumigants or residual pesticides. However, the continued success of such methods demands good storage practice, i.e., grain hygiene, reduction in grain moisture and temperature, and minimisation of the storage interval.

Grain hygiene is greatly facilitated if, during the design and construction phase, attention is given to the requirements of cleaning. Carryover of pest populations can be further minimised by spray application of a residual insecticide to the fabric of empty storages before inloading. Exclusion of birds and rodents is important and storages sealed to a high degree of gastightness exclude insects also.

The parameters for grain moisture and temperature are generally determined by the requirements of quality preservation but any reduction is beneficial to pest control and both must be known since they influence the efficacy and rate of breakdown of protectant insecticides.

Pest populations increase exponentially with time so the storage interval is crucial. Rotation of stocks on a 'first-in-first-out' basis is fundamental. Short-term storage may require no additional pest control measures unless commodity standards are very high.

Additional pest control measures using residual insecticides involve spray application to the grain during inloading and, if needed, to the grain surface during storage. Alternatively, fumigation may be used, but it demands gastight conditions. Long-term storage of bagged rice under carbon dioxide is possible in high quality plastic enclosures.

Further research is necessary into the insecticide resistance status of important pests in regard to insecticides and fumigants. The Codex Alimentarius Commission of the United Nations has recommended maximum residue limits for a range of pesticides but it is also essential that pesticide use conforms to legislation in individual nations.

THE term integrated pest management will be used to describe the combination of pest control procedures that needs to be integrated into a storage system to give optimum pest control. An optional system includes consideration of costs but these are not specifically covered in this paper.

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The change from bag to bulk handling provides an opportunity to improve standards of pest control, but it also increases the penalties for failures. The requirements for pest control need to be considered during the design and construction phases as well as during storage operations.

The nature of pest control problems changes somewhat with the introduction of bulk handling. For example, the importance of moths decreases, since they fly and lay eggs only from above the grain surface. Rodent problems also decrease. However, the mixing of grain that occurs during inloading means that a single, heavily infested load of grain may jeopardise an entire storage. In addition, hot spots tend to be more serious since the heat and moisture generated by metabolic activity are lost less rapidly from bulk than from bagged grain. Moisture migration, yellowing, and moulding may be accentuated by uncontrolled insect infestations.

Implementation of Integrated Pest Management

Optimal implementation of integrated pest management will include consideration of the following:

- design features to promote grain hygiene or sanitation
- an adequate level of maintenance of storages and facilities
- management to ensure grain hygiene, stock control and rotation, and reduction in grain moisture and temperature
- management to ensure prompt control of infestations
- capacity to apply pesticides to the storage fabric
- capacity to admix pesticides with the grain
- capacity to fumigate

Parameters that Determine the Level of Pest Infestation

The basic parameters defining the magnitude of pest problems in grain storages are well known. They are grain hygiene, grain temperature, grain moisture, and length of storage interval. At common insect densities, the growth of populations is exponential:

$$N = N_0 e^{rt}$$

where N is the number of individuals at any specified time, N_0 is the number of individuals at commencement, r is the population growth rate, and t is time, i.e. length of storage interval.

Grain hygiene or sanitation is the fundamental technique to reduce the number of individuals at the commencement of storage, i.e. the N_0 of the above equation.

Population growth rate r acts exponentially and depends chiefly on grain temperature and grain moisture. Under the range of temperature and moisture conditions prevailing in the humid tropics, population growth will increase with both grain temperature and grain moisture. As is well known, the various pest species have different population growth rates in different commodities.

Time also acts exponentially, and length of storage interval has a major bearing on the magnitude of pest problems. In short-term storage, pest problems are minor and the cost-effective pest control procedure will probably be to do nothing. Stock management and stock rotation involving the 'first-in-first-out' principle are crucial.

Ease of Cleaning

Attention to detail during the design and construction stages can produce dramatic gains in the maintenance of grain hygiene or sanitation. Features such as self-shedding ledges, smooth surfaces, absence of hollow double walls, and orientation of structural elements to shed grain are obvious once the importance of grain residues as a source of infestation is appreciated. Similar features in grain handling machinery are important but too numerous to detail in this paper.

Fumigation

Fumigation is the most effective method of disinfesting grain. Only the major fumigants phosphine, methyl bromide, and carbon dioxide will be considered here. A minimum concentration of each of these gases must be maintained for a minimum time and the simplest description of the requirements is known as Haber's Rule, given in the following equation:

$$Ct = k$$

where k is the constant dosage required to achieve a specified level of kill, C is the concentration of the fumigant, and t is the length of time the commodity is exposed to the fumigant. A more general description is given by the equation

$$C^n t = k$$

where n is the toxicity index which indicates the relative importance of the variables. For $n > 1$, concentration is more important than time (e.g. methyl bromide), and for $n < 1$, time is more important (e.g. phosphine and carbon dioxide). More complex equations have been used to describe the relationships (Winks 1986), but those given here provide a description adequate for most practical situations.

Effective fumigations require a gastight enclosure or other means of ensuring the fumigant concentration for adequate time. The definitive method of testing for gastightness is a test of pressure decay (Zahradnik 1969). A range of techniques has been developed for sealing storages, and structures with a high level of gastightness must be fitted with pressure relief valves. Other methods of compensating for loss of fumigant in partly leaky storages have involved the addition of fumigant to balance losses whilst the fumigation is in progress.

The flow-through method of phosphine fumigation (Winks et al. 1984) currently under development in Australia may have wide application. A cylinder of phosphine gas, combined with carbon dioxide to reduce flammability, is applied throughout the fumigation interval with air under positive pressure to storages with a moderate degree of leakiness. This permits the low concentration of phosphine to be maintained for the required time. The lower concentration of fumigant is less dangerous in the workspace.

Despite the conversion to bulk handling, the end products of storage are likely to be handled in bags. Carbon dioxide fumigation for long-term storage of milled rice in plastic enclosures of high quality has been successful in practice in Indonesia (Suhano et al. 1984) and on a pilot scale in ACIAR Project 8307 in Malaysia, the Philippines, and Thailand (Annis and van Graver 1986). The costs of initial sealing and application of the gas are relatively high so the technique is most valuable for long-term storage.

It must be emphasised that safe and effective fumigation depends on the availability of suitable facilities and equipment, and trained personnel.

Treatment of Storage Fabric

The central importance of grain hygiene in reducing the initial level of pest infestation has already been mentioned. Further significant reductions in these initial infestations require the application of pesticides to the storage fabric before grain is loaded into the storage. A spray unit capable of high pressure application is required to access the surface of tall structures. A mobile unit capable of servicing several storage complexes may be the most economic solution.

It is usually most convenient to use the same insecticides as those which are used as grain protectants. Some residues, albeit at low levels, will be detectable in the grain, especially that adjacent to the storage fabric. Concrete accelerates the decomposition of some pesticides, especially the organophosphorus compounds, and it may be preferable to use wettable powder instead of emulsifiable concentrate formulations for this purpose. Wettable powders also avoid solvent build up in the airspace in enclosed storages.

Grain Protectants

Undoubtedly the biggest advantage to pest control in bulk handling is the opportunity to admix insecticides into the grain stream during inloading to storage. Correct choice of a grain protectant and application rate means that residual protection may be attained right up to the time of consumption. This gives a degree of management flexibility unsurpassed by other pest control techniques.

Requirements for Insecticide to be Used in Grain Storage

The choice of insecticides that may be used is limited by the very strict requirements that may be enforced to ensure absolute safety for consumers and also a range of other factors associated with grain storage. Specialists from FAO (FAO 1982) have listed 10 requirements of a suitable protectant.

1. It must have a wide spectrum of high insecticidal activity.

2. It must present no hazard to consumers of grain and grain products.

3. It must be acceptable to health authorities.

4. It must be acceptable to international grain trade.

5. Legal limits must be established for the resulting residues under the laws of the country where the grain is stored.

6. It must not affect the quality, flavour, smell, or handling of grain.

7. It must be capable of being used without hazard to operators.

8. It must be effective at economic rates of use.

9. It must not be flammable, explosive, or corrosive.

10. Its method of use must be compatible with established grain handling procedures.

Insecticide Resistance

Malathion was the first insecticide to be widely used as a grain protectant. It is still in use in some areas but worldwide its efficacy has been decreased by the development of resistant strains (Champ and Dyte 1976). More detailed surveys have established the occurrence of malathion resistant strains in the Southeast Asian region (Morallo-Rejesus 1973; Caliboso et al. 1986), and its efficacy has declined (Rahim 1986; Sidik et al. 1986).

Good storage practices may delay the onset of major problems with insecticide resistance but clearly there is a need to develop a range of alternative pesticides so that resistance to any one compound can be circumvented.

Candidate Compounds

The insect pest complex in grain storages constitutes possibly 10 major pest species and up to 200 minor ones. There are large differences in the susceptibility of the various species to particular insecticides.

For that reason it has sometimes been necessary to use combinations of insecticides to control the entire pest complex. Considerable research has been carried out in Australia on grains such as wheat and sorghum (Bengston 1979, 1986a; Bengston et al. 1975, 1980, 1984). Field trials are in progress in Malaysia (A. Rahim Muda, personal communication) and the Philippines (P.D. Sayaboc, personal communication).

Compounds and combinations which have been found effective in Australia on wheat of 12% grain moisture at 30°C for 3 to 9 months storage are given in Table 1.

More recent work has centred on insect growth regulators especially methoprene (Bengston 1986b).

All of these compounds have significant acceptance in the processes of the Codex Alimentarius Commission. A very useful book detailing the properties of grain protectants has been published by ACIAR in conjunction with the Australian Department of Primary Industry (Snelson 1987). To date there has been relatively little work on commodities such as rice or maize in humid tropical regions and this is currently being addressed in the ACIAR-supported projects in the region.

Application Techniques

The most common technique for applying insecticides to grain involves a low-pressure spray pump, bypass agitation, rotameter, on/off valves, and spray nozzle. Typically, one litre of insecticide diluted with water is applied to a tonne of grain and this adds 0.1% of grain moisture. Studies have shown that it is necessary to apply the insecticide to only 1% of the grains provided these are mixed evenly throughout the grain mass (Minett and Williams 1971). Insecticide concentrates may also be applied at ultra-low volumes (ULV) using medium to high pressure or else at low pressure utilising gravity feed (Minett et al. 1984), or metered application (J.H. Ardley, personal communication 1987; B.A. Kelly, personal communication 1987). Insecticide concentrates may also be propelled by carbon dioxide in cylinders.

Application of insecticides to the grain surface during storage may be made by a variety of portable spray devices.

TABLE 1. Grain protectant insecticides effective on wheat of 12% grain moisture at 30°C for 3 to 9 months storage in Australia

For most species	For multiresistant strains of *Rhyzopertha dominica*
chlorpyrifos-methyl 10 mg/kg	bioresmethrin 1 mg/kg plus piperonyl butoxide 8 mg/kg
OR	OR
fenitrothion 12 mg/kg	carbaryl 8 mg/kg
OR	OR
pirimiphos-methyl 8 mg/kg	fenvalerate 1 mg/kg plus piperonyl butoxide 8 mg/kg
	OR
	permethrin 1 mg/kg plus piperonyl butoxide 8 mg/kg
	OR
	(IR)-phenothrin 1 mg/kg plus piperonyl butoxide 8 mg/kg
	OR
	pyrethrin 3 mg/kg plus piperonyl butoxide 20 mg/kg

For all species
methacrifos 20 mg/kg
OR
deltamethrin 1 mg/kg plus piperonyl butoxide 8 mg/kg

Rate of Breakdown

The rate of breakdown of insecticide residues on grain is determined by the grain temperature and grain moisture. The work of Desmarchelier (1978) showed that the rate of breakdown of residues typically follows first-order kinetics.

$$R = R_0 e^{-kt}$$

where R is the residue level at any specified time, R_0 is the residue at commencement, e is the base for natural logarithms, k is the decay constant for the environmental conditions, and t is time from commencement.

The decay constant is more readily comprehended in terms of the half-life ($t_{1/2}$) of the residue, to which it is related by the formula

$$t_{1/2} = 0.693/k$$

The rate of breakdown is increased with increasing temperature according to the Arrhenius equation which approximates to the following relationship

$$\log k = \log k_0 + b\,(T - T_0)$$

where k is the decay constant at any nominated temperature, k_0 is the decay constant at the reference temperature, T is the nominated temperature, and T_0 is the reference temperature for the determination of k_0.

The rate of breakdown is influenced by equilibrium relative humidity as follows

$$k = k_0\,(ERH/ERH_0)$$

where k is the decay constant at any nominated equilibrium relative humidity, k_0 is the decay constant at the nominated reference equilibrium relative humidity, ERH is any nominated equilibrium relative humidity, and ERH_0 is the reference equilibrium relative humidity for the determination of k_0.

Given a knowledge of the basic parameters, the decay constant may be calculated for any other set of storage conditions.

Reference data for some of the more important compounds are given in Table 2.

Efficacy

The efficacy of pesticides is also affected by grain temperature and moisture but to date it has been necessary to determine such effects empirically. The efficacy of most organophosphorus

TABLE 2. Half lives and Arrhenius coefficients for the breakdown of pesticide residues on wheat. Reference conditions for t were 30°C and 50% relative humidity (Desmarchelier and Bengston 1979)

Protectant	Half life (weeks)	Arrhenius coefficient B/ °C
Bioresmethrin	24	0.033
Bioresmethrin*	38	0.031
Carbaryl	21	0.031
Chlorpyrifos-methyl	19	0.04
Fenitrothion	14	0.036
Malathion	12	0.05
Methacrifos	8	0.055
(IR)-Phenothrin	38	0.029
(IR)-Phenothrin*	40	0.029
Pirimiphos-methyl	70	small
Pyrethrum	34	-
Pyrethrin*	55	0.022

*Plus piperonyl butoxide 20 mg/kg

compounds increases as temperature increases but the reverse is true for most synthetic pyrethroids. The efficacy of most pesticides decreases as grain moisture at the time of application increases (Samson 1986). This will influence the choice of protectant and its application rate for grains treated at relatively high moistures, say on intake to in-store drying.

Maximum Residue Limits

Safety of residues arising from pest control procedures is a crucial issue (Snelson 1986). All residues must conform to the laws of individual nations but there is a great deal of cooperative effort in the work of the Codex Alimentarius Commission of the United Nations. Toxicologists determine the no-effect level in two-year studies on animals, then a one-hundred-fold safety factor is applied to determine the acceptable daily intake for humans. The dietary intake of the particular commodity is then considered to indicate an upper limit to the maximum residue limit. The actual maximum residue limit which will be permitted must be less than this and is the level of residue which must arise from good agricultural practice.

Some of the legislative controls on pesticides in the Asian region were outlined by Magallona (1986), and Gaston (1986) outlined progress in harmonisation of the registration requirements.

Research Needs

The following research is suggested:

- survey of the resistance status of prevalent strains of major species to grain protectants and fumigants;
- validation of minimum effective doses of grain protectant and fabric treatments on a range of commodities and under a range of conditions;
- evaluation of newer insecticides including insect growth regulators; and
- determination of residue levels in both the stored grains and products derived from them.

Legislation Needs

Legislative authorities need to determine the legislative constraints which will apply to both new and existing pesticides.

Training Needs

Training of both management and operators in the safe and effective use of pesticides is essential. The 'Suggested Recommendations for Fumigation of Grain in the ASEAN Region' currently being developed under ACIAR sponsorship by relevant authorities in each country will be a useful resource document.

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Port Handling Facilities for Grain

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Abstract

This paper outlines the range of options available for handling of grain at ports, including the various types of storages and ancillary services that might be incorporated at shipping terminals.

New bulk systems will have special requirements when a large variety of crops has to be handled. There may be special needs when incorporating new systems into existing port facilities.

Various types of loading and unloading gear available for transferring bulk cargoes to and from ships are described. Reference is made to modern developments of particular relevance to ASEAN. The place of self-unloading ships and the conditions under which they may have application is discussed.

The author suggests that a methodology for introduction of new systems should take full advantage of the very significant technology which is available today from manufacturers and operators in different parts of the world.

It is not the time for 'reinventing the wheel', but rather for using the existing dynamic technology with the innovative inputs needed to service particular needs.

Photographs, diagrams, and addresses are provided, to assist the reader locate appropriate equipment and manufacturers.

THE word 'port' by derivation means a gate and a passageway and by its definition indicates an interruption in the flow of material transport. In considering the operations of a port, one must be aware that the effectiveness of the port's operation depends upon the appropriate selection of the warehousing and storage and handling functions, and vitally depends on the proper functioning of the equipment installed there. Because of the key role of the port in the transportation system, its effective operation is a decisive factor in trade both within the country and outside of it.

This is a discussion paper, intended to give an overview of situations and facilities at ports as they might be seen from an ASEAN point of view. The paper contains:

- a description of an interface analysis between the port terminal size, its efficiency, and the handling capacity and efficiency of the up-country storages and transportation system;
- description of facilities required at a port installation;
- description of ship loading equipment;
- the expertise available in ship unloading equipment;
- self-unloading ships; and
- some comments on philosophy and methodology for planning a new port installation in ASEAN.

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The Interface – Up-country Grain Handling and the Port Facility – Computer Modelling

The grain handling and transportation system for a particular commodity or group of commodities includes many interactive factors, with social and economic implications which influence the ability of the storage and handling system to operate effectively and which have an interactive role with it. For example, if a grain handling system which placed severe hardships on large numbers of people in the industry were to be imposed, it would be doomed to economic failure because of internal resistance by the people and therefore its basic unsuitability. Without touching on social implications here, there are some tools of practical importance in the economic operation of a terminal which planners should be aware of.

Very practical computer programs have been developed which model and analyse the logistical aspects of bulk systems and their impact on the port terminal. One such program has been very helpful to one of the Bulk Handling Authorities in Australia.

The program includes among its inputs:

- the existing bulk storage capacities at different points in the system;
- transport parameters (the normal tonnages moved per day); and
- the train days required to move grain and the average of trip times.

Other data used in the input parameters include grower performance, farm storage, measurement of the average delivery distance to country silos, and delivery costs and other costs associated and chargeable to the grower on the basis of the silo's situation. Other inputs include grain handling performance by measurement of the detailed costs incurred at various facilities and the amount of grain received and outloaded from each facility, the number of days each facility is required to be open, and the amount of grain remaining in each facility at the end of the year.

The computer model simulates the on-farm storage inputs, varietal segregation for different varieties of grain, the inland terminal and unit train strategy, and the interaction of all of these elements. Taking into account the planned capacities and planned operations of the terminal, interactive effects are generated with the sizes and frequencies of arrivals of vessels and the turnaround times for them. The appropriate storage capacities for the terminal are developed from outputs as the computer model simulates the different operating circumstances based on different input assumptions. This computer model is one of several developed in recent years, and is an example of an important type of management tool that should not be overlooked in strategic operational planning and designing of port terminals.

Facilities Required at a Port Terminal

All ports require a minimum of facilities for processing and adequate storage of the grain.

Receival Facilities from the Inland Bulk Handling System

Receival facilities for road and rail need to be provided and sufficient area allocated especially for road receivals so that the incoming vehicles can be parked, weighed, and turned around whilst still maintaining an adequate flow of grain into the system.

Road and Rail Outloading Facilities

For import terminals (receiving grain from ships) adequate facilities must likewise be provided for loading trains and/or road vehicles and for weighing them and despatching them from the terminal. The siting of the terminal, whether it be export or import, requires adequate attention to impact at the harbour area and other environmental factors so that the work and the involvement of the terminal does not have a harmful effect on neighbourhood and other services in the area.

Weighing

Grain received into a bulk handling system must be weighed to an accuracy that is satisfactory to the statutory authorities and to the commercial interests involved in using the facilities. Whilst road weighbridges will be satisfactory for road receivals and road outloading, it is necessary to weigh the bulk grain after it has been put into the system on weighers which would have accuracies of greater than 0.1% in order to meet statutory authorities' requirements. Similarly, at the end of the chain before grain is shipped out at an export terminal, a high degree of accuracy is required. This weighing is normally carried out using modern automatic batch weighers. Load cell weighing equipment is universal today and is used with permanently fitted test weights which can be remotely activated so that the scale calibration can be checked daily.

Weighing will also be carried out within the terminal facilities usually by belt weighers to maintain internal stock control and for determination of freight charges. Belt weighers can sometimes be calibrated against the batch weigher of the system when an appropriate grain movement is undertaken. Belt weighers are not usually required to have an accuracy greater than 0.5% and operation is usually satisfactory at 1% for flow control purposes.

Dust Control and Good Housekeeping

It has proven essential in modern port storages to control the emission of dust. Dust is generated at all points where grain streams change, that is, where the grain is transferred from one conveyor to another. These points are carefully enclosed and the shrouds of the conveyors exhausted pneumatically so the dust is removed and transported to remote collectors for a central dust collection hopper. In some installations the dust is again put back on the stream of the grain and sold at the point of shipment. Some operators, however, remove the dust completely from the plant and it is disposed of either commercially in the form of feed stock or, where this is not possible, it is sent away for disposal as trash.

Good housekeeping is an essential aspect of a modern grain terminal, so as to minimise the accumulation of dust on silo superstructures and other areas where it can collect and become a nuisance and a fire hazard. It is important to provide hosing down and compressed air facilities in all areas where their use for cleaning is permissible.

It must be borne in mind that grain dust is a highly explosive material and in the planning of new terminals great care must be taken in its collection and control because of the hazards to life and property when proper housekeeping and good maintenance procedures are not followed.

In the recently constructed grain export terminal at Fisherman Islands, near Brisbane, Australia a significant step in minimising risk of fire and explosion was taken in the planning stage. All grain in the main stream of flow from rail through storage to ship is handled on belt conveyors, thus eliminating the use of bucket elevators, which are considered to have been the main source of ignition in the disastrous explosions and fires which devastated many large export terminals in the USA, and some in Europe, in the late 1970s and early 1980s. The risk of fire is also reduced by attention to detail in design, avoiding pockets within enclosed grain transport spaces where grain and grain dust might lodge.

Sampling and Quality Control

Once grain is in a bulk stream, quality control and sampling are essential. Modern grain terminals contain automatic sampling equipment which cuts a thin sample from the grain as it is discharged from a conveyor head pulley, and automatically despatches that sample to a laboratory at a grain inspection station. The sample is assessed for grain quality and conformity with specifications and is examined for the presence of insects. It is usual where insect infestation is discovered for grain to be diverted to a pre-assigned silo for fumigation.

Fumigation

Whether the grain in transit is coming into or leaving the country, it is most important that some storage silos be equipped with fumigation equipment. Such silos must be made in gastight construction and fitted with diffusers and ducting for injecting and recirculating fumigant gases. The grain can then be quickly disinfested and sent on its way.

Grain Storage and Work Area

A port terminal is not usually a place for long-term storage although it may be necessary from time to time to keep grain of a certain quality in inventory at a terminal. The function of a terminal is to provide a quick transfer of grain into or out of the country and not to hold up the operations of a comparatively expensive part of the bulk storage system with long-term storage.

If a terminal storage is designed to maintain strategic stocks, or if its geographic location is such that it is also an important local storage in a production area, additional and appropriate storage must be provided for that function.

Port storage has usually been in the form of vertical, reinforced concrete silos, at least for a significant part of the storage construction. Steel silos are sometimes used, but once again, the height/diameter ratio is usually fairly high. The silos are usually fitted with hopper bottoms so that the grain can be fully discharged without the use of manual labour when they are used for filling ships. Silos of 9 to 20 metres in diameter and as high as 20 metres or more are employed in large export terminals. Sufficient hopper bottom storage is usually provided to cater for the cargo of the larger ships, to avoid unnecessary delays and demurrage on the ships.

In the humid tropics it is highly likely that some forms of squat storage (Figs 1–3) would also be built to provide aeration facilities for cooling grain and maintaining grain quality. Squat storages are storages with low wall height compared to diameter, usually with walls not higher than about 6 or 7 metres. They allow aeration to be carried out far more efficiently than vertical storages. Squat storages are much cheaper to build (perhaps 30% to 45% of the cost of vertical storage). Although higher labour costs have been involved in their unloading, the use of modern grain sweeps has introduced a completely mechanised function to this operation so that squat circular storages are easily integrated into a fully automated terminal operation.

Some storage that may be used for at least part of the time for bag storage may also be required at ports. This is because it is highly likely at many Asian centres the ports will be close to centres of distribution and there may be a need to bag and warehouse grain in a way that will maintain its quality for reasonably long periods. While this type of storage may not usually be regarded as the main function of a port terminal,

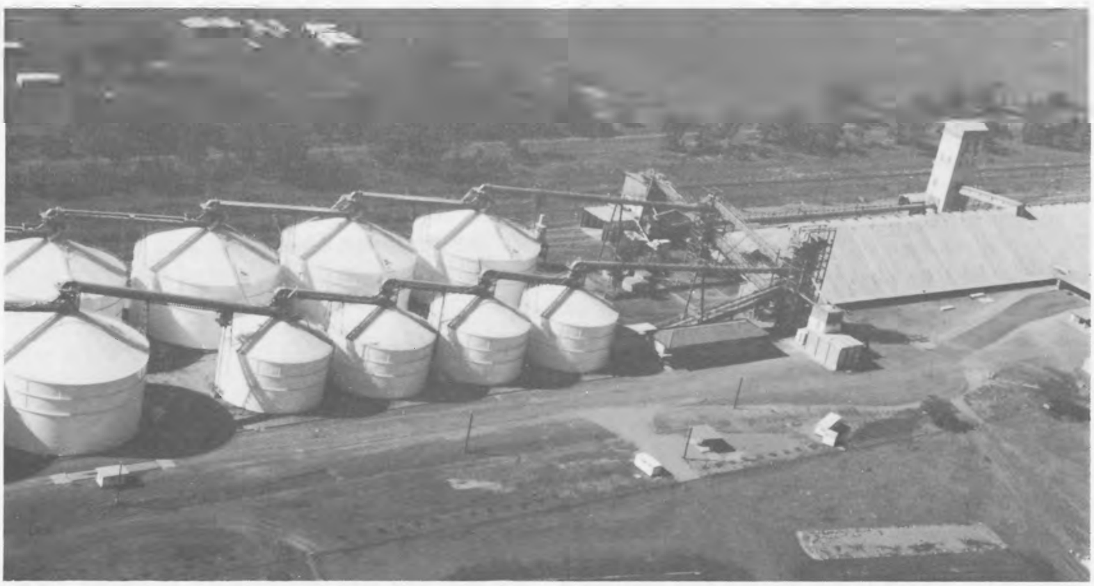

Fig. 1. Squat storage, at the sub-terminal at Parkes, New South Wales, Australia. This major inland 'port' receives grain by rail and road for despatch in unit trains to export terminal requirements.

Fig. 2. Large doors allow squat storages to be used for economical, sealed-for-fumigation bag storage when not required for bulk grain, a useful option at a port where bagging is done.

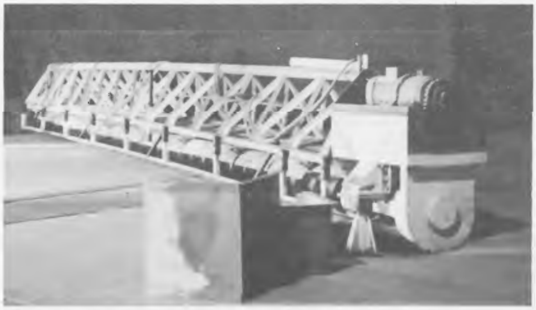

Fig. 3. Floor sweep in large squat storage

its inclusion will very likely come under the control of the management of the terminal and appropriate technology and storage facilities must be provided.

Ship Loading

At port terminals the grain to be discharged to ships or barges is first transferred from storage and elevated for weighing through highly accurate batch-weighing equipment. Weighing at this point in the product flow is required to be very precise since it is the basis on which payments are made.

During transfer to the weighers, it is usual practice to sample the quality of the grain so that accurate records are maintained for both the seller and the purchaser. Quality is assessed at this point and samples kept. An essential part of inspection at this time is the assurance of freedom from insects, or at least the assurance that requirements for numbers of insects committed in a cargo are within acceptable limits. Grain which is discovered to be infested with insects is usually diverted to a pre-assigned silo where it is fumigated to kill all insects before shipping of the commodity is recommenced.

Fixed Ship Loaders

Ship loading today is almost uniformly carried out using continuous loaders which reach out across a ship's deck and drop the grain in a continuous stream into the cargo holds. Fixed loaders may be provided either operating directly from high silos or from high level conveyors running in enclosed galleries along the wall.

Travelling Ship Loaders

Loaders may be travelling units mounted on rails on the wharf deck or on rubber tyres, the former being the more usual.

A common type of travelling ship loader has a luffing boom attached to a tower on the gantry of the loader with either a vertical or luffing and/or pivoting spout which reaches down into the hold of the ship. The grain may be carried along the boom on chain-type or belt conveyors.

Dust Suppression in Loading

An essential aspect of ship loading these days is the suppression of dust which billows out from the holds of ships when grain is being discharged at the end of the spout. Two main types of dust suppressing equipment are in use. The more popular one is the dead box, a device for stopping the flow of the grain at the end of the spout and releasing it in a deeper but slower stream close to the pile of grain. Sensors may or may not be provided to ensure that the dead box is maintained within a short distance of the pile of grain it is feeding. Many variations on this principle are in use.

The second type of dust suppression device is fitted to a vertical fall of grain. Typical of this type is the Midwest loading spout developed in the USA. In this case the grain falls vertically through a concertina-type enclosure onto a small hopper similar in function to the dead box, from whence it is released by automatic means in a controlled manner. Once again, the grain stream is maintained at only a short distance above the pile of grain building up inside the ship or barge.

An interesting loader recently completed in

Fig. 4. Shiploader at Fisherman Islands grain export terminal, Brisbane, Queensland, Australia: photograph taken during construction in 1985

Fig. 5. Dust suppressor at a Cargill Inc. (USA) export terminal, 1982

Australia at the Fisherman Islands train terminal in Brisbane is based on the Peco loader developed through sponsorship from Cargill Inc. of the USA. This loader, of capacity 2200 tonnes per hour, the highest capacity single-belt outloading system yet employed in Australia, has a pivoting and luffing boom on a travelling gantry. The machine has a lower profile and is a much more efficient method of accessing a ship's hold than the fixed luffing boom type in more common use in Australia. This particular machine was built to performance specifications on open tendering against a consultant's design.

Auxilliary Equipment— Ships Thrower

Except on bulk cargo ships, which are specifically designed to render trimming unnecessary, cargo holds require special attention to fill the voids underneath the overhanging deck surrounds of the holds (the 'tween-decks). This extra loading cannot be achieved completely using just a vertical or inclined gravity loading spout and belt trimmers are provided at wharves loading such ships. Trimmers use short-length, high-speed conveyor belts which throw the grain into the 'tween-deck spaces. Trimmers may be suspended from the spouts of the shiploader or may be cable supported either from the boom of the loader or the ship's gear.

Equipment for Unloading Ships

The range of equipment available today for unloading bulk cargoes and the variety of situations in which it is applied is too large a subject to treat exhaustively here.

Bulk cargoes at ports are usually transferred at wharf installations, and a large part of this paper describes such installations. However, there are important bulk handling systems around the world which involve barge movement and lighterage, for which specialised equipment has been evolved. Notable amongst these are the Mississippi River transport system and the canal systems of Europe. Some of this technology may have application in ASEAN, where many diverse types of water movement of cargoes are possible.

The equipment described and referred to is selected as representative of the range likely to be incorporated in Asian countries. References are appended for further guidance. It is noted that some types of equipment which would be highly suited for unloading grain at a particular berth might not be selected if that berth were to be used for other bulk commodities for which that equipment was not suited.

Traditionally, that is from the turn of the century until about 20 years ago, there were basically two types of ship unloading equipment to choose from, namely:

- the grab or clam shell unloader attached to a standard wharf crane or a specialised travelling gantry, and
- the pneumatic unloader or 'leg', which was the only type of continuous ship unloader (CSU) available during that time.

Both types of unloader are still in use today and the pneumatic leg is still being chosen for new construction. Each type has had its limitations, leading to the development of many interesting new types of equipment.

The Grab Unloader *versus* the Continuous Ship Unloader (CSU)

Most commonly, the clam shell or grab unloader is fitted to a travelling portal crane or a fixed jib crane operating on the wharf. Frequently, the clam shell is detachable so that the crane can also be employed for general cargo operations using the crane hook.

Grabs mounted on travelling gantries are commonly encountered in coal and mineral unloading operations where massive capacities are required and readily achieved.

Some excellent comparative studies have been made of grab unloaders versus continuous unloaders, and these have favoured the use of continuous unloaders.

Advantages of continuous unloaders are:

- no spillage (on wharf aprons and ship's deck);
- less dust emission;
- lower capital cost;
- lower total weight and therefore significant savings in cost of the deck structure;
- better overall unloading rate resulting in lower capacity of installed on-shore equipment to maintain average throughput; and
- shorter installation time

As against these advantages, continuous unloaders are dedicated machines and cannot perform a double function as general purpose cargo cranes as can the clam shell mounted on a portal crane. Also in favour of the grab is its high degree of mechanical reliability due to its simplicity.

Types of Continuous Ship Unloaders (CSU)

Partly due to limitations in capacity of the traditional pneumatic leg and partly due to its high power requirements, maufacturers of handling equipment have developed other types of CSUs for unloading grain and other small particle size bulk solids. Perhaps the best known alternative until the 1980s was the chain-type unloader of Buhler-Miag, in which a fully enclosed drag chain elevator leg lifts the commodity from the ship's hold to conveyor systems, either on a travelling gantry or directly to other land-based systems. The digging end of the leg is sometimes fitted with a reclaiming scraper for feeding non-free-flowing materials into the elevator. This Buhler-Miag unloader has been supplied as a combined loader and unloader for special circumstances.

Other types of mechanically driven CSUs have been built with different types of mechanical elevating legs. Those that may be suitable for the ranges of capacity of possible interest in the ASEAN region are described below.

Other elevator legs make use of pocket belt elevators, bucket elevators, and disc elevators. Feeder attachments are provided to bring material to the loading end in the ship's hold.

Caterpillar-type or wheel-type front loaders are employed in the ship's hold to complete the unloading cycle in each hatch by bringing dead pockets of grain to the unloading leg.

Other interesting developments are covered in the sections following.

The Bucket Elevator Unloader

The PWH, Weserhutte, West Germany bucket elevator unloader has an angle deflection on the loading end allowing the machine to scrape the bottom of the ship's hold.

The Continuous Catenary Unloader

This unloader, developed by the US company Paceco, is the type built in 1985 by Mitsui Engineering and Shipbuilding Co. Ltd, Japan for the Singapore bulk cargo terminal at Jurong for unloading fertiliser, cement clinker, and raw sugar.

Its rated capacity is given as 600 tonnes per hour based on fertiliser of relative density 1.2. In grain this volumetric rate would equate to about 400 tonnes per hour but presumably by varying bucket size, line speed, and other interactive components, a rate of 600 tonnes per hour would be achievable.

The 'Sandwich-belt' Simporter Unloader of Simon Carves , U.K.

In this unit, grain is taken in from the ship's hold by way of a feeder which comprises a multi- bladed rotary paddle flanked by two screw sections. The feeder collects the grain and transfers it to a twin belt (sandwich) system. The twin belts are brought together with idlers and sealed with light air pressure allowing the product to be conveyed vertically at high capacity without breakage or damage of any kind. The Simporter has been very successfully applied to a wide range of products, including grain. There have been recent installations in the U.K., Japan, and China.

At the top of the elevator section and whilst still entrained between two belts, the grain passes into the boom section of the Simporter, from where it is discharged by gravity either to the land side system or into a barge outloading system which may be part of the same machine. As with other CSUs final clear up is effected by lowering a front-end loader into the ship's hold.

The Screw-type Unloader

One of the most interesting developments in CSUs has been the Siwertell ship unloader. This company pioneered the development of the vertical screw elevator by introduction of an ingenious counter-rotating feeder at the end of the vertical screw. The feeder forces the grain down into the lower portion of the internal screw of the vertical leg and allows it to charge the tube fully and bring about an effective screw elevating mechanism inside the tube.

The use of the screw leg has enabled very simple and effective arrangements to be made for reaching into all parts of a ship's hold, minimising the clean-up time required. The Siwertell screw ship unloader has been supplied in capacities up to 1100 tonnes per hour. New contracts are reported for ratings of 2000 tonnes per hour in coal unloading.

The Siwertell company has now amalgamated with Nordstroms, forming a company known as Consilium Materials Handling, a highly innovative development group catering for all aspects of marine development. Amongst their most successful developments is the E-type light-weight ship unloader. Based on their successful screw type leg, the E-type unloader may take the form of a pneumatic-tyred mobile machine that can be easily manoeuvred onto the wharf apron of a multipurpose wharf. It may also be rail mounted in the conventional way or mounted on a stationary column at berths where it is convenient to move the ship during the unloading process and so position the unloader alongside different holds. The E-type unloader is designed for grain handling rates of 140, 390, and 490 tonnes per hour and is capable of reaching into the holds of Panamax vessels.

This company also has the resources to build dedicated self-unloading ships: bulk carriers ranging in size from 5000 to 40 000 tonnes deadweight. An example is the recently completed Bei-Ji-Xing.

Self-unloading Ships

Recently, development of self-unloading bulk carriers has been extended into the smaller vessels. Ships of around 5000 tonnes deadweight and larger are being put into service.

The conditions under which self-unloading bulk carriers would be introduced in the ASEAN area, would probably fall into three categories:

- The supply of grain from one island province of a nation to another, from surplus production areas to deficit areas, for example in the Philippines, in the context of corn and rice production.
- The export of surplus production of brown rice from Thailand to its neighbouring countries. This development would require cooperative action on the part of receiving countries to install handling and conveying equipment on the wharves. This would be filled directly from the self-unloading ship.
- The establishment and development of a grain shipping line within a country, to facilitate the shipping and receival of grain purchased from neighbouring countries.

A 27 000 tonne deadweight vessel is being used in China for exporting its considerable surpluses of coal, and for transporting its coal by sea to its own power stations along its coast and up its rivers. The distances from the loading port to the end users are fairly short and, in most cases, the receiving port has no or very limited facilities for unloading the coal. There may be obvious economic parallels in grain traffic in the Asian countries.

These new systems should not be overlooked when the introduction of bulk handling is being considered. Their costs may be lower than land-based unloading systems.

A Methodology for Introduction of New Systems and Port Installation

It is my view that many projects have been undertaken in the countries of the humid tropics where researchers focused on development of equipment that already exists in other parts of the world. Research programs have been put in hand which, while very interesting for the research workers, have not yielded new information and have not had the impact that the dynamic requirements of the commercial world has yielded. I believe the extensive efforts of research workers to develop options for the inefficient Engleberg rice mill so widely used in the ASEAN are an example of this.

In the context of bulk handling facilities at ports, especially in the area of movement of grain into and from ships, the more recent developments of light-weight and rubber tyred equipment which can travel on existing wharves and the development of this technology provide opportunities for planners and engineers to find creative and innovative solutions for the introduction of bulk handling systems. Research effort might be more appropriately targeted at finding the right localities and situations at which port bulk handling systems can be introduced.

The successful introduction of bulk grains handling at ports depends on the implementation of sound policy. In my view, a successful methodology, one for determining the most appropriate strategy for a port installation, should include an approach with three ingredients. I suggest these three because on reflection I have noticed they were consistently present in those of my projects which were notably successful and were noticeably absent in those jobs or parts of projects which did not come up to expectation. This is not to say they are the only ingredients, but at least worthy of your checking to see if they may apply to you. My three key ingredients for creating a successful new project then are these:

Stage 1 — A willingness to learn from the state-of-the-art technology in the places where it is practiced the best. Don't reinvent the wheel at this stage. Engineers and planners should go to the areas and to the specialists in the places where the technology has been developed. For example, if barge loading seems attractive, they should go to visit specialists and operators in barge loading in Europe or to the Mississippi River areas of the USA. In the case of ship unloading, discussions could be held with two or three of the most successful manufacturers of the type of equipment envisaged.

Stage 2— Development of new ideas relevant to the new situation, and their integration with the old system. This is the 'open mind' phase and is best carried out in close collaboration with technologists in the area from which the new technology is to be drawn, whether they be consultants, manufacturers or operators, who have demonstrable skills and abilities in that work area.

Stage 3 — Innovative adaptation of the new technology to the new environment. This work must be done by technologists in close contact with the needs and problems of the area to which the development is targeted. Adaptation and development skills will lead to the creation of efficient and fully functioning plants with great commercial benefit to all.

Sources of Further Information

- *Continuous ship unloading and self-unloading vessels*—a collection of 48 papers published in the journal Bulk Solids Handling between 1981 and 1985. Trans Tech Publications, P.O. Box 266, D-3392 Clausthal-Zellerfeld, West Germany.
- Various papers published in the same journal since 1986.
- *Grain handling and storage*, by G. Boumans: published by Elsevier, Amsterdam as the fourth volume in the series Developments in Agricultural Engineering Practice.
- Buhler Brothers Ltd, CH-9240 Utwil, Switzerland.
- Consilium Materials Handling (Siwertell), Box 88, S-267 00 Bjuv, Sweden.
- Bulk Grains Queensland, 619 Ruthven Street, Toowoomba, Queensland 4350, Australia. (Operators of Fisherman Islands Terminal, Brisbane.)

Technical Aspects of Bulk Handling and Storage–State of the Art Session Summary

Chairman: B.R. Champ*
Rapporteur: Kriang-krai Mekvanich†

THE second session, on the state of the art in technical aspects of bulk handling and storage, was designed to outline some of the technology that is available to grain industries to make bulk handling feasible. A prime objective was to present the range of technology available and place it in perspective as regards regional needs and problems. There were six speakers who firstly examined the pressing technical matters that are constraints to the development and improvement of grain handling and storage in the humid tropics. They then went on to outline some of the technology that might overcome these constraints.

Mr Loo Kau Fa from LPN, Malaysia delivered the first paper on 'Harvesting to procurement, including field collection, transport, and grading'. He described the current practices and constraints to paddy harvesting, transportation, and procurement. Emphasis was placed on the difficulties faced in combine harvesting and field transportation. He also referred to grading of paddy for procurement.

Mr J.A. Tumambing from NAPHIRE in the Philippines then discussed 'Current grain drying practices and needs in ASEAN'. He gave a general survey of existing drying practices in the region. The advantages and disadvantages of sun drying were mentioned and types and characteristics of operational and experimental mechanical dryers were detailed. In addition, he outlined the constraints on and factors to be considered in mechanical dryer application in the region. Finally he listed priorities for future research.

Dr R.H. Driscoll from the University of New South Wales, Australia followed with a presentation on 'Grain drying systems for the humid tropics'. He identified the problems that were experienced where adequate grain drying facilities were not available. He then considered approaches that could be taken at different levels of operation to solve specific drying problems. Cost determinations were given in terms of financial, social, and quality parameters. Finally, he explained various methodologies and simple methods for economic assessment for specific conditions and dryers.

Mr C. Newman from Bulk Grains Queensland, Australia gave a very comprehensive coverage of available 'Storage and ancillary equipment'. He first cited the factors to be considered in storage design. He then gave general information on storage, conveying systems, aeration, pesticide application,

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fumigation, weighing, dust control, automation, and control systems. Application of various types of silos and bunker storages were covered.

Dr M. Bengston from the Queensland Department of Primary Industries, Australia presented information on 'Integrated pest management'. He detailed essential storage management practices, including aspects of hygiene, stock control, grain temperature, and moisture content. Capacity to apply residual pesticides and capacity to fumigate were also cited. A list of grain protectants available for wheat was provided and the breakdown and residual life of grain protectants were discussed.

Mr J.V. Moore, a grain handling consultant from Australia, delivered the last paper of the session, on the topic 'Port handling facilities'. Various systems of port handling were shown and their operations discussed. Facilities available for port storage, shiploading, dust suppression etc. were detailed, for both dockside use and for up-country assembly of grain scheduled for transport by ship.

In the general discussion that followed, many issues relevant to introduction of bulk handling were raised. In response to a question on the length of paddy fields that gave highest efficiency in combine harvesting, it was indicated that, ideally, combine harvesters should reach the other end of the field when the receptor tank was full of grain. As a rule of thumb, about 200 metres (600 feet) of field length was suggested.

There were detailed discussions on the problems of transporting combine harvested paddy from small holdings. Current practice is bagging the harvested paddy and transporting the bags by motorcycle on the field bund as combine harvesters cannot travel back and forth through the other farmers' fields to unload the paddy at the roadside. This is both labour and time consuming. There were suggestions from the floor concerning trials on balloon-tyre type transporters and low-speed travel combine harvesters that avoid destroying the neighbouring paddy field. Another proposal concerned employing movable screw conveyors to transport the paddy from a collecting tank (mobile filling bin) to the truck at the roadside.

Referring to the presentations on 'Current drying practices in ASEAN' and 'Drying systems in the humid tropics', there were questions relating to grain breakage levels when subjected to 85–100°C drying air in the continuous-flow dryer, as well as proper storage capacity and drying requirements for in-bin drying. In the studies on two-stage drying, the first partial drying for high moisture content paddy (more than 18%) by continuous-flow dryers has not shown any significant increase in percentage of broken grain.

For the in-bin drying stage, storage capacities of 200 tonnes with 4 m grain depth were recommended, with a drying requirement of 10–14 days for continuous drying and greater than 14 days for intermittent drying subject to weather conditions.

There were comments on the application of mechanical dryers. A Malaysian participant suggested that partial drying was more suited to small-scale use and single pass drying for large-scale use. With respect to the limited application of dryers at farm level, it was suggested that small dryers would be more economic for use by cooperatives, traders, or other small collecting units. Other matters raised included creation of an inventory of dryers available and their evaluation for proper application by the target users. Another question related to the quality changes in grain in terms of gelatinisation when subjected to high temperature drying. Rapid drying at high temperatures could cause partial gelatinisation or parboiling but can also induce favourable effects: higher resistance to mechanical breakage can occur, for example. Gelatinisation of rice will start when the grain temperature reaches 65°C so high air temperatures and airflow can be employed as long as the grain temperature can be controlled.

With respect to port handling facilities, the applicability to grain of shiploaders used for coal in China was discussed. It was suggested that this type of shiploader was appropriate for any commodity with free-flowing characteristics, including grain.

The papers and discussions in this session indicated quite strongly that technology appropriate to bulk handling and storage of grain in the humid tropics is available. The challenge is how best to use it so as to provide benefits that accrue to all sectors of the postharvest chain, from farmers through to consumers.

Case Studies on Bulk Handling and Storage in the Humid Tropics—I

The papers presented in this session of the workshop reported the results of studies undertaken in ACIAR Project 8344—Bulk Handling of Paddy and Rice in Malaysia: an Economic Analysis.

Transportation and Assembly Costs for Paddy and Rice in Malaysia

Muzafar Shah Habibullah*

Abstract

This paper presents the results of a pilot survey on transportation costs, which was part of a larger scale project on paddy bulk handling. The survey was conducted between August and October 1985, in the Tanjung Karang paddy growing area, Selangor Darul Ehsan, Malaysia.

The main objective of the study was to estimate costs pertaining to transportation activity in the paddy sector. Estimates were made of the trucking cost function (later used to analyse the extent of economies of size in paddy transport in the area), queuing cost, and road transport charges (road pricing). These functions were estimated for both farmers and lorry operators.

The results suggest that economies of size prevail in paddy transportation activities in Tanjung Karang. The cost per output-kilometre decreases as the volume of paddy carted and the trip distance increases. The results also suggest that queuing cost at the complexes is affected by the amount of paddy delivered and the number of workers at the receival site. Further, the results indicate that the quantity of paddy delivered, trip distance, and expected queuing cost affect the road transport charges for lorry operators, whereas for farmers trip distance is unimportant.

TRANSPORTATION is an important activity in the paddy growing area at least for two reasons. First, it presents logistic problems to the farmers to ensure that the grain is taken out immediately after bagging to minimise losses (mainly through deterioration), especially during the off-season harvest when the fields are wet and when rain is an almost daily affair. Secondly, paddy transportation costs are important components of the total cost of paddy production. The major costs incurred in paddy production are for harvesting, threshing, and transport, which vary between 19 and 34% of the total cost of production for different states or areas. The high contribution reflects the cost incurred in hiring labour for harvesting and threshing, and that for hiring lorry operators to transport paddy from the field to the complexes. This ultimately affects farmers' incomes (Noor 1980).

Paddy transportation activities can be summarised as follows. At the farm level, after the grain is harvested by combine harvester, it is bagged. If the crop is harvested manually by sickles, threshing is required before bagging. About 80 kg of grain can be placed in each bag. The bags are then carried manually to the bunds (embankments) that separate each farmer's plot of land.

The bags containing paddy are then transported to the procurement centres, directly to the milling complexes, or to any other licensed or

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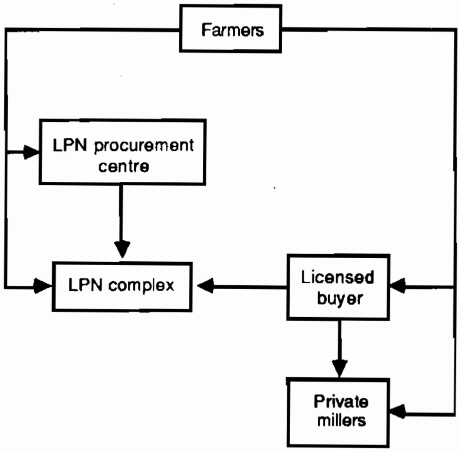

Fig. 1. Paddy marketing system in the Tanjung Karang area of Selangor Darul Ehsan, Malaysia.

private buyers (see Fig. 1). The most important means of transportation at this stage of the marketing channel are motorcycles and lorries. The process of selling and buying is concluded at these procurement centres. It then becomes the responsibility of the buyer to store and finally transport the grain to the milling complexes. In all cases, except at the milling complexes, the process of loading and unloading the grain is done manually. At the milling complexes, unloading is assisted by motorised conveyor belts.

In the transportation system, vehicles are required to queue at several places. Queuing can occur at the procurement centres while the grain is graded and the transaction concluded. Sometimes lorries queue before the grain is loaded onto them to be transported to the mills. At the mills, the lorries are also required to queue for the weighbridge at the unloading station, and again at the weighbridge after unloading.

Although this transportation system has existed for more than 20 years, little is known about its cost structure and efficiency. Also, little is known about the factors affecting the queuing costs or about how the road transport charges were determined. These issues are crucial because, unless these costs are identified, the present system cannot be evaluated.

This paper reports on an investigation of the mode of transport in the Tanjung Karang paddy area. Also, costs of trucking, queuing, and the factors affecting road transport charges are determined empirically.

Methodology

The Survey

The models used in this study require cost data which are available only from the farmers and those directly involved in the delivery of grains from the field (farm) to the milling complexes. This being so, a survey of farmers and lorry operators was undertaken during the harvest period of August-October 1985 in the Tanjung Karang paddy area.

Tanjung Karang, a well-developed rice growing area in Peninsular Malaysia, was selected not only because it is relatively close to the Malaysian capital of Kuala Lumpur but also because it was felt that the area would provide reliable sets of data to empirically evaluate and test the specified models.

Before the survey, a questionnaire was prepared and local personnel were selected to become the interviewers. The interviewers were stationed at the various procurement centres and milling complexes where the interviews were conducted.

Type of Data

The objective of the survey was to obtain the following information:

1. The characteristics, particularly the type and size, of transport facilities used by farmers and lorry operators to deliver paddy from the farm to the procurement centres and finally to the milling complexes. These data were then used to estimate the transportation costs in the system and subsequently to generate cost functions for paddy assembly, i.e. the movement of paddy from the farms to the milling complexes.

2. The time and costs of queuing and their relation to the level of receivals and receival capacity at each of the procurement centres and milling complexes.

3. Other data, such as the determinants of the transport charges for carting grain.

Analytical Framework

The Trucking Cost Function

In this study, road transport costs were divided into three major components

1. variable costs, which varied directly with trip distance;
2. transfer costs (the costs of loading and unloading the vehicle), which were a fixed amount per trip and independent of the trip distance; and
3. fixed costs, which were a fixed amount per annum and independent of distance travelled.

The variable trucking costs included the costs of fuel, lubrication oil, tyres, repairs and maintenance, and the driver's wages. The transfer costs in this particular case represented the value of time spent in the process of loading and unloading the vehicle. The fixed trucking costs, on the other hand, were divided into two components, namely, the capital purchase costs and the annual fixed costs comprising registration fees, road tax, and insurance. These cost data were then used to estimate the trucking cost functions.

Although more complex trucking cost functions have been derived by other researchers (French 1977; Fleming and Uhm 1982; Goyette et al. 1982), a simplified one specified by Kerin (1985) was used in this study. It takes the form

$$COST_{c/T/KM} = f\ (DIST_{KM}) \qquad (1)$$

Equation (1) postulates that the cost of trucking per tonne-kilometre ($COST_{c/T/KM}$) is proportional to the distance in kilometres ($DIST_{KM}$). The relationship between cost and distance is expected to be positive. It can be expressed in terms of either total or average cost and the marginal cost functions can be derived from it.

Queuing Cost Model

One of the main problems in a typical grain transportation system is queuing. Queuing can occur at the collection centre (loading in the field and loading at procurement centres), and at the milling complexes (weighbridge, grading, unloading). Queuing always occurs in a system when the rate of arrival is greater than the unloading or service rate for a given time period.

In this study, the daily queuing cost function was estimated. The daily queuing cost was a function of two variables, namely the arrival rate and service rate. Since the model was specified in total daily terms, the arrival rate was defined as the quantity of grain received on the day in question, while the service rate was defined as a measure of the maximum quantity of grain which could be received at a site per day. The number of workers was used as a measure of the daily service rate since queuing cost depended on the speed at which the grain was unloaded from the vehicle. On the other hand, the total queuing costs can be represented as the sum of the opportunity costs of idle labour (driver's time), idle vehicle, and idle harvesting equipment and labour.

Following Kerin (1985), queuing cost model is specified as

$$TQC = f\ (PQDEL,\ NWUNLOAD) \qquad (2)$$

where TQC = total queuing costs (cents) on the sample day, PQDEL = total receivals on the sample day (tonnes), and NWUNLOAD = the number of workers available at the site on the sample day.

It would be expected that TQC would be positively related to PQDEL and negatively related to NWUNLOAD.

Road Transport Charges (Road Pricing)

If the farmers and lorry operators are rational and profit motivated, then it is important for them to know the factors that determine the road transport charges for carting grains. Following Kerin (1985), a road transport charges model can be specified as

$$RTC = f\ (PQDEL,\ DIST,\ EQC) \qquad (3)$$

where RTC = road transport charges, i.e. farmers' and lorry operators' charges (c/t), and EQC = expected queuing cost (cents). All other variables are as defined previously.

It is expected that RTC would be positively related to PQDEL, DIST, and EQC.

TABLE 1. Types, sizes, and ownership of vehicles used to transport paddy in Tanjung Karang, Selangor, Malaysia

Vehicle type	Capacity range (tonnes)	No. of vehicles Farmer	Lorry operator	% of total vehicles	Grain delivered Farmer	Lorry	% of grain delivered	Average load Farmer	Lorry operator
Motorcycle	< 0.1	137		18.79	23.08		1.65	0.17	
	0.1-0.2	443		60.77	74.64		5.33	0.17	
	0.2-1.0	1		0.14	0.17		0.01	0.17	
Small lorry	1- 5		78	10.69		369.22	26.37		4.73
	5-10		21	2.98		226.61	16.19		10.79
Large lorry	10-15		33	4.53		423.56	30.25		12.84
	15-20		8	1.10		139.08	9.93		17.39
	> 20		8	1.10		143.71	10.26		17.96
Total		581	148	100.00	97.89	1302.18	100.00	100.00	

Source: Computed from the survey

Results of the Study

The study included all grain handling facilities which were in operation during the period of the survey and thus involved 23 out of the total 40 handling facilities in the region. These included three (out of four) milling complexes and 20 procurement centres. The milling complexes, belonging to the National Paddy and Rice Authority (LPN), were located in Sekinchan, Sungai Besar, and Ulu Tiram Buruk.

The Mode of Paddy Transport

The survey revealed that (see Table 1) out of the total number of 729 respondents, about 80% were farmers, and the remainder lorry operators. Also, there were two main types of paddy transport in Tanjung Karang paddy area: motorcycles and lorries of various sizes and types (makes). Motorcycles were owned by the farmers, while the lorries were owned by private transport operators.

In terms of the volume of paddy delivered, farmers accounted for less than 10% of the total amount of paddy carted in the area. The average amount of paddy carted on each motorcycle trip was about 0.17 tonnes, for all sizes of machine. However, for the lorries, the quantity of paddy carted ranged from 5.0 to 18.0 tonnes depending on the size of the vehicle (see Table 1).

Total Trucking Cost Function

In the developed countries, there is evidence that economies of size prevail in grain farming (Johnson 1977; Sorboe 1978; Longworth and McLeland 1972). Economies of size in the delivery of grain would imply that, for a given distance, the average trucking cost per unit of output would decrease as the volume to be delivered increased and, for a given volume, the average trucking cost per kilometre would decrease as distance increased. Hence, considering the trucking cost function measured in output-kilometres, if volume and distance increased, independently or simultaneously, the average cost per output-kilometre would decrease (Fleming and Uhm 1982).

In order to arrive at the total trucking cost function, cost components relating to transportation activity were obtained, and the total trucking cost function derived from these. The technical derivation of the total trucking cost function is discussed in detail in Kerin (1985) and is therefore not covered again here.

The continuous trucking cost functions by distance classes for farmers and lorry operators are presented in Table 2. These trucking cost functions imply that total variable cost (TVC) and total cost (TC) increase as trip distance increases. Since these cost functions were estimated for each distance class, it is possible that they could be generated into a single trucking cost function by estimating its appropriate functional form. In order to do that, we have calculated TVC and TC for each distance in kilometres from Table 2, by substituting numerical values of, say, 1 to 50 km for distance. Thereafter, we regressed the respective costs (TVC and TC) against distance (DIST), by experimenting with the following functional cost relationships:

MODEL I. $COST = f_1\ (DIST)$ (4)

MODEL II. $COST = f_2\ (DIST, DIST^2)$ (5)

MODEL III. $COST = f_3\ (DIST, DIST^2, DIST^3)$ (6)

MODEL IV. $COST = f_4\ [(1/DIST)]$ (7)

MODEL V. $COST = f_5\ [(1/DIST), (1/DIST^2)]$ (8)

MODEL VI. $VOST = f_6\ [(1/DIST), (1/DIST^2), (1/DIST^3)]$ (9)

The results of the regression analysis are presented in Tables 3 and 4 for farmers and lorry operators, respectively. We can observe from Table 3 that for farmers, judging by the value of R^2 and the standard error of regression (SER), Model III gives the 'best' estimated equations both for TVC and TC. For lorry operators (Table 4), Model III also gives the 'best' estimated equations with the highest R^2. From these estimated equations we can calculate the average variable cost (AVC) and the average total cost (ATC) for both farmers and lorry operators. Figures 2 and 3 show the AVCs and ATCs for farmers and lorry operators, respectively. The cost curves clearly depict an L-shape cost curve, implying that economies of scale prevail in paddy transport in the Tanjung Karang paddy growing area for both farmers using motorcycles and lorry operators, at least for trip distances of 5-10 kilometres.

Queuing Cost Model

The estimated queuing cost function for farmers, in its linear form, is as follows:

TABLE 2. Trucking costs of farmers and lorry operators in the Tanjung Karang, Selangor, Malaysia rice industry, as a continuous function of one-way trip distance

Distance (km)	Total operating costs (c/t)	Total capital and operating costs (c/t)
A. Trucking costs for farmers		
0 < D [Z≤] 1.5	119.78 + 210.64 D	119.78 + 290.56 D
1.5 < D [Z≤] 4.0	435.74 + 199.51 (D-1.5)	555.62 + 275.81 (D-1.5)
4.0 < D [Z≤] 7.5	934.51 + 215.22 (D-4.0)	1245.15 + 309.07 (D-4.0)
7.5 < D [Z≤] 15.0	1688.93 + 217.22 (D-7.5)	2326.89 + 262.04 (D-7.5)
15.0 < D	3318.08 + 211.06 (D-15.0)	4292.19 + 276.00 (D-15.0)
B. Trucking costs for lorry operators		
0 < D [Z≤] 1.5	197.33 + 16.76 D	197.33 + 19.03 D
1.5 < D [Z≤] 4.0	222.47 – 11.04 (D-1.5)	226.28 – 9.20 (D-1.5)
4.0 < D [Z≤] 7.5	194.87 + 8.55 (D-4.0)	203.28 + 10.65 (D-4.0)
7.5 < D [Z≤] 15.0	224.80 + 6.80 (D-7.5)	240.56 + 9.21 (D-7.5)
15.0 < D [Z≤] 25.0	275.80 + 2.61 (D-15.0)	309.64 + 3.63 (D-15.0)
25.0 < D [Z≤] 35.0	301.90 + 13.25 (D-25.0)	345.94 + 15.70 (D-25.0)
35.0 < D [Z≤] 45.0	434.40 – 31.45 (D-35.0)	502.94 – 6.92 (D-35.0)
45.0 < D	119.90 + 7.14 (D-45.0)	433.74 + 8.56 (D-45.0)

TABLE 3. Cost coefficients (b, c, and d) and associated statistics for farmers, relating to a model of the rice industry in Tanjung Karang, Selangor, Malaysia

	a	b	c	d	R^2	SER
A. Total Variable Cost						
I	TVC = 91.186	214.41 (513.06)***			0.9999	10.41
II	TVC = 99.748	212.08 (128.69)***	0.11119 (1.4587)		0.9999	10.10
III	TVC = 131.24	196.01 (131.66)***	1.9784 (12.164)***	-0.05927 (-11.625)***	0.9999	3.38
IV	TVC = 3060.7	-3992.3 (-4.1979)***			0.4947	926.43
V	TVC = 4121.1	-14924.0 (-6.9973)***	11353.2 (5.3397)***		0.8112	582.61
VI	TVC = 5418.8	-35528.4 (-10.150)***	75300.1 (7.3176)***	-44879.6 (-6.2556)***	0.9452	323.52
B. Total Cost						
I	TC = 195.78	272.82 (86.009)***			0.9975	81.79
II	TC = 128.93	291.06 (22.462)***	-0.86825 (-1.4486)		0.9978	79.41
III	TC = 17.807	347.76 (10.675)***	-7.4567 (-2.0952)***	0.20915 (1.8745)*	0.9982	74.12
IV	TC = 3994.0	-5189.9 (-4.3732)***	0.5151	1156.09		
V	TC = 5335.0	-19013.9 (-7.3109)***	14357.0 (5.5375)***		0.8270	710.44
VI	TC = 6909.9	-4402.2 (-10.196)***	91965.3 (7.2459)***	-54467.6 (-6.1554)***	0.9486	416.32

Note: ***statistically significant at the one percent level; **statistically significant at the five percent level; *statistically significant at the ten percent level. Values in parentheses are 't-statistics.'

$$TQC = -1.32736 + \underset{(9.752)^{***}}{23.70793}\ PQDEL + \underset{(0.173)}{0.05902}\ NWUNLOAD \quad (10)$$

$$R^2 = 0.1178$$

Equation (10) implies that queuing cost is determined by the amount of paddy delivered, but not the number of workers unloading paddy at the complexes, as shown by the high significance of the variable PQDEL (*** = statistically significant at the 1% level), and the insignificance of NWUNLOAD. However, estimating the function in logarithmic form yields the following:

$$\log TQC = 0.53992 + \underset{(6.565)^{***}}{0.30623} \log PQDEL - \underset{(-3.932)^{***}}{0.32814} \log NWUNLOAD \quad (11)$$

$$R^2 = 0.0671$$

The result in log form shows that the variables PQDEL and NWUNLOAD are significant at the 1% level and that both variables have the expected sign. However, the R^2 is lower than in the linear equation.

TABLE 4. Cost coefficients (b, c, and d) and associated statistics for lorry operators, relating to a model of the rice industry in Tanjung Karang, Selangor, Malaysia

	a	b	c	d	R^2	SER
A. Total Variable Cost						
I	TVC = 272.41	-0.13086 (-0.16233)			0.0005	82.25
II	TVC = 120.45	17.403 (8.6192)***	-0.34380 (-8.9575)***		0.6308	50.52
III	TVC = 213.62	-3.4904 (-0.86371)	0.67031 (3.6599)***	-0.01325 (-5.6124)***	0.7808	39.34
IV	TVC = 279.02	-110.52 (-1.5191)			0.0458	80.36
V	TVC = 291.30	-344.84 (-1.5986)	270.86 (1.1533)		0.0721	80.09
VI	TVC = 292.66	-382.89 (-0.7452)	413.63 (0.23481)	-107.04 (-0.08179)	0.0722	80.95
B. Total Cost						
I	TC = 209.02	6.165 (19.746)***			0.8903	31.85
II	TC = 166.67	11.051 (10.466)***	-0.09581 (-4.2735)***		0.9261	26.42
III	TC = 214.11	0.41304 (0.19204)	0.42056 (4.3145)***	-0.00675 (-5.3695)***	0.9546	20.93
IV	TC = 397.08	-342.77 (-4.7807)***			0.3225	79.20
V	TC = 447.71	-1308.7 (-8.4349)***	1116.8 (6.6106)***		0.6489	57.61
VI	TC = 508.05	-3001.2 (-12.181)***	7465.9 (8.8388)***	-4760.0 (-7.5858)***	0.8440	38.81

Note: ***statistically significant at the one percent level. Values in parentheses are 't-statistics.'

Nevertheless, equation (11) implies that as larger quantities of paddy are carted, queuing costs will increase and, concomitantly, that if more workers are stationed at the complexes to unload, the queuing cost will be lowered.

The estimated total queuing cost function for lorry operators in its linear form is as follows:

$$TQC = 6.2964 + \underset{(48.102)^{***}}{14.057}\ PQDEL - \underset{(-6.435)^{***}}{6.287}\ NWUNLOAD \qquad (12)$$

$R^2 = 0.8251$

Equation (12) shows that all variables are important and have the correct signs. However, unlike the estimated TQC for farmers, the R^2 for the estimated TQC for lorry operators has a high value of 0.8251.

Road Transport Charges

In order to determine the factors that influence road transport charges, three parameters were taken into consideration: quantity of paddy delivered (PQDEL), trip distance (DIST), and expected queuing cost (EQC). As a substitute for

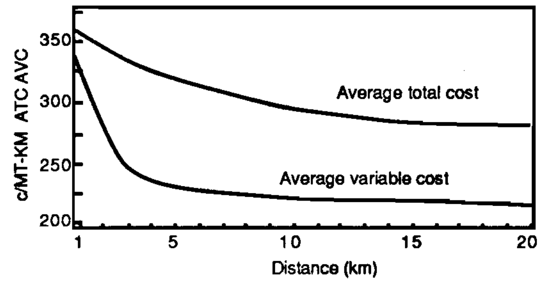

Fig. 2. Trucking cost functions for paddy farmers in the Tanjung Karang area of Selangor Darul Ehsan, Malaysia.

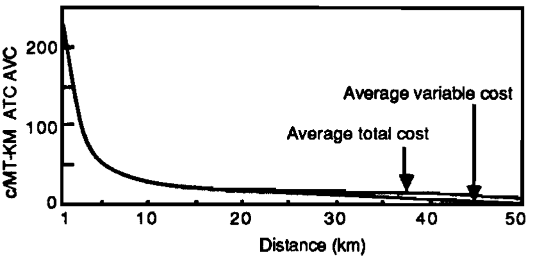

Fig. 3. Trucking cost functions for lorry operators carting paddy in the Tanjung Karang area of Selangor Darul Ehsan, Malaysia.

the expected queuing cost, in this study we used the actual queuing time, valued at the weighted average wage rate. The results of the estimate of road transport charges are as follows:

Farmer

$$RTC = 0.28491 + \underset{(9.56)^{***}}{4.0522\ PQDEL} - \underset{(-1.737)}{0.01591 DIST} + \underset{(226.63)^{***}}{8.2649\ EQC} \quad (13)$$

$$R^2 = 0.9879$$

Lorry operator

$$RTC = -1.8517 + \underset{(25.994)^{***}}{11.340\ PQDEL} + \underset{(4.993)^{***}}{0.61265\ DIST} + \underset{(13.91)^{***}}{1.8471\ EQC} \quad (14)$$

$$R^2 = 0.9447$$

Equation (13) implies that, for the farmers, the amount of paddy delivered and the expected queuing cost are important factors that determine the road transport charges. However, distance seems to be unimportant and further has negative sign. On the other hand, equation (14), covering lorry operators, shows that all three variables are important and have the expected sign.

Conclusion

The main objective of this study was to determine the total trucking cost functions, queuing cost, and road transport charges for farmers and lorry operators.

The study indicated that economies of size apply to paddy transportation activity in the Tanjung Karang paddy area. The cost per output-kilometre decreases as the volume of paddy carted and the trip distance increases. This is made possible if larger vehicles are used in transporting paddy to the milling complexes.

The results also suggest that the queuing cost at the complexes could be reduced if more weighbridges were installed, and more workers were involved in grading and unloading the grain. However, to make this possible, the capacity of the complexes (in terms of storage and milling capacity) would have to be increased or upgraded in order to cope with the amount of paddy delivered. Further, the results indicate that the amount of paddy delivered, trip distance, and expected queuing cost affect the road pricing for lorry operators, whereas for farmers, trip distance is not important.

The results of the study suggest that if a bulk handling transportation system were implemented in the area, there would be additional economies of size in transportation, leading to a reduction in the cost of production/transportation for farmers and therefore to an increase in farmers' incomes. The system could be established by the government or by private sector lorry operators with some form of government control. The system could benefit the lorry operators as well as the farmers.

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Rice Processing in Malaysia: an Evaluation of Cost Structures

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Abstract

Modelling rice processing costs is often complicated because of the various stages involved, multiple outputs produced, and the lack of data needed for such effort. Against this background, this paper reports an attempt to analyse the costs for rice processing in Malaysia. The cost structures for all processing activities, namely buying, drying, milling, and administration, are discussed and the volume-cost relationships for drying and milling are specified and cost functions estimated.

The analysis of processing costs proceeded in three ways for all four activities. First, a descriptive analysis of the various cost components is presented. The processing complexes are stratified into the four phases according to the year they were commissioned. Following this stratification, analysis of costs by phases was done. Finally, quadratic and inverse cost functions were estimated for drying and milling activities.

The results indicate that, on the whole, the per unit cost for the various activities ranges from $7.52 to $36.75. Results from the cost functions estimation suggest that statistically significant cost economies exist for this sample. There is also evidence that processing complexes which belong to the later phases have significantly lower total average costs.

FOR many years the Malaysian paddy/rice industry has been government controlled. This has generated undue constraints on the efficient running of the industry. One major consequence of government intervention has been the shut-down of many private rice mills. Thus, rice processors and Malaysians in general are concerned about the extent to which constraints in the rice handling and processing system are limiting production, impairing output quality, and generating losses to the industry and the public as a whole.

Various factors have been cited as contributing to the constraints in the present paddy/rice handling system. The more prominent and contentious issues are the price control on rice, which has been in operation since 1974, and the enforcement of a paddy price subsidy, which has indirectly contributed to the consolidation of paddy flows to government processing complexes.

Despite talks about removal of the paddy price subsidy and freeing of the price of rice from government control, efforts in that direction have been painfully slow. This can be partly attributed to the reluctance of the implementing agency to incur the wrath of the public; both consumers and producers will be affected by such a move. A suggested alternative that has been

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gaining attention is to reduce the cost of handling as well as improve the quality of paddy that comes into the processing complex. To allow for the implementation of this suggestion the bulk handling method has been considered. With this method paddy could be moved speedily to the processing complexes. This is likely to reduce the presence of long queues, which often take several days to clear, thus also reducing the amount of poor quality paddy which would be processed by the processing complexes.

In the light of this suggestion, it was therefore considered desirable to have a better understanding of the structure of rice processors' costs and the relative importance of various processing activities involved. Also of interest would be the association between costs and the level of processing output generated. This should also indicate the degree to which cost can be reduced if output increases.

Method of Analysis

Classification of Costs

Basically, there are four major categories of activities involved in the rice processing complexes. They are: paddy purchase, drying, milling, and administrative activities. The classification of the activities will facilitate assignment of cost components to each specific function. Tables 1–5 present the cost components of each activity. Cost components of each activity were also further divided into either fixed or variable costs.

Data and Data Collection

Cross-sectional cost data were obtained from LPN. Data from all the 25 integrated processing complexes, i.e. those with both drying and milling activities, were obtained and the costs were grouped into the categories described earlier. The integrated processing complexes were then stratified into four phases according to the years the complexes were commissioned. These time periods were defined by LPN to reflect technological change. Data were obtained for quantities of paddy bought, dried, and rice milled. All cost data pertinent to plant operation, including depreciation, insurance, labour and management salaries, fuels, electricity, office supplies and other cost items, were obtained for each processing complex.

Modelling Drying and Milling Costs

Theoretically, the cost functions for a firm or business entity are derived from its production and, given the requisite assumptions on factor prices, the corresponding cost functions can be derived empirically by relating them to the level of output. Evidence on the estimation of such functions has been somewhat mixed, however. Cost functions have been estimated in the form of total cost as the dependent variable (see Ghaffar et al. 1986a; Koot and Walker 1970; Ryland 1969). At the same time, estimates of average cost as the dependent variable are also available (e.g. Ghaffar et al. 1986b; McLemore et al. 1983; Barthwal and Nair 1978; Phillips 1956).

Thus, the appropriate functional form is a problem often encountered in work of this kind. There has been no definite indication as to which functional form is appropriate, however. As theory only suggests that output is functionally related to cost, determination of functional form has been relegated to statistical criteria, such as goodness of fit and significant values of the test statistics, as well as conformation with *a priori* expected signs for the estimated coefficients.

We are also aware, apart from output, of a host of other factors that influence variations in rice processing costs. Recovery rate for example is pretty much determined by the quality of paddy being processed. This in turn influences costs. It is very well known that paddy delivered to the complexes in recent years contains excessive moisture. Attempts to incorporate this aspect into the model have not been successful, however. In part, this has been due to the difficulty in getting an appropriate variable to reflect the moisture content in the model. In fact, in our survey in Tanjung Karang, little variation was noted in the amount of moisture contained in each batch of paddy delivered to LPN complexes. So, due to this difficulty, at this point we decided not to incorporate this quality aspect. Another important variable not incorporated in the cost model is capacity. We have attempted to include this variable in

TABLE 1. Processing costs[a] per tonne of paddy for Phase I

	Buying	Drying	Milling	Admin.	Total
Fixed Costs					
Emolument	3.00	4.44	15.54	24.85	47.83
Depreciation		8.35	3.96	0.18	12.49
Insurance				0.16	0.16
Total fixed costs	3.00	12.79	19.50	25.19	60.48
Variable Costs					
Handling	2.76	6.96	1.84	0.13	11.69
Direct labour	1.08	4.66	5.58		11.32
Electricity		3.05	5.94	0.48	9.47
Generator fuel		6.11	1.19		7.30
Repairs/parts	1.40	2.30	5.78	0.87	10.35
Others				16.75	16.75
Total variable costs	5.24	23.08	20.33	18.23	66.88
Total costs	8.24	35.87	39.83	43.42	127.36

[a]Costs are in Malaysian ringgit ($M). During October 1987, $M25 = US$1.

TABLE 2. Processing costs[a] per tonne of paddy for Phase II

	Buying	Drying	Milling	Admin.	Total
Fixed Costs					
Emolument	2.97	3.14	6.07	11.95	24.13
Depreciation		6.96	8.30	0.51	15.77
Insurance				0.90	0.90
Total fixed costs	2.97	10.10	14.37	13.36	40.80
Variable Costs					
Handling	2.44	7.75	0.15	0.15	10.48
Direct labour	2.10	4.75	4.84		11.69
Electricity		5.26	7.35	2.14	14.75
Generator fuel		8.23			8.23
Repairs/parts	0.46	2.92	3.48	2.86	9.72
Others				2.70	2.70
Total variable costs	5.00	28.91	15.82	7.85	57.58
Total costs	7.97	39.01	30.19	21.21	98.38

[a]Costs are in Malaysian ringgit ($M). During October 1987, $M25 = US$1.

our earlier work. The results, however, have not been very enlightening. Again, the reason for the lack of significance of this variable is due to the low variability between complexes in their rated capacity (see Ghaffar et al. 1986a).

Apart from model specification, several other problems were also encountered. In rice processing, given the various stages involved, the definition of output has been rather elusive. It is difficult to model rice processing cost as an aggregate activity when there are at least four major activities involved: buying, drying, milling, and administration. One issue that often arises is, given that these activities are often done in the same processing complex, the point at which each individual activity begins and ends. Within the multiple stages of operation, buying, drying, milling, and administration may run concurrently. Consequently, most efforts have taken the approach of modelling such activities one by one (e.g. see Ghaffar et al. 1986a).

Given the multi-stage operation inherent in rice processing, the next problem encountered is in the measurement of the output of each processing stage. An ideal measure of output would be what is actually produced at the end of each stage. However, the output of drying is the same as the input: paddy. While this problem can be circumvented by using the volume of paddy dried, as recorded by each processing complex, the output for the milling process is more difficult to define. In the first place, the rice produced often comes out in various grades. Depending on processing efficiency, the proportion of each grade tends to vary among complexes. In the absence of more reliable estimates, one is forced to use the total amount of rice actually produced. This is the approach employed in this study.

Directly related to the above problem is the question of which unit of analysis is appropriate for cost function estimation in rice processing. As has been mentioned earlier, there has been no clear indication as to which is the preferred alternative. Several estimates were attempted with total costs as the dependent variable. The results (not reported here), were often counter to expectations. In most cases, the variables included were not significantly different from zero. Given our problem in estimating the total cost function, this study uses the average costs for drying and milling, separately, as the units of analysis.

Results and Discussion

This section discusses the costs by processing complexes and phases for each activity. Average total costs for all 25 processing complexes were also analysed. Quadratic and inverse functions were estimated for drying and milling activities.

Buying

This activity includes weighing, unloading, and grading of paddy. Grading is done to determine the moisture content level and amount of impurities, such that payment made to farmers takes into account the quantity and quality of the paddy being sold.

Total average cost for buying for all the 25 complexes is \$7.52 per tonne (Table 5). This constitutes 8% of the total rice processing costs. A major portion of cost per unit is attributed to handling and labour charges. Comparing phases, phase I has the highest buying cost with \$8.24 per tonne (Table 1) while the lowest is Phase III with \$7.08 per tonne (Table 3).

Drying

The next activity to be considered is drying. During this stage, the paddy is fed into large-scale, continuous dryers to be dried to a moisture content of 13% (wet basis). Two types of dryers serve as back-up units to cater for the large volumes of paddy that often cannot be immediately fed to the large-scale, continuous dryers during the peak harvesting period. Paddy must be dried as soon as possible to a moisture content of at most 18% to avoid deterioration. Without this back-up unit paddy bought with high moisture content will deteriorate rapidly.

The total average cost for drying paddy is \$36.75 per tonne (Table 5). This constitutes 38% of the total average rice processing cost. Energy, in the form of electricity and generator fuel, makes up the largest component with 33% of the drying cost. Given the fact that investment in mechanical dryers is often costly, depreciation contributes a significant proportion (24%) of drying costs. Drying costs by phases range from $35.87 to $39.01 per tonne (Tables 1–4).

As indicated in the previous subsection, costs appear to have a tendency to vary with output. To illustrate further the effect of volume changes on processing costs, various forms of the average drying cost model were estimated. Based on criteria such as R^2, standard error, t-statistics, and consistency of sign for each regression coefficient, as well as the F-statistics, the 'best' equation for the average milling cost model was selected as:

$$DC = 23.8352 + 270.3799(1/DQ) - 0.8640(1/DQ)^2$$
$$(4.5709) \quad (2.3490) \quad (-1.9296)$$

$R^2 = 0.2743$ $\qquad$ $F = 4.1569$

values in parentheses are t-statistics

DC = average drying cost per tonne

DQ = drying output in units of a thousand tonnes

All estimated coefficients are significant at the 5% level. The positive sign for the coefficient of (1/DQ) is consistent with the a priori expectation that average cost declines as output increases, hence suggesting the presence of economies of size. As for the variable $(1/DQ)^2$, a definitive interpretation cannot be made. However, it should have the right sign such that the appropriate curvature of the estimated function can be obtained. Figure 1 represents the curve that resulted from the estimated regression, which is continuously declining.

It is also of interest to consider the extent towards which costs could be saved if output were to be increased. This may be achieved by looking at the cost elasticity with respect to output.

The elasticity of cost with respect to output for drying was computed at -0.4219. This value indicates that a 1% increase in drying output will decrease costs by 0.42%.

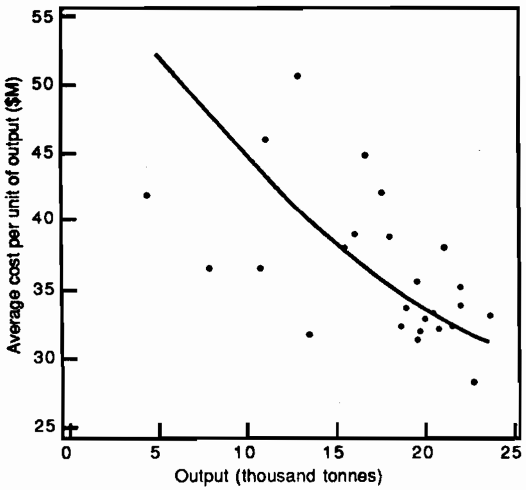

Fig. 1. Drying cost curve for paddy, relating drying output and average cost per unit of output.

Milling

Milling of rice involves the removal of the husk and the outer bran layer in order to produce polished rice. On the average, the output of the milling process consists of about 20% husk, 8% bran, and around 65% milled rice, with the balance representing losses.

The total average cost of milling is $27.52 per tonne (Table 5). This contributes 28% of the total rice processing cost. Lower milling costs were noted for complexes which belong to Phases III and IV (Tables 1-4).

As attempted with the average drying cost model, various forms of average milling costs functions were also estimated. Based on the same criteria, the 'best' equation for the average milling cost model was selected as:

$$MC = 118.1040 - 16.9107MQ + 0.8436MQ^2$$
$$(7.9001) \quad (-3.9245) \quad (2.9999)$$

$R^2 = 0.5981$ $\qquad$ $F = 16.3720$

Values in parentheses are t-statistics

MC = average milling cost per tonne

MQ = milling output in unit of thousand tonnes

All estimated coefficients are significant at the 1% level. The estimated results for average

TABLE 3. Processing costs[a] per tonne of paddy for Phase III

	Buying	Drying	Milling	Admin.	Total
Fixed Cost					
Emolument	2.45	3.29	6.32	12.99	25.05
Depreciation		9.00	4.62	0.36	13.98
Insurance				0.43	0.43
Total fixed cost	2.45	12.29	10.94	13.78	39.46
Variable Cost					
Handling	2.56	5.03	0.08	0.18	7.85
Direct labour	1.33	3.07	2.26		6.66
Electricity		5.66	6.71	0.96	13.33
Generator fuel		6.66	0.12		6.78
Repairs/parts	0.74	3.20	3.91	1.43	9.28
Others				7.35	7.35
Total variable cost	4.63	23.62	13.08	9.92	51.25
Total cost	7.08	35.91	24.02	23.70	90.71

[a]Costs are in Malaysian ringgit ($M). During October 1987, $M25 = US$1.

TABLE 4. Processing costs[a] per tonne of paddy for Phase IV

	Buying	Drying	Milling	Admin.	Total
Fixed Cost					
Emolument	2.52	2.02	1.74	9.26	15.54
Depreciation		11.56	7.96	0.67	20.19
Insurance				0.28	0.28
Total fixed cost	2.52	13.58	9.70	10.21	36.01
Variable Cost					
Handling	2.85	5.04	0.10	0.04	8.03
Direct labour	1.53	3.27	2.69		7.49
Electricity		5.77	5.65	0.82	12.24
Generator fuel		7.33			7.33
Repairs/parts	0.67	2.40	4.25	0.51	7.83
Others				5.51	5.51
Total variable cost	5.05	23.81	12.69	6.88	48.43
Total cost	7.57	37.39	22.39	17.09	84.44

[a]Costs are in Malaysian ringgit ($M). During October 1987, $M25 = US$1.

TABLE 5. Processing costs[a] per tonne of paddy for all complexes

	Buying	Drying	Milling	Admin.	Total
Emolument	2.65	3.24	7.01	14.08	26.98
Depreciation		8.89	5.79	0.41	15.09
Insurance				0.46	0.46
Total fixed cost	2.65	12.13	12.80	14.95	42.53
Variable Cost					
Handling	2.62	5.89	0.38	0.14	9.03
Direct labour	1.47	3.69	3.37		8.53
Electricity	5.18	6.54	1.10	12.82	
Generator fuel	6.99	0.25		7.24	
Repairs/parts	0.78	2.87	4.18	1.48	9.31
Others				7.63	7.63
Total variable cost	4.87	24.62	14.72	10.35	54.46
Total cost	7.52	36.75	27.52	25.30	97.09

[a]Costs are in Malaysian ringgit ($M). During October 1987, $M25 = US$1.

milling cost suggest that, in general, there is support for the negative relationship of average cost with output volume. The estimated coefficient for MQ is consistent with *a priori* expectation. The negative coefficient obtained for MQ^2 is indicative of the presence of cost economies. That is, there is a reduction in the average cost as milling output is increased. The nature of size economies may be seen further by drawing the actual and estimated cost curves. The estimated cost curve (Fig. 2) appears to take the typical U shape.

As for the previous activity, it can be of interest to consider the cost saving if milling output were to be increased. This may be achieved by looking at the cost elasticity with respect to output, which was computed as −0.7867. This figure indicates that a 1% increase in milling output will reduce the milling cost by 0.78%.

Administration

This activity involves clerical work, office supplies, and all management side expenses, including managers' salaries.

The total average cost for administration is $25.30 per tonne (Table 5). This constitutes 26% of the total average rice processing cost. Comparing the phases, it is evident that the later phases have much lower costs (Tables 1–4).

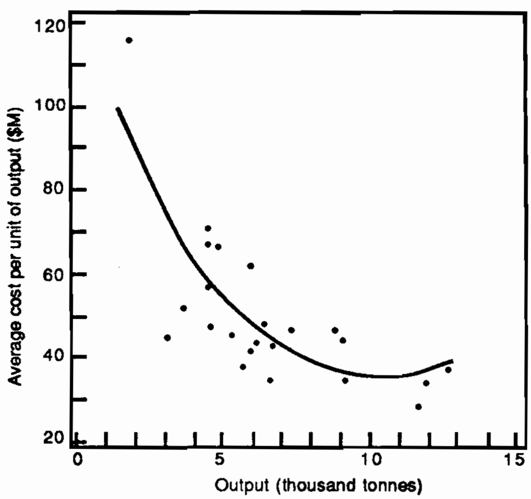

Fig. 2. Milling cost curve for paddy, relating milling output and average cost per unit of output.

Total Processing Costs

Adding all the total average costs for processing activities, the total average rice processing costs amounts to $97.09 per tonne (Table 5). The major components are handling and direct labour, which take up 18% of the total rice processing cost, while energy (electricity and generator fuel) contributes about 21%. Depreciation of buildings and equipment makes up 16% of the total rice processing cost. Emolument is the largest single component, with 28% of the total processing cost. Total processing costs are much lower in complexes which belong to the later phases.

Conclusions

In this paper we have presented an estimate of rice processing costs for the four activities of buying, drying, milling, and administration. We have also presented estimates of the average cost functions for drying and milling.

Our analysis of the per unit rice processing costs as a whole revealed that emolument is the largest component constituting 28% of the total processing costs. Energy (electricity and generator fuel) makes up 21% of the total processing cost, while depreciation contributes 16%.

Drying takes the largest share of the total rice processing costs with 38%. About 33% of the drying cost is spent on energy. In fact, energy has been noted to be a major cost component in several other studies (e.g. Ghaffar and Hassan 1985; Fredericks and Wells 1983; USDA 1973).

Results from the cost function estimations for both drying and milling indicate that cost economies were present. Cost economies were exhausted at a fairly high output level. Further examination of the cost output data indicates that 13% of the drying output was operated at a level less than 15 500 tonnes, while 26% of the milling output was produced at a level less than 5600 tonnes. This finding is similar to that of an earlier study we conducted (Ghaffar and Hassan 1985), which indicated that a substantial proportion of rice processing complexes operate at volumes that leave substantial cost economies unexploited.

In addition, it is clear that the more recently commissioned rice processing complexes have very significantly lower total average costs. Ghaffar and Hassan (1985) and Runte and Ali (1973) made the same finding.

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A Model of the Paddy and Rice Industry in Tanjung Karang, Malaysia Based on the Current Marketing Chain

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Abstract

Delay in processing wet paddy and improper handling methods cause losses in paddy production. A model is developed to capture the diverse elements in the paddy postharvest system. The model is basically a linear programming model with the objective function of maximising net industry revenue subject to constraints. Specifically, the objective function is to maximise net industry revenue after deduction of all costs involved in the industry, such as purchasing costs, milling costs, drying costs, queuing costs, storage costs, and transportation costs. The model constraints consist of thirty-one equations related to paddy and rice flow, capacity, queuing, handling, pricing, supply, and demand constraints.

The short-run economic situation is simulated in the model to find the optimal solution by rationalising the existing handling facilities. Results obtained from the model will show the optimal flows of paddy and rice between production areas, procurement centres, mills, and final markets, together with the costs involved in each of the activities. The model results were first calibrated against actual grain flows in the Tanjung Karang area. It was found that the theoretical results were 'sufficiently close' to the actual grain flows to justify confidence in the validity of the model. The model is also capable of analysing whether other systems of handling paddy and rice can be applied. This can be done by inflicting changes in selected parameters used in the model.

SINCE 1957, the paddy and rice industry in Malaysia has undergone rapid extension, stimulated by a range of government subsidies in the form of price supports, irrigation and infrastructure developments, research and extension, farmer training, farm mechanisation, credit and input subsidies, as well as processing and marketing facilities. Since then the Malaysian Government has granted subsidies of not less than $M2000[1] million to this sector (Alwi 1986).

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The government investment had a positive effect on paddy production in Malaysia. In 1960, about 303 000 hectares of land were planted with paddy, producing 756 000 tonnes of paddy. By 1981, the total planted area had risen to 561 000 hectares. The increase was mainly due to the rise in the off-season crop as a result of double cropping. The percentage of double cropping rose from 2.8% in 1960 to 73% in 1981, producing 1.7 million tonnes of paddy. However, since 1983 the total planted area has declined. The decline is mostly due to late

[1] During October 1987, $M2.50 = US$1.

planting of off-season crops and the domestic policy of concentrating production in the more cost-efficient areas (Ministry of Finance 1987). According to Ministry of Agriculture statistics, Peninsular Malaysia has been producing, on average, about 1.65 million tonnes of paddy annually, 44% of this being from the off-season crop. Paddy planted in the main season is generally harvested during the months of February to April, which are in the dry season. The off-season crop is normally harvested during the months of July to October, which are in the wet season.

The increase in paddy area planted with double crops has in general benefitted the various parties involved in the industry, particularly the paddy farmers. However, this situation has an adverse effect on Malaysian paddy postharvest handling facilities. This is because the existing facilities are inadequate to process the paddy during peak harvesting periods. The problem is further aggravated by the increasing amount of paddy produced during the off-season periods, where paddy is normally harvested with a higher moisture content (Leong and Fredericks 1986).

Currently, there are 34 LPN (Lembaga Padi dan Beras Negara; National Paddy and Rice Authority) complexes and 258 private mills involved in the purchasing of paddy in Peninsular Malaysia. In 1986, private mills purchased about 1.3 million tonnes of paddy. Their total drying capacity is about 897 000 tonnes per year (Ministry of Finance 1987). Of the 34 LPN complexes, 22 of them are integrated complexes with facilities for drying and milling. The total amount of paddy purchased by LPN complexes was 560 100 tonnes in 1985 and 630 900 tonnes by 1986 (LPN 1986). The unusually large amount of paddy purchased in 1986 resulted in many of the complexes being loaded with more paddy than they could handle. The average operating drying capacity per day is about 136 to 160 tonnes and the average maximum capacity about 184 to 296 tonnes per day. The inadequate handling facilities resulted in queuing at LPN complexes during peak harvesting periods[2].

[2]Reported in the New Straits Times, 2 January 1986.

Postharvest losses in Malaysia range from 10 to 37%. About 10% of the losses are unavoidable and the remaining 27% may be recovered with improved handling facilities. Losses during manual handling at harvesting have been reported to be as high as 20%, while losses during threshing, drying, and storage are between 5 and 17%. Losses during milling have been recorded at between 2 and 10%. The major causes of grain loss and damage are attributed to improper methods of grain handling and inadequate drying facilities (Leong and Fredericks 1986).

Farmers also have to pay $M3–6 per bag of paddy transportation costs. Assuming a yield of 4 tonnes per hectare the transportation cost alone will be $M180–300 per hectare (Ali and Fa 1986).

In summary then, the paddy and rice industry in Malaysia is facing three major problems. There is a handling and transportation problem related to the methods of handling and the types of transport used in moving the paddy from the fields to the processing complexes. Inadequate handling facilities cause queuing and delays in drying wet paddy, resulting in a reduction of the quality of rice produced. A processing problem is associated with the production of low quality rice and the time taken to re-polish old stocks of rice. A marketing problem is related to the difficulties in selling the low quality rice produced.

The basic objective of the study reported here was to develop a model that can be used to analyse the transportation system for paddy and rice in Tanjung Karang, Malaysia. The model is capable of determining the optimum flows of paddy and the optimum capacities of various handling facilities in the system. A short-run economic situation will be assumed in determining the optimum solution, by rationalising the size, number, and location of paddy handling facilities. The model can be further extended to:

- analyse the effect of changes in the decision variables if other handling systems need to be introduced; and
- conduct sensitivity analyses.

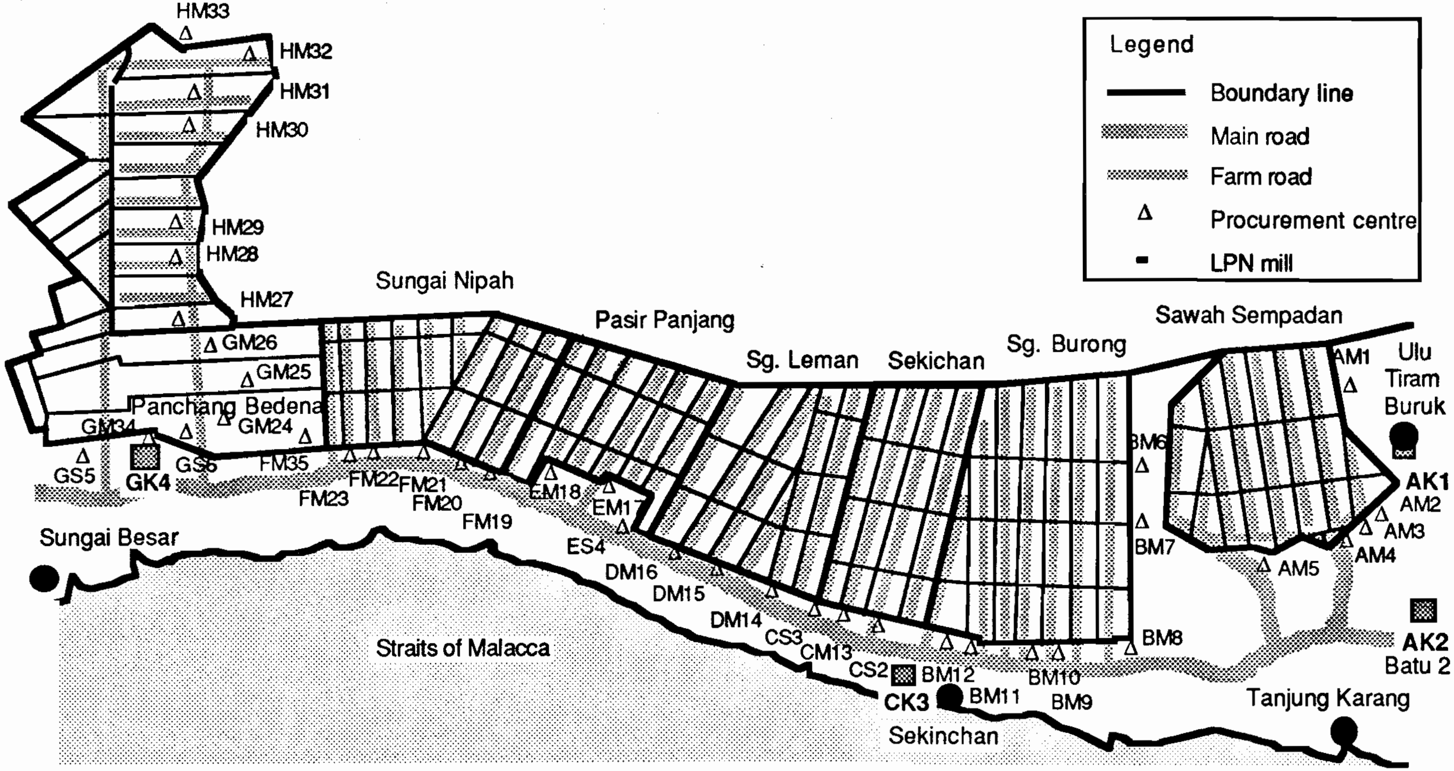

Fig. 1. Project area, consisting of some 100 200 hectares in the Tanjung Kerang area of Selangor Darul Ehsan, Malaysia. Also shown on this map is the subdivision of the production area used in developing the model.

Postharvest Operations for Paddy and Rice in Tanjung Karang

Postharvest operations for paddy and rice in Tanjung Karang are used as the basis for modelling the paddy and rice industry in Malaysia. The study area is part of the Northwest Selangor Integrated Agriculture Development Project, begun in 1978. The project covered an area of 100 200 hectares in the districts of Sabak Bernam and Kuala Selangor, as shown in Figure 1. About half of the farmers in the area are sole-crop farmers and half mixed-crop. The average farm size of sole-crop farmers, most of whom are paddy growers, is 1.55 hectares. There are 19 500 farm households in the project area with an average of six persons per farm family. Some 5900 farm households are involved in paddy cultivation, over an area of 19 600 hectares.

The postharvest operations can be illustrated as in Figure 2. Paddy from production areas is transported either to procurement centres and then to LPN mills or direct to LPN mills. At the mills, paddy will be processed before being transported to final markets. For the purpose of model construction, the eight production areas in Tanjung Karang are further divided into 147 blocks based on 100 farm households per block (see Fig 1). It is assumed that about 80% of the paddy produced is marketed while the remaining 20% is kept by farmers for their own consumption.

Farmers can sell their paddy either to procurement centres or directly to mills. The transport vehicles used for carting the paddy are motorcycles and small lorries. The capacity of small lorries ranges between 1 and 10 tonnes. There are 41 procurement centres in the area managed by 31 farmers' cooperatives and 6 farmer associations acting as buying agents for LPN mills. There are also four LPN mills operating in the area, at Ulu Tiram Buruk, Sekinchan, Batu Dua, and Sungai Besar. Transportation of paddy from the procurement centres to the mills is usually by lorries with capacities of 10–20 tonnes. Transportation costs are calculated based on the distance per trip and the quantity transported. The distances from the supply points to the procurement centres and mills are measured from the mid-point of each supply block, to reflect average distances over the blocks. At the mills, the paddy purchased will go through the process of weighing, grading, unloading, and drying before being stored or milled. The rice produced is then transported to the four final markets at Kuala Lumpur, Melaka, Seremban, and Klang.

Model Specification

The model used in this study is basically a linear programming model with the objective function of maximising the net industry revenue subject to constraints. Results from the model will show the optimal flows of paddy and rice from fields to procurement centres, mills, and final markets, as well as giving a total cost for each of the activities such as milling, drying, transportation, storage, and purchasing cost of paddy. The model was initially developed by Ryland and Guise (1975) to solve a spatial and deterioration problem in the sugar industry in Australia. The major extension from that model is the inclusion of storage and drying facilities and a parameter for rice recovery rate.

The model can be used to simulate three different economic environments covering long-run, short-run, and intermediate situations. From the industry planning viewpoint, the long-run and intermediate case are not applicable, because the existing facilities cannot immediately be redesigned to implement the optimal solution. Therefore, the short-run situation is considered in this study. In using a short-run approach, the locations, numbers, and sizes of existing handling facilities are assumed. The operating and transportation costs are considered in the model: only capital cost is ignored. The objective is to determine the flow activities among supply points, procurement centres, mills, and final markets. Gains from the solution will arise from rationalising the flow patterns and the trade-off between operating costs of handling facilities and transportation costs.

The objective function of the model can be stated as maximising the annual net industry revenue less all the postharvest costs, such as purchasing costs of paddy, transportation, drying, and milling and storage costs of paddy and rice. Specifically, the objective function can be defined as follows:

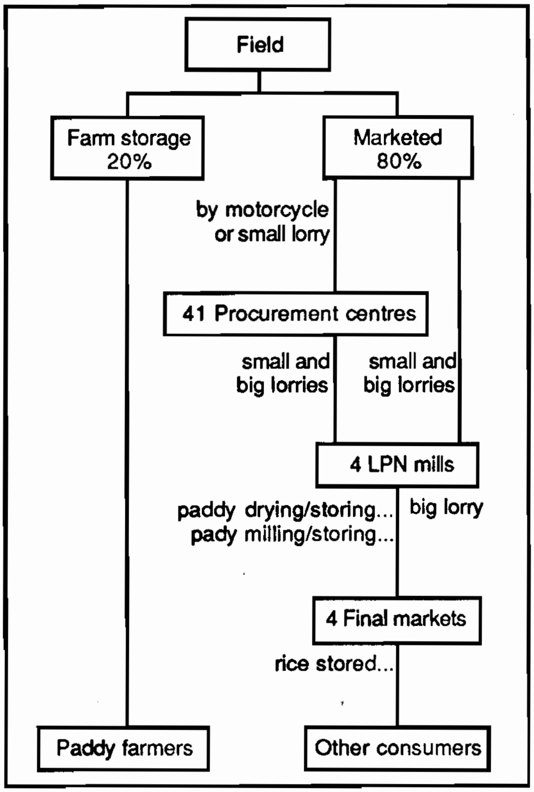

Fig. 2. Diagram of the paddy and rice transportation system in Tanjung Kerang, Malaysia.

$$\begin{aligned} \text{Max} = {} & P^t_{rg}RD^t_g - P^t_wWT^t_{i,jk} - P^t_dDT^t_{i,jk} \\ & - A^t_{ijk}\,[WT^t_{ijk} + a^{-1}DT^t_{ijk}] \\ & - A^t_{klg}\,[RT^t_{klg}] - B^t_{ijk}\,[S^{t,t+1}_{ijk}] \\ & - BR^t_{klg}\,[R^{t,t+1}_{klg}] - C^t_{ijk}\,[D^t_{ijk}] \\ & - E^t_{kg}\,[Y^t_{kg}] \end{aligned}$$

The variables presented in the objective function are defined as follows:

i, j, k, l, g : supply region (i), procurement centre (j), LPN mill (k), final market (l), and rice grade (g)

t : t = 1, 2, 3, 4 denote time period, t = 1, 3 represent harvesting periods, and t = 2, 4 represent postharvest periods.

Pr : market price of different grades of rice.

RD : demand of different grades of rice.

Pw and Pd : price for wet and dry paddy paid to producer.

WT and DT : quantity of wet and dry paddy transported.

Rt : quantity of rice of different grades transported.

S and R : quantity of rice and paddy stored.

D : quantity of paddy dried.

Y : quantity of paddy milled into different grades.

A, B, C, E : represent assembly, storage, drying, and milling costs respective.

a : parameter for converting dry paddy to wet paddy.

DC, YC, SC, RC, and HC : represent drying capacities, milling capacities, paddy storage capacities, rice storage capacities, and handling capacities, respectively, at various locations.

The objective function specified above is subjected to various constraints as stated below. Equations (1) to (10) are related to paddy and rice flow constraints, equations (11) to (24) to capacity constraints, equations (29) to (33) to queuing and handling costs, and equations (34) and (35) to paddy prices. In addition, the last two equations are used to ensure supplies do not exceed demand. The model also contains adjustable parameters α, β, and σ. In the model application, α is used for converting dry paddy to wet paddy, β is used as a quality adjuster for milled rice, and σ is the utilisation factor relating receivals of paddy and rice to handling capacity.

Paddy and Rice Flow Constraints

(1) $SS^t_i > WT^t_{ij} + WT^t_{ik} + \alpha^{-1}{}_i[D^t_i]$

Equation (1) states that the supplies of wet paddy made available to procurement centres (j) and LPN complexes (k) plus the quantity dried in the regions (i) cannot exceed regional supplies of paddy (SS).

(2) $Wt^t_{ij} > WT^t_{jk} + \alpha^{-1}{}_j\,[D^t_j]$

Equation (2) states that the supplies of wet paddy made available to LPN complexes (k) plus the quantity dried at the procurement centres (j) cannot exceed the total availability of wet paddy to procurement centres (j).

$$WT^t_{ik} + WT^t_{jk} > \alpha^{-1}_k[D^t_k] \quad (3)$$

Equation (3) states that the quantity of wet paddy dried at the LPN complexes (k) cannot exceed the total availability of wet paddy to the LPN complexes (k).

$$S^{t-1,t}_i + D^t_i > DT^t_{ij} + DT^t_{ik} + S^{t,t+1}_i \quad (4)$$

Equation (4) states that the supplies of dry paddy made available to procurement centres (j) and LPN complexes (k) plus that quantity placed into storage at regions (i) at the end of period (t) cannot exceed the total availability of dry paddy at regions (i).

$$S^{t-1,t}_j + D^t_j + DT^t_{ij} > DT^t_{jk} + S^{t,t+1}_j \quad (5)$$

Equation (5) states that the supplies of dry paddy made available to LPN complexes (k) plus the quantity placed into storage at procurement centres (j) at the end of period (t) cannot exceed the availability of dry paddy at procurement centres (j).

$$S^{t-1,t}_k + D^t_k + DT^t_{ik} + DT^t_{jk} > S^{t,t+1}_k + Y^t_{kg} \quad (6)$$

Equation (6) states that the quantity of paddy milled and stored at LPN complexes, cannot exceed that total availability of dry paddy at LPN complexes (k).

$$\sigma_k Y^t_{kg} + R^{t-1,t}_{kg} > RT^t_{klg} + R^{t,t+1}_{kg} \quad (7)$$

Equation (7) states that the supplies of different grades of rice made available to final markets (l) plus quantity of different grades of rice placed into storage at LPN complexes cannot exceed the total availability of different grades of rice at private mills (k).

$$RT^t_{klg} + R^{t-1,t}_{lg} > RD^t_{lg} + R^{t,t+1}_{lg} \quad (8)$$

Equation (8) states that the supplies of rice made available to meet final market demand for rice plus the quantity stored at the market place (l) cannot exceed the total availability of rice at final markets (l).

Capacity Constraint

$$D^t_* < DC_* \quad \text{for all } * = i, j, \text{ and } k \quad (9\text{-}11)$$

Equations (9) to (11) state that the quantity of wet paddy dried at each region (i), procurement centre (j), and LPN complex (k) cannot exceed the respective drying capacity (DC) in each time period.

$$Y^t_{kg} < YC_k \quad \text{for all } k, g \quad (12)$$

Equation (12) states that the quantity of paddy milled at LPN complexes into different grades (g) cannot exceed the milling capacity at the complex (YC) in each time period.

$$S^t_* < SC_* \quad \text{for all } * = i, j, \text{ and } k \quad (13\text{-}15)$$

$$R^t_{*g} < RC_{*g} \quad \text{for all } * = k, g, \text{ and } l \quad (16\text{-}18)$$

Equations (13) to (15) and (16) to (18) state that the quantity of paddy stored (S) at each region (i), procurement centre (j), and LPN complex (k) cannot exceed the respective storage capacity (SC). Similarly, the quantity of rice of different grades stored (R) at LPN complexes (k) and final markets (l) cannot exceed the respective storage capacity for different grades (RC).

Throughput Constraints Relating to Handling Capacity

$$WT^t_{ij} + \alpha^{-1}_j [DT^t_{ij} + S^{t-1}_j] < \delta_j HC_j \quad (19)$$

Equation (19) states that the quantity of wet and dry paddy received at each procurement centre (j) during each time period, plus carryovers, must not exceed some multiple j of the handling capacity at each centre.

$$WT^t_{ik} + WT^t_{jk} + \alpha^{-1}_k [DT^t_{ik} + DT^t_{jk} + S^{t-1,t}_k] < \delta_k HC_k \quad (20)$$

Equation (20) states that the quantity of wet and dry paddy received and stored at each LPN complex must not exceed some multiple k of the complex's handling capacity, during each time period.

(21) $RT^{t}_{klg} + R^{t-1,t}_{lg} < \delta_l \, HC_l$

Equation (21) states that the quantity of rice receivals at the markets plus previous time period carryovers must not exceed some multiple (l) of the handling capacity at the market for milled rice.

Receival Constraints Relating to Queuing Costs

(22) $WT^{t}_{ij} + \alpha^{-1}_{j} \; DT^{t}_{ij} - RC^{t}_{j} < 0$

Equation (22) states that the receivals of wet and dry paddy at procurement centres (RCj) must not be exceeded by the flows to the centres (j).

(23) $WT^{t}_{ik} + WT^{t}_{jk} + \alpha^{-1}_{j} \, [DT^{t}_{ik} + DT^{t}_{jk}] - RC^{t}_{k} < 0$

Equation (23) states that the quantity of wet and dry paddy transported to LPN complexes (k) from all sources must not exceed total receivals at these centres. Equations (22) and (23) are purely to collect receivals for the purpose of determining queuing cost function.

Throughput Constraints Relating to Handling Costs

(24) $WT^{t}_{ij} + WT^{t}_{jk} + \alpha^{-1}_{j} \, [DT^{t}_{ij} + DT^{t}_{jk}] - Q^{t}_{j} < 0$

Equation (24) states that the receival and outloadings of wet and dry paddy at procurement centres (j) must not exceed throughput (Qj) at these centres, in each time period.

(25) $WT^{t}_{ik} + WT^{t}_{jk} + \alpha^{-1}[DT^{t}_{ik} + DT^{t}_{jk}] + \alpha^{-1}\sigma^{-1}RT^{t}_{klg} - Q^{t}_{k} < 0$

Equation (25) states that the receival and outloadings of wet and dry paddy and different grades of rice at LPN mills (k) must not exceed throughput (Qj) at these mills, in each time period.

(26) $RT^{t}_{klg} + RD^{t}_{lg} - Q^{t}_{l} < 0$

Equation (26) states that the receival and outloadings of different grades of rice at the final marketplaces (l) must not exceed throughput (Ql) at these places, in each time period.

Grower Deliveries—Relating to Paddy Prices

(27) $WT^{t}_{i*} - IRC^{t}_{*} < 0$ when $t = 1$

Equation (27) states that the flows of wet paddy from supply region i to procurement centres or LPN complexes (* = j, k) must not exceed wet paddy deliveries to these centres, when t = 3 the above equation becomes:

$WT^{t}_{i*} - 2RC^{t}_{*} < 0$

(28) $DT^{t}_{i*} - ARC^{t}_{*} < 0$ when $t = 1, 2, 3,$ and 4 and $A = t + 2$ over all t.

Equation (28) states that the flow of dry paddy from supply region i to procurement centres or LPN complexes (* = j, k) must not exceed dry paddy deliveries to these centres over time.

Demand Related Equation

(29) $RT^{t}_{klg} + R^{t-1,t}_{lg} - R^{t,t+1}_{lg} - RDT^{t}_{lg} < 0$

Equation (29) is the same as equation (8), other than that rice demand is now collected from flows within the model (RDT), not as an exogenously determined (RD) variable.

(30) $RDT^{t}_{lg} < RD^{t}_{lg}$

Equation (30) ensures that supplies do not exceed demand at the marketplace.

Model Application

The solution based on the 'best available' coefficients was derived after consultations with LPN. The values for the key coefficients used are given in Appendix 1. This run represents the normative optimal paddy and rice flows in the Tanjung Karang area that would occur under competitive market conditions given current technology. We need to compare the results of this run with field data on actual paddy and rice flows to validate the model and to provide explanations for any discrepancies that may occur between model results and actual occurrences.

First, we looked at the overall paddy flows. The LPN figures are compared with model results in Table 1. The model results are reasonably close to LPN records. In the model, 27% of paddy goes directly from field to mill compared with an average (for 1985 and 1986) of 28% for LPN records. What is important is that there is an 'inconvenience cost' in the model of an extra $M3.00 per tonne attached to the field to mill route. In other words, from a farmer's viewpoint, it is 'more convenient' by $M3.00 per tonne to deliver paddy to procurement centres, which are nearby and where there is less queuing compared with delivering paddy to mills. This is so even if the field to mill route is shorter than the field to procurement centre to mill route. Farmers are charged paddy transport costs, including the cost of carrying paddy from procurement centres to mills in LPN vehicles.

Next, the specific routes in terms of paddy moving from specific procurement centres to specific mills, as derived from the model, were compared with actual paddy flows as given in LPN records. This comparison is shown in Appendix 2. Two observations emerge from this comparison. Firstly, in our model, paddy from any procurement centre goes to only one mill, whereas LPN records show paddy from one procurement centre going to several mills. Given the linearity assumption in our model, we can expect a single destination for paddy from any one procurement centre, unless we have reached the limit of capacity in a particular mill. Secondly, a certain amount of 'misallocation' of paddy flow is apparent in the LPN data. A clear example can be seen in Appendix 2 where paddy from procurement centres FM20 and FM21 (for season 2/85) goes to various mills but not to CK3, which is the closest. In the model, paddy from the procurement centres cited goes to CK3. It is clear, therefore, that LPN directs paddy from its various procurement centres to its various mills on the basis of considerations other than transport cost minimisation. We learnt that LPN frequently directs paddy from a procurement centre to a distant mill if that mill happens to be short of paddy at a particular time. LPN keeps records of transportation costs for moving paddy from procurement centres to mills. For equivalent weights of paddy moved, we computed that LPN incurs an 'excess cost' of about $M361 776 in transport, compared to the cost given by the model (see Table 2 and later discussion of cost components).

TABLE 1. Paddy flows from field to mill: comparison of model results and LPN records (%).

Routes	From LPN records 1985	1986	Basic run results
Field to procurement centre to mill (i-j-k)	78.06	64.99	72.52
Field to mill (i-k)	21.94	35.01	27.48

In the next stage of the analysis, we broke up the net industry loss into its various components and evaluated these components against comparable LPN data, where possible. This is shown in Table 2. We do not expect identical correspondence between model results and LPN records. Given the type of data we are using, we consider any divergence less than 20% as acceptable. Differences greater than 20% need to be explained.

The lower revenue received by LPN from sales of rice, compared with our theoretical results, reflects the lower grades of rice it produces. In Tanjung Karang, this is not a particularly serious problem, as it is reported (LPN 1986) that only 7% of rice produced is of lower grades. However, in other parts of the country (e.g. Kedah) as much as 44% is reported to be of lower grades. In this case, the 36% discrepancy in income (Table 2) is overstated. The model result is a theoretical maximum and is unlikely to be achieved in actual practice.

Why LPN produces large quantities of low grade rice is too complex an issue to be discussed here. Suffice it to say that LPN mills are not run in the same way as private commercial mills where profit maximisation is the only motive.

TABLE 2. Cost components: model solution versus LPN records

Space	Model	LPN	Model-LPN	%
Income				
Sale of rice	35 598 992	22 943 265	12 655 727	35.55
Costs				
Purchase of paddy	26 892 293	26 764 013	128 280	0.48
Subsidy payment	9 190 062	9 190 062		
Milling cost	1 352 877	1 272 159	80 718	5.96
Drying cost	2 241 818	1 856 657	385 161	17.18
Handling cost	381 404	440 51	–59 160	–15.49
Paddy transport cost (i-j-k)	1 066 241	1 428 017	–361 776	–33.93
Paddy transport cost (i-k)	493 207	n.a.		
Rice transport cost	712 427	n.a.		
Queuing cost	1 519 952	n.a.		
Paddy storage cost	66 291	n.a.		
Rice storage cost	13 151	n.a.		
Commission	not considered	835 460		
Net industry loss	8 330 731	n.a.		

Notes:

(a) All figures are in Malaysian ringgits ($M). During October 1987, $M25 = US$1.

(b) LPN figures were adjusted linearly to correspond to the same amounts of paddy and rice handled in the model, i.e. 62 938 tonnes of paddy (at 24% moisture content) and 36 203 tonnes of rice.

(c) LPN figures were for the year 1986, for which complete records for all the four mills are available. 1986 is not special in any way; hence the figures for that year can be considered representative.

(d) For LPN figures, administration cost was subdivided and allocated to handling cost, drying cost, and milling cost in the ratio of 20%, 40%, 40%, respectively.

(e) LPN pays a commission to procurement centres at the rate of $M15 per tonne of paddy purchased. The procurement centres belong to farmers' cooperatives. The centres act as LPN agents.

(f) n.a. = not available.

Looking at drying cost, the model figure is about 17% higher than the LPN cost. The LPN cost does not include depreciation in infrastructures and capital equipment. Allowing 5% for depreciation, our figure is higher by about 12%. Thus, we can conclude that the value of $40.25 per tonne that we used for drying in our model was somewhat high. Discounting $M40.25 by 12%, we obtained $M32.42 per tonne for drying cost, which may be more appropriate.

As noted previously, there is a considerable amount of transfer of paddy among mills and from procurement centres to distant mills. The LPN cost for transportation, for equivalent amounts of paddy moved, is 33% higher than the cost derived from our model. There is therefore a sizeable increase in social welfare of over $M361 776 that is potentially realisable if the routine used in directing paddy flows were improved.

The other items, rice transport cost, queuing cost, and paddy and rice storage costs are either paid for by clients or are implicit costs for which records are not kept by LPN. All these costs totalled $M2 689 181, which we consider is excessive. In the model, we assume a queuing cost of $M14.00 per tonne at the procurement centres. This may be somewhat unrealistic. If we make allowance for this overestimation, we obtain a total cost of around $M2.3 million.

There is a discrepancy of 15% in handling cost. We assumed a value of $M6.06 per tonne for handling cost. LPN figures give a handling cost of $M7.00 per tonne. The handling cost is made up mainly of the cost of labour for loading and unloading vehicles at procurement centres or mills. If we assume a handling cost of $M1.00 per bag, this works out at around $M12.00 per tonne. Hence, we believe that the handling cost used in the model is too low.

The model gives a net industry loss of $M8 330 731. Considering that we have overvalued income obtained from sale of rice and have not included commission paid to procurement centres, a better estimate of the net industry loss would be $M10–11 million. This loss pertains to 62938 tonnes of paddy at 24% moisture content passing through the model. It is difficult to assess whether the estimated net industry loss is reasonable or not. The best we can do is compare it with the government grants given to LPN every year. In its 1985 Annual Report, LPN reported a deficit of $M221 million. This works out to a net industry loss of about $22 million compared with our figures of $M8.3 million, for equivalent volumes of paddy.[3]

It is interesting to look at the cost components in terms of percentages (Table 3). What is remarkable in Table 3 is the high proportion (82%) of the farmer's share of the total cost. In this case, the farmer's share of the consumer dollar cannot be evaluated, as returns to processing cannot be determined, but it would certainly be high. The critical importance of the price paid to farmers, compared with other cost components, is thus obvious.

On the whole, we can accept that the model is a valid representation of reality in Tanjung Karang. Where discrepancies exist between the

TABLE 3. Cost components as percentages of total cost.

Components	Cost of component as % of total cost
Purchase of paddy	61.4
Subsidy payment	20.6
Milling cost	3.1
Drying cost	5.1
Handling cost	0.9
Paddy transport (i-j-k)	2.4
Paddy transport (i-k)	1.1
Rice transport	1.6
Queuing	3.4
Paddy storage	0.2
Rice storage	0.0

Notes:

(a) As explained earlier, drying cost may be overstated and handling cost understated.

(b) Paddy transport (i-j-k) refers to field to procurement centre to mill route, whilst paddy transport (i-k) refers to the field to mill route.

[3]This comparison cannot be taken too literally, as LPN undertakes many activities, including maintenance of essential stockpiles of rice, curbing smuggling, and so on. Thus, the $22 million cited is not for paddy processing alone.

model's results and LPN records, they can be easily explained.

Conclusion

The final model has a matrix size of 3743 rows and 14 936 columns. The solution is obtained through AESOP package running on an IBM mainframe computer. The results of the optimal solution shows the transportation network for paddy and rice which will maximise the net industry revenue. It also determines the costs of various activities in the industry. The results of the model were first calibrated against appropriate field data so that its weaknesses could be identified. On the whole, the model produces plausible and acceptable results. The model can also be used to assess the feasibility of introducing new systems, such as bulk handling. This can be done by inflicting changes in selected parameters.

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Appendix 1. Capacity Used in the Model

Item	Amount (tonnes)
Paddy production per hectare	3.2
Drying capacity:	
AK1	12 375.0
AK2	12 375.0
CK3	12 375.0
GK4	6 187.0
Milling capacity:	
AK1	4 800.0
AK2	4 800.0
CK3	4 800.0
GK4	2 400.0
Storage capacity (paddy):	
AK1	10 000.0
AK2	10 000.0
CK3	10 000.0
GK4	5 000.0
Storage capacity (rice):	
AK1	1 500.0
AK2	1 500.0
CK3	1 500.0
GK4	800.0
Kuala Lumpur	12 000.0
Kelang	8 000.0
Seremban	8 000.0
Malacca	12 000.0
Handling capacity (receiving and storage):	
AK1	20 140.0
AK2	20 030.0
CK3	20 140.0
GK4	20 030.0
Kuala Lumpur	10 180.0
Kelang	10 170.0
Seremban	10 180.0
Malacca	10 170.0
Each procurement centre	2 000.0

Notes
LPN complexes: AK1—UTB (Ulu Tiram Buruk); AK2—Batu 2; CK3—Sekinchan; GK4—Sungai Besar.
Rice demand in final market is calculated based on following percentages: Kuala Lumpur 80%; Kelang 10%; Seremban 5%; Malacca 5%.

Price of rice at final market ($M/tonne)

	Kuala Lumpur	Kelang	Seremban	Malacca
Grade 1	1070	1070	1080	1090
Grade 2	990	990	1000	1010
Grade 3	910	910	920	930
Grade 4	1010	1010	1020	1030
Grade 5	940	940	950	960
Grade 6	860	860	860	880
Grade 7	740	740	750	760
Grade 8	660	660	670	680

Costs used in the model

Cost	i-j	j-k ($M/tonne)	i-k
Queuing	14.00	14.00	14.00
Drying		40.25	
Milling		24.29	
Handling		6.06	6.06
Storage		1.00/month	
Paddy purchased		408.30	
Subsidy		165.00	
Rice recovery rate		65%	

Note: i = field; j = procurement centre; k = mill.

Appendix 2

Transport of paddy in Tanjung Karang: comparison of data collected and results from the model in season 1/85

Procurement centre	From the data collected in Tanjung Karang To LPN mills				From the model To LPN mills			
	AK1	AK2	CK3	GK4	AK1	AK2	CK3	GK4
AM1		297.0			2000.0			
AM2	202.2	352.2			366.6			
AM3	656.6	489.6		13.3	211.1			
AM4	245.1	645.6			611.0			
AM5	181.6	434.4		5.7	250.3			
BM6					2000.0			
BM7	269.2		86.4	48.2	1536.2			
BM8	385.9	104.3		11.7				
BM9	387.3	246.7	440.8			552.3		
BM10	751.5	71.6	1906.3		262.5			
BM11								
BM12							830.5	
CS1							716.4	
CS2							2000.0	
CS3							222.1	
CM13			1154.3				1589.7	
DM14	127.3	337.3	1087.8	102.3				
DM15	370.1	105.2	706.4	14.8			109.9	
DM16	383.1	287.5	1158.3				1347.9	
ES4								
EM17	324.6		867.7				2000.0	
EM18		348.6		103.1				
FM19	306.7			23.1			51.4	
FM20	348.4	416.2		31.2	1117.0			
FM21	151.6	681.3		161.8		650.6		
FM22	366.8	526.9		896.1				
FM23	460.9	436.6		228.7				
FM35				448.5				
GS5								
GS6								
GM24	464.3	382.9		679.7				
GM25	426.1	257.1		458.9				
GM26	339.4	235.2		68.3				
GM34	44.6	10.8		1239.9				2000.0
HM27	862.5	225.3		513.9		1083.3		
HM28	769.1	57.5		1578.5	314.4			
HM29	385.2	238.6				552.1		
HM30	478.7	404.7		952.8		669.8		
HM31	441.1	489.8		541.9				
HM32	482.1	449.9		880.5				
HM33								

AK1—Ulu Tiram Buruk; AK2—Batu 2; CK3—Sekinchan; GK4—Sungai Besar

Appendix 2 (continued)

Transport of paddy in Tanjung Karang: comparison of data collected and results from the model in season 2/85

Procurement centre	From the data collected in Tanjung Karang To LPN mills				From the model To LPN mills			
	AK1	AK2	CK3	GK4	AK1	AK2	CK3	GK4
AM1		195.0		6.7	1934.2			
AM2	236.2	245.3			467.8			
AM3	866.4	244.5		13.9				
AM4	282.0	235.9		13.6				
AM5	97.6	370.1		42.8	214.5			
BM6						2000.0		
BM7	149.7	559.1		10.6		1370.7		
BM8	119.9	572.7		67.2				
BM9	144.7	1064.9	517.6	130.1		534.8		
BM10	166.7	297.5	922.1	209.2		256.3		
BM11							620.8	
BM12							626.4	
CS1				306.2			881.9	
CS2							2000.0	
CS3								
CM13			1720.5				1775.1	
DM14	92.4	93.1	1012.5	125.9				
DM15	55.0	107.9	625.1	12.1			56.7	
DM16	618.3	60.7	699.7	60.1			1303.2	
ES4								
EM17	488.4		720.9				998.2	
EM18		493.4						
FM19	327.6	52.9		202.4				
FM20	66.9	364.1		246.8			1076.2	
FM21	264.4	337.3		547.4			417.3	
FM22	357.1	222.0		626.8				
FM23	176.2	194.7		426.5				
FM35				27.9				
GS5								
GS6								
GM24	85.4	270.3		464.3				
GM25	43.6	303.2		432.9				
GM26	22.0	59.0		421.7				
GM34				605.6				2000.0
HM27	41.3	429.7		1141.5		1133.4		
HM28	47.3	136.3		1346.1	407.6			
HM29	48.1	93.1			506.1			
HM30	12.5	263.4		944.7	1965.6			
HM31		686.7		1054.2				
HM32	82.3	276.2		1154.0				
HM33								

Appendix 2 (continued)

Transport of paddy in Tanjung Karang: comparison of data collected and results from the model in season 1/86

Procurement centre	From the data collected in Tanjung Karang To LPN mills				From the model To LPN mills			
	AK1	AK2	CK3	GK4	AK1	AK2	CK3	GK4
AM1		176.4		63.2	2000.0			
AM2	264.3	285.5		52.6	366.0			
AM3	822.3	291.3		129.0	211.1			
AM4	356.4	500.4		131.3	611.0			
AM5	377.6	155.6		59.9	250.3			
BM6					2000.0			
BM7	87.0	123.7		54.8	1536.2			
BM8	103.1	502.1		35.9				
BM9	202.4	191.1		46.3		552.3		
BM10	61.6		513.0	52.1	262.5			
BM11		506.1	1166.1					
BM12							830.5	
CS1							716.4	
CS2							2000.0	
CS3		782.7					222.1	
CM13				1495.4			1589.7	
DM14	67.2	353.5	985.8	5.3				
DM15		102.9	1398.9				109.9	
DM16	328.1	197.8	890.6	13.9			1347.9	
ES4								
EM17			755.9				2000.0	
EM18		282.1		201.2				
FM19	365.9	248.4		94.4			51.4	
FM20	169.0	224.9		191.7	1117.0			
FM21	509.5	386.7		227.8		650.6		
FM22	522.3	437.1		878.2				
FM23	552.8	702.5		219.3				
FM35				401.3				
GS5								
GS6								
GM24	340.9	520.3		548.7				
GM25	209.6	317.1		831.6				
GM26	165.3	396.6						
GM34		66.7		1232.2				2000.0
HM27	480.6	365.9		868.6		1083.3		
HM28	682.8	162.4		1195.5	314.4			
HM29	320.8	306.1				552.1		
HM30	564.3	276.1		211.2		669.8		
HM31	366.3	300.1		673.2				
HM32	350.4	391.6		783.2				
HM33								

Appendix 2 (continued)

Transport of paddy in Tanjung Karang: comparison of data collected and results from the model in season 2/86

Procurement centre	From the data collected in Tanjung Karang To LPN mills				From the model To LPN mills			
	AK1	AK2	CK3	GK4	AK1	AK2	CK3	GK4
AM1		158.4			1934.2			
AM2	451.7	433.1			467.8			
AM3	1161.3	182.8						
AM4	515.2	280.0		11.1				
AM5	554.4	97.2			214.5			
BM6						2000.0		
BM7	460.7	497.5		46.5		1370.7		
BM8	184.9	548.4		47.7				
BM9	156.0	759.2		122.2		534.8		
BM10	280.9		779.7	120.8		256.3		
BM11		610.5	1158.4				620.8	
BM12							626.4	
CS1		58.6					881.9	
CS2		1977.4		57.5			2000.0	
CS3				32.1				
CM13			1842.6				1775.1	
DM14		138.2	806.5					
DM15	271.6	176.9	688.1				56.7	
DM16	353.6	43.8	878.2				1303.2	
EM17			673.3					
EM18		147.6		48.7			998.2	
FM19	383.7	39.3						
FM20	162.7	123.7		115.0				
FM21	155.5	292.7		524.5			1076.2	
FM22	230.6	274.9		597.5			417.3	
FM23	193.6	101.5		264.9				
FM35				41.9				
GS5								
GS6								
GM24		44.9		236.5				
GM25	168.8			321.2				
GM26	75.8	29.6		139.9				
GM34				1017.4				2000.0
HM27	279.4	24.9		491.7		1133.4		
HM28	66.0	22.1		1065.8	407.6			
HM29	152.7	140.2			506.1			
HM30	305.1	114.8		712.8	1965.6			
HM31	464.6	392.5		760.1				
HM32	258.8	205.9		933.8				
HM33								

A Comparative Economic Analysis of Bulk Handling Methods and their Rates of Adoption

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Abstract

Most Malaysian paddy farmers have adopted mechanical harvesting technology. This technology has shortened the harvest period and placed additional pressure on paddy postharvest handling facilities, resulting in congestion and delays in the paddy delivery system. Handling of paddy in bags contributes substantially to these problems. This paper, using two different techniques, evaluates the economics of converting the current system of bag handling to potentially more efficient bulk and semi-bulk handling systems.

The first part of the paper specifies the modifications required in the various components of the postharvest system for bulk handling. This is followed by a partial equilibrium model which projects additional costs and benefits and determines whether conversion to bulk handling provides net social benefits to the entire paddy industry.

The second technique is basically a general equilibrium model designed to evaluate current postharvest activities and to analyse the effect of nominated changes in the conversion to bulk handling on total paddy handling costs and net social benefits. The results indicate that conversion to bulk handling is an economically viable proposition.

THE introduction of high yielding varieties and the provision of irrigation and drainage facilities in the 1960s and 1970s resulted in a rapid expansion of the Malaysian paddy and rice industry. Following this, considerable investment has been made in the modernisation of harvesting as well as processing facilities. However, despite the technological improvements at production and processing levels, the method of conveying harvested paddy from fields to mills is still very much traditional.

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With a shorter harvesting period, made possible by the adoption of mechanical harvesting technology by most paddy farmers, greater pressure has been placed on paddy postharvest handling facilities. This has resulted in congestion and delays in the paddy delivery system, leading to deterioration in grain quality, one of the factors contributing to the problem of postharvest losses.

The current system of handling paddy in bags also entails the hiring of labour for loading and unloading, thus adding to handling costs. The shortage of farm labour during peak harvesting periods compounds the problem.

In order to alleviate these problems and to keep abreast of technological improvements in other areas of the rice production system, appropriate technology should be introduced into the postharvest handling system. The adoption of bulk handling technology and movement of harvested paddy directly from the fields to the mills is therefore being considered as an alternative to the current system of handling paddy in bags.

Objective

The objective of the study reported in this paper was to evaluate the economics of converting the current system of bag handling of paddy to the potentially more efficient system of bulk handling in the paddy growing area of Tanjung Karang. The paper specifies the modifications of the various components of the postharvest handling system required for conversion to bulk handling. It also seeks to determine whether the conversion is of net benefit to the entire paddy industry. This assessment is based on estimates of both the private and social costs and benefits associated with the conversion to bulk handling.

Methods of Analysis

This study hinged strongly on the assumption that the proposed systems are technically feasible. Two different analytical frameworks were employed to evaluate the economics of the conversion to bulk handling. The first was basically a partial equilibrium technique. In this case, the additional costs, reduced costs, additional benefits, and reduced benefits associated with the conversion were computed, in order to facilitate a comparison between the total costs, consisting of both additional costs and reduced benefits, and the total benefits of the conversion, comprising both additional benefits and reduced costs.

The second analytical framework involved a paddy bulk handling model which is essentially a spatial equilibrium model incorporating all the diverse components of paddy assembly, transportation, queuing, drying, storage, milling, and distribution of rice at the wholesale level.

The objective function of the model is to maximise annual net industry return. This was achieved by maximising revenue from sales of rice less all postharvest costs, such as purchase cost of paddy, transportation cost, queuing and assembly costs, drying and milling costs, and storage costs for both paddy and rice. The opportunity costs of such activities as queuing, own transportation, and storage were imputed.

The mathematical formulation and underlying assumptions of the model are discussed in the paper by Salleh bin Yahya, Siow Kiat Foo, and Omar bin Yob in these proceedings. The constraints used were as given in that paper, in which equations (1) to (8) relate to paddy and rice flow constraints, and equations (9) to (21) to capacity constraints. Equations (22) to (26) are 'collection rows' that tabulate quantities of paddy flow for easy pricing of queuing and handling costs. Similarly, equations (27) to (28) are 'collection rows' for pricing of paddy purchases. Two additional equations—(29) and (30)—ensure that supplies did not exceed demand and 'close' the model. The specifications also had two adjustable parameters, one for conversion of wet paddy to dry paddy and the other for conversion of paddy to its milled form (rice).

The model comprised 150 production points, 35 government paddy procurement centres, 6 private paddy procurement centres, and 4 government milling complexes. There were provisions in the model to handle up to 8 grades of rice. The complete model was made up of 3743 rows and 14 936 columns.

Current Postharvest Handling System

The current postharvest handling system in Tanjung Karang, as depicted in Figure 1, is characterised by the handling of paddy in bags at the various transition points.

At the field level, paddy after being harvested by combine harvester is gathered on a piece of mat placed on the ground. Up to this stage, paddy is handled in bulk. The paddy is then packed in gunny sacks. In the case where harvesting is carried out manually by sickles, threshing would be required before the grain is loaded into the sacks. However, manual harvesting is employed by only a small proportion of the farmers (less than 10%) whose paddy land is inaccessible to combine harvesters. The gunny sacks are then carried manually to the nearest bunds and subsequently to the access roads where they are loaded onto motorcycles and small lorries of less than 5 tonnes capacity.

Transition points	Flow of activities	Form of paddy/rice handled	Flow of activities (bulk handling compared with current)	End results of conversion to bulk
A Field	1. harvesting using combine harvester 2. paddy grain gathered on ground	90% bulk	1. unchanged 2. not necessary	No additional investment required. There will be cost saving and time saving
	3. packing of grain in gunny sacks 4. sacks carried manually to bunds and access roads 5. loading	100% bag	3. not necessary 4. not necessary 5. loading direct from combine harvester onto lorries (1-3 t)	
B Transportation from field to procurement centre or milling complex			modified	Modification to lorries i. need container-like structure ii. need mechanism for unloading
C Procurement centre	1. (a) weighing, grading (b) unloading 2. buying and selling 3. loading	100% bag	1. modified 2. modified 3. modified	i. cost saving and time saving ii. 6 upgraded procurement centres with drying facilities and handling about 40%-50% of paddy
D Transportation from procurement centre to milling complex			modified	
E Milling complex	1. weighing, grading 2. unloading 3. storage (temporary) 4. predrying 5. debagging	100% bag	1. unchanged 2. modified 3. not necessary 4. unchanged 5. not necessary	Plant modification or new equipment required i. ground receival hoppers ii. holding bins with cleaners iii. additional bulk storage iv. additional bulk storage capacity
	6. precleaning, drying 7. storage of paddy	70% bulk and 30% bag	6. unchanged 7. modified	
	8. milling	100% bulk	8. unchanged	
	9. repacking 10. storage 11. loading	100% bag	9. unchanged 10. unchanged 11. unchanged	
F Transportation from milling complex to market			unchanged	
G Market			unchanged	

Fig. 1. The current paddy postharvest handling system in Tanjung Karang, Malaysia and changes that would result from conversion to bulk handling.

These are the two most important means of transportation of paddy to the procurement centres.

At the procurement centres, the usual activities of unloading, weighing, and grading of paddy take place before buying and selling is concluded. It is then the responsibility of the buyer to transport the paddy to one or other of the four rice milling complexes, located in Ulu Tiram Buruk, Sekinchan, Batu Dua, and Sungai Besar, by means of small and large lorries. Paddy handled at this stage is handled entirely in bags.

A sequence of activities takes place in the rice milling complex. The process of weighing, grading, and unloading is carried out before the gunny sacks containing paddy are stacked temporarily in the mill. Unlike the process of loading and unloading at previous transition points which is done manually, unloading at this stage is assisted by motorised conveyor belts. In-sack pre-drying of the paddy using mobile moisture extraction units is then carried out, followed by debagging of the paddy to facilitate the subsequent process of pre-cleaning and drying of paddy in bulk. Using multi-pass continuous-flow dryers (15 bags per hour, 100 tonnes per day throughput) of Louisiana State University (LSU) design, paddy is first dried to between 13% and 14% moisture content, then transferred to tower silos for bulk storage for 2 to 4 months. About 30% of the paddy, however, is dried in bulk using flat-bed batch dryers rather than LSU dryers. In this case, in-sack pre-drying is not required and the dried paddy is repacked and transferred to bag storage.

Paddy from the storage is conveyed to the mill for processing into white rice. The milled rice is then packed in bags of various sizes, ranging from 10 kg for direct sale to 50 kg for storage. The transportation of rice to the market is usually undertaken by contract lorry operators using lorries of more than 20 tonnes capacity.

Changes Required for Conversion to Bulk Handling

To convert the current postharvest paddy handling system to bulk handling, considerable changes, largely in the form of modification to the handling facilities and infrastructure, would have to be made. A summary of the flow of bulk handling activities and the results of a change to bulk handling are given in Figure 1.

At the field level, paddy from the combine harvester is now loaded directly onto lorries. Costs and time involved in the process of packing the paddy in gunny sacks and manually carrying these sacks to bunds and access roads will therefore be saved. However, with only an estimated 30% of the existing paddy land on Tanjung Karang having direct road access, modification to the present road system is required so that the entire area is accessible to lorries. For bulk handling operations, the lorries used must be modified to hold and prevent spillage of paddy. In addition, they need to be fitted with tipping gear to facilitate unloading. Alternatively, tractors equipped with grain tanks or lifting devices for steel containers may be used to transfer paddy from the combine harvester to secondary transport vehicles (trailers or trucks) fitted with tipping gear, parked on the access roads.

As the paddy can be transferred directly from the field to the rice milling complexes, there now appears to be no need for the procurement centres. However, in order to avoid the possibility of congestion at the mills, even if they are able to handle paddy in bulk, some of the procurement centres may continue to exist. To further justify their existence, they may also serve as satellite drying centres, provided the appropriate drying facilities are installed. Some 40-50% of total paddy production is expected to be handled by the remaining centres. Hence, as well as time savings there will be costs arising from the process of manual loading and unloading at this stage of the paddy handling system.

To facilitate the bulk handling of paddy, a number of modifications to the existing rice milling complexes would be required, particularly in terms of receival, cleaning, drying and storage facilities for paddy. The milling operation, however, will remain unchanged. Renovation work and additional capital investment will therefore be required in the existing milling complexes.

At each of the four milling complexes, two ground receival hoppers, each with a handling capacity of 20 tonnes per hour, will be constructed to facilitate unloading of bulk paddy. One of the hoppers will be equipped with a tipping platform, to handle lorries without tipping gear, while the other will have a fixed platform.

As temporary storage and debagging of paddy prior to drying will not be necessary in the bulk handling system, paddy from the receival hopper will be conveyed by means of bucket elevator and chain conveyor to holding bins of 200 tonnes capacity. Before storage, all paddy is cleaned, necessitating the installation of pre-cleaning equipment.

Additional capacity will also be required for subsequent drying. This requirement could be met by the installation of an additional LSU dryer of 100 tonnes per day capacity at each of the four complexes. This would cope with the increase in the rate of paddy receivals as a result of the conversion to bulk handling. Alternatively, the paddy could be dried in an inclined batch dryer, or by a combination of both rapid drying and slower in-bin drying. The dried paddy will then be transferred to bulk storage.

Additional bulk storage capacity will also be required at each of the four complexes. This requirement will be partially met by the conversion of existing horizontal bag storage to bulk storage with temporary walls formed by bags of paddy. At the Batu Dua and Sungai Besar complexes, it will be necessary to demolish the dilapidated godowns and replace them with appropriate bulk storage facilities.

As for the subsequent processes of milling, packing, storage, and transportation of rice to the market, no further modifications are required.

Benefits and Costs of the Changes

The Partial Equilibrium Technique

The additional costs involved in the modification of the system of postharvest handling from bag to bulk are shown in Table 1. The cost of modifying access roads to the farms is $M10 468 200[1], while the cost of modifying the existing milling complexes to cater for bulk handling operations is $M16 170 000, giving a total additional cost of $M26 638 200. Annual operating and maintenance costs are assumed to be around 2% of the total additional costs.

Conversion from the current system is also expected to reduce some of the costs of operations, particularly those related to handling. These include the costs of handling paddy at the fields, procurement centres, and mills; costs of the gunny sacks; costs of bagging and debagging of paddy; and commissions paid to the operators of the procurement centres by the National Paddy and Rice Authority. Table 2 gives a list of those items for which costs are expected to fall. The expected total reduction is $M41.85 per tonne of paddy handled. In addition to the above, the total transportation cost is also reduced. The estimated reduction is $M517 000, which is about 20% of the current total cost of transportation.

From the estimated total marketable surplus of 95 718 tonnes of paddy, the total additional benefit resulting from the conversion is expected to be $M4 005 798. The total additional benefit has two components: reduction in postharvest losses; and improvement of the recovery rate of rice from paddy. Table 3 shows that the total benefit resulting from the reduction in postharvest losses is $M1 108 895, while the benefit resulting from an improvement in the recovery rate is $M1 366 970. This is based on the assumptions that postharvest losses will be reduced from 10% to 8% and the rate of recovery will improve from 65% to 66%.

Using the above figures, a 20-year cash flow is estimated. The net present value of the cash flow at a 10% discount rate is found to be $M30 831 297, while the internal rate of return is 28.2% (Table 4).

The conversion to full bulk handling may not be particularly easy. The major constraint to the conversion to a full bulk system is found at the farm level. Small farm sizes (*c.* 1 ha) and the current ownership may hinder the success and efficiency of bulk handling operations, especially in terms of identifying the owners of the paddy harvested. A possible solution is for the farmers to group together and share the costs and returns according to the area of land they farm as part of the group. Again, this arrangement may not be agreeable to all the

[1]Costs are in Malaysian ringgit ($M). During October 1987, $M2.50 = US$1.

TABLE 1. Details of additional costs that would be incurred in converting from bag to bulk handling

Road modification

Cost estimates ($M)[a] for proposed construction of 2.4 m wide and 15 cm thick laterite road

i. Roads, 526 km @ $7200/km	3 787 200
ii. Culvert crossing, 327 units @ $M3000/unit	981 000
iii. Land acquisition, 192 ha @ $M29 687.50/ha	5 700 000
Total:	10 468 200

Plant modification

Cost estimates	For each complex	Total
i. 2 units of ground receival hoppers	100 000	400 000
ii. 200 t holding bins and associated handling equipment	100 000	400 000
iii. 2 units of cleaners and associated handling equipment	175 000	700 000
iv. Additional drying plant of 100 t per day capacity	1 700 000	6 800 000
v. Storage conversion plus aeration and inter-connection conveyors	400 000	800 000
vi. Bulk storage construction and conversion plus aeration and inter-connecting conveyors (for two complexes)	2 800 000	5 600 000
Total:		14 700 000
Plus contingencies (10%)		1 470 000
Total including contingencies		16 170 000
Total additional costs		26 638 200

[a]Costs are in Malaysian ringgit ($M). During October 1987, $M2.50 = US$1.

farmers, especially if the fertility of the land differs greatly between plots.

Another possible solution is to load the transportation vehicle, on any one trip, with paddy harvested from only one plot of land or belonging to only one owner if his plots of land are side by side. Under this arrangement, the farmer may have to pay higher transport charges per tonne if the vehicle is not fully laden.

Construction of additional farm roads will remove some land from production. The areas needed will have to be acquired from several farmers. Land acquisition has always been a difficult process: the affected farmers may not agree to the level of compensation or they may even refuse to release their land.

Another constraint that tends to make the proposition socially, and perhaps also politically, less acceptable is the fact that most of the procurement centres will disappear from the system. The people currently involved in operating the centres will be very unhappy to lose their business.

Considering the above circumstances, this paper also considers the conversion to semi-bulk rather than full bulk handling. In this case, the proposition is to leave the handling operations from the fields to the procurement centres as

TABLE 2. Cost reductions ($M)[a] expected from the introduction of bulk handling of paddy[b]

One gunny sack is assumed to contain 80 kg of paddy. So 1 t of paddy is assumed to be packed in 12 gunny sacks.	
1. Cost of gunny sacks 12 × 0.05/bag	0.60
2. Handling costs—packing, transferring paddy from field to road, loading 12 × 1.30/bag	15.60
3. At procurement centre, handling costs—loading/unloading 12 × 0.50/bag	6.00
4. At milling complex, handling costs—unloading, stacking 12 × 15.3/bag	1.84
5. (Assuming equal proportions of paddy are dried by LSU dryer and flat bed batch dryer) —debagging (LSU dryer) 0.7 × 12 × 11.3/bag	0.95
—debagging, repacking, stacking (flat bed batch dryer) 0.3 × 12 × 0.35/bag	1.26
—debagging (prior to milling) 0.3 × 12 × 0.15/bag	0.60
6. Commission to operator of procurement centre	15.00
Total per tonne	41.85
7. Transportation costs saved (about 20% of the current costs)	517 000

[a]Costs are in Malaysian ringgit ($M). During October 1987, $M2.50 = US$1.

[b]After introduction of bulk handling, there would be 6 upgraded procurement centres handling about 40-50% of total paddy production.

they are, while the rest of the system is converted to a bulk handling one.

Under such a system, modifications occur only at the milling complexes. However, should the procurement centres decide to install satellite drying facilities, they can do so. Operations at the procurement centres and the mills will thus have to be coordinated and arrangements will have to be made to remunerate the procurement centres for the drying they do.

The additional cost, i.e. the cost required for the modification, is estimated to be approximately $M16 170 000. The additional operating and maintenance costs are again assumed to be about 2% of the total additional costs. The expected cost saving is $9.65 per tonne (only $5 per tonne saving in the handling cost at the procurement centre), making a total of some $M923 679. Postharvest losses are expected to fall by about 1% giving a saving of $M554 447, while recovery rate is expected to increase by 1%, adding $M960 842 to the additional benefit (Table 3).

Investment in the conversion to semi-bulk in the postharvest handling system is expected to yield a net present value of $M867 204 at a 10% discount rate. The estimated internal rate of return is 13.8% (Table 4).

The adoption of a new system can be expected to take time, and the rate of adoption over time can be introduced into calculations. Using an example of a 6-year adoption period at the various cumulative rates of 0.1, 0.2, 0.5, 0.7, 0.9, and 1.0, the return to investment was computed. The results (Table 4) show that the internal rate of return is 28.0% for the full bulk option and 13.1% for conversion to a semi-bulk system.

The General Equilibrium Model

The values of the key variables used in the model are given in the paper preceding this one in these proceedings. This basic run represents the normative optimal paddy and rice flows in the Tanjung Karang area that would occur under competitive market conditions given current technology. The results of this basic run were compared with real field data on the flow of paddy and rice, in order to validate the model and to provide explanations for any discrepancies that may occur between model results and actuality.

On the whole, it was found that the model is a valid representation of reality in Tanjung Karang. Where discrepancies exist between model results and LPN records, these differences can be explained (Chew et al. 1987[2]).

[2]Chew Tek Ann, Roslan A. Ghaffar, and Salleh Yahya. Bulk handling of paddy: some further results from the paddy handling model. Draft manuscript dated August 1987.

TABLE 3. Production of paddy and benefits of bulk handling

Total area under paddy production in Tanjung Karang: 18 887 ha less 192 ha for infrastructures					
Average yield per hectare per season:	3.2 t				
Total production for two seasons:	119 648 t				
Total marketable surplus (80% of production):	95 718 t				
		'Full bulk'		'Semi-bulk'	
	Current	Amount	Diff.	Amount	Diff.
Postharvest losses (%)	10	8		9	
(t)	9572	7658	1 914	8615	975
Value[a]			1 108 895		554 447
Milling recovery rates (%)	65	66		66	
(t)[b]	49275	51 145	1 870	50589	1 314
Value[c]			1 366 970		960 842

[a]Values are in Malaysian ringgit ($M). During October 1987, $M2.50 = US$1. Price of paddy is $M579 per tonne.
[b]Wet paddy is converted to dry paddy by a factor 0.88.
[c]Average price of various rice grades is $M371 per tonne.

The following changes were inflicted on the model. (i) Introduce bulk handling facilities starting at the field. Paddy is then transported from the field directly to the mills, bypassing the procurement centres. This is called a full bulk system. (ii) Introduce bulk handling facilities from the procurement centres. Paddy is brought to the procurement centres in the traditional bagged form, but once accepted, it is placed in bulk facilities and subsequently transported to the mills and processed there in bulk. Additional drying facilities may be installed at the procurement centres or at the mills. This system is called the semi-bulk system.

For each change noted, certain key variables in the model, including handling costs, queuing costs, moisture levels at different points in the system, and rice recovery rates were altered to correspond to the change. The model was then run and the net industry return obtained compared with the industry return for the basic run. A conventional cash flow analysis was made, to examine if the proposed change is viable, assuming certain capital costs required to make the changes.

The total costs of converting to full bulk handling, as in the previous analysis, was $M26 638 200, consisting of $M10 468 200 for farm road modifications and $M16 170 000 for plant modification. The internal rate of return over 20 years was found to be 19.7%(Table 4).

The capital cost required to convert the existing system to a semi-bulk system with improved drying facilities at the procurement centres was about $M16 170 000. The internal rate of return of the semi-bulk system was 13.4%. Table 4 also show the results of a 6-year adoption rate under both the full bulk as well as the semi-bulk system. The internal rates of return are 19.3% and 12.7%, respectively.

TABLE 4. Return on investment in converting traditional handling method to full and semi-bulk handling

Proposition	Internal rate of return (%) Partial Eq.	Internal rate of return (%) Gen. Eq.
Full bulk handling	28.2	19.7
Semi-bulk handling	13.8	13.4
Full bulk (6 year adoption rate)	28.0	19.3
Semi-bulk (6 year adoption rate)	13.1	12.7

The results of the two analytical frameworks indicate that the partial equilibrium model generally overestimates the rates of return to the additional capital investment. The results of the second model, which considers a global rather than a local optimum, are more realistic in the sense that they take into account the interactions of the various activities in the entire postharvest handling system.

Conclusion

The existing system for postharvest handling of paddy in Tanjung Karang is at best traditional even though large, modern harvesting equipment has been introduced to the region, beginning some 10 years ago. The results of the study reported in this paper clearly show the feasibility of introducing full bulk postharvest handling. However, due to the existence of constraints at farm level and at procurement centres, this economically attractive proposition may not be socially and politically acceptable. The introduction of bulk handling from the procurement centres to the mills may be the next best alternative for the immediate future. Efforts, however, should be geared towards full conversion, perhaps phasing out the traditional handling method whenever and wherever circumstances permit.

Sensitivity of a Model of the Malaysian Rice Economy to Price and Quality Parameters

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Abstract

The economic model of the Malaysian rice industry developed by ACIAR Project 8344 is a spatial equilibrium model that incorporates all the important diverse elements in the paddy postharvest industry in Tanjung Karang. As background to this paper, the model is first briefly described, calibrated, and used to assess the economic viability of the introduction of a semi-bulk grain handling system in the area. It is found that the semi-bulk system is an acceptable economic proposition. Changes are then inflicted on the model to evaluate the robustness of the results to variations in selected key parameters. The results show that the sensitive variables, in descending order, are the price paid for paddy, the rice recovery rate, drying cost, and milling cost. The sensitivity of the rice recovery rate has important policy implications. The effect of the closure of one mill and 19 procurement centres that are currently underutilised in our model is also tested. We obtain an increase in net industry loss of 14.6%, which is small, compared with an 11.6% change accruing from a 1% change in rice recovery rate. Hence, considerable welfare gains may be obtained by reducing in number and reorganising the existing procurement and processing points in Tanjung Karang.

ACIAR Project 8344 has developed a detailed model of the Malaysian rice economy. This paper discusses the sensitivity of the model to price and quality parameters and the resulting implications. As background, we first discuss, very briefly, the salient features of the model, its calibration with actual events in the field, and its use to evaluate the economic feasibility of introducing semi-bulk grain handling facilities into the system. In the second part of the paper, we inflict variations in selected key parameters, related to price and quality, to test the sensitivity of the model to changes. We also tested the closure of one mill and 19 procurement centres to evaluate the effects of organisational changes to the present system. The implications of all these changes are discussed in the last part of the paper.

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Background

The model developed by Project 8344 is a spatial–temporal equilibrium model, which incorporates all the important diverse components of paddy assembly, transportation, queuing, drying, storage, milling, and distribution of rice at the wholesale level in the Tanjung Karang area[1] of Peninsular Malaysia. The mathematical formulation and underlying assumptions of the model are discussed in Ryland and Hansen (1986) and Hansen and Ryland (1986).

[1]See Figure 1 in the paper by Salleh Yahya, Siow Kiat Foo, and Omar bin Yob in these Proceedings.

The objective of the model is maximisation of annual net industry return. This is achieved by maximising revenue from sales of rice then deducting all postharvest costs, such as purchase cost of paddy, transportation cost, queuing and assembly costs, drying and milling costs, and storage costs for both paddy and rice. The opportunity costs of such activities as queuing, own transportation, and storage were imputed from data obtained from surveys. The model specification has two adjustable parameters—one for conversion of wet paddy to dry paddy and the other for conversion of dry paddy to its milled form, rice. The model has 150 production points, 35 government paddy procurement centres, 6 private paddy procurement centres, and 4 government milling complexes. There are provisions in the model to handle up to 8 grades of rice. The model size is 3743 rows by 14 936 columns. Given modern computing capabilities, the size of models such as this is no longer a problem.

The model was first run with the 'best available coefficients' derived after consultations with LPN (Lembaga Padi dan Beras Negara) and the results calibrated against actual LPN records. Tables 1 and 2 show the comparisons. On the whole, the model results match reasonably well with LPN records.[2] Discrepancies between model results and LPN records occur in four items.

(i) Sales of rice: the model gives higher revenue compared with LPN sales because it produces high grades of rice, whereas in reality about 6% of rice produced in Tanjung Karang is of lower grades.

(ii) Drying cost: we assume a drying cost of $M40.25 per tonne of paddy. In retrospect, this seems high compared with LPN records.

(iii) Transportation cost: there is a considerable amount of paddy flow between mills and between procurement centres and mills in LPN records that seems unwarranted by the minimum transportation cost principle. From our model, we estimated a possible saving of about $M361 776[3] if directions of paddy flows in Tanjung Karang were improved.

(iv) Handling cost: this includes the cost of labour used in loading and unloading the bags of paddy. We used a value of $M6.06 per tonne which seems low.[4]

TABLE 1. Paddy flows from field to mill (%)

Routes	From LPN records 1985	1986	Basic run result
Field to procurement centre to mill (i–j–k)	78.06	64.99	72.52
Field to mill (i–k)	21.94	35.01	27.48

It is interesting to look at the cost components in terms of percentages, as in Table 3. What is remarkable here is the high proportion (82%) of the farmer's share of the total cost. In this case, the farmer's share of the consumer dollar cannot be evaluated, as returns to processing are not available, but it would certainly be high.

The model was used to assess the economic viability of initiating a semi-bulk handling system for grain, in which bulk handling would be introduced at procurement centres. Paddy would be transported from the procurement centres to the mills in bulk containers. Drying facilities would be introduced at the procurement centres to reduce the moisture content (m.c.) from 24% to 18%. Paddy transfer from the field to the procurement centres will still be made using the traditional 'bag' method.

[2]A more detailed comparison of model results with LPN records is available in another paper (Chew et al. 1987). A certain amount of arbitrariness is inevitable in this calibration process. Just as in certain econometric models where the signs of certain coefficients are more relevant than their exact magnitudes, so in programming models the illumination and clarification that these models provide may turn out more useful than the exact sizes of variables.

[3]Prices are given in Malaysian ringgit ($M). During October 1987, $M2.50 = US$1.

[4]All these discrepancies were easily corrected in a re-run without the overall paddy and rice flows being altered in any way. Only the magnitudes of the relevant components were altered. One may ask why we present results that we know to be 'wrong'. This is to illustrate that the 'best available' coefficients may still not be accurate. The other possibility also exists that LPN records may not be accurate.

TABLE 2. Comparison of cost components of model solution with LPN records

	Model	LPN	Model-LPN	%
Income				
Sale of rice	35 598 992	22 943 092	12 655 900	35.55
Costs				
Purchase of paddy	26 892 923	26 764 013	128 200	0.40
Subsidy payment	9 190 062	9 190 062		
Milling cost	1 352 877	1 272 159	80 718	5.96
Drying cost	2 241 818	1 856 657	385 161	17.18
Handling cost	381 404	440 510	– 59 106	- 15.49
Paddy transport cost (i-j-k) route	1 066 241	1 428 017	– 361 776	- 33.93
Paddy transport cost (i-k) route	493 207	NA		
Rice transport cost	712 427	NA		
Queueing cost	1 519 952	NA		
Paddy storage cost	66 291	NA		
Rice storage cost	13 151	NA		
Commission	not considered	835 460		
Net industry loss	8 330 731	NA		

Notes:

(a) All figures are in Malaysian ringgit ($M). During October 1987, $M2.50 = US$1.

(b) LPN figures were adjusted linearly to correspond to the same amounts of paddy and rice handled in the model, i.e. 62 938 tonnes of paddy (at 22% m.c.) and 36 203 tonnes of rice.

(c) LPN figures were for the year 1986 for which complete records for all the four mills are available. 1986 is not special in any way; hence the figures for that year can be considered representative.

(d) For LPN figures, administration cost was subdivided and allocated to handling cost, drying cost, and milling cost in the ratio of 20:40:40, respectively.

(e) LPN pays a commission to procurement centres at the rate of $M15 per tonne of paddy purchased. The procurement centres belong to farmers' cooperatives. The centres act as LPN agents.

(f) NA = not available.

The parameters in the model that were altered by this change to the semi-bulk system are handling cost (from $M6.06/tonne to $M1.00/tonne), moisture level in paddy transported from procurement centres to mills from 24% m.c. to 18% m.c. because of drying facilities at the procurement centres), cost of drying at the procurement centres ($M33.81) and at the mills ($M10.00) instead of at the mills only ($M40.25), and improvement in rice recovery rate from 65% to 66%.[5] The changes seem slight, but the effect is dramatic. There is a

[5]These are conservative estimates of the benefits of introducing bulk handling, after consultations with both LPN and private sector people.

TABLE 3. Cost components of the paddy postharvest system.

Component	Cost of component as % of total cost
Purchase cost of paddy	61.2
Subsidy payment	20.9
Milling cost	3.1
Drying cost	5.1
Handling cost	0.9
Paddy transport (i-j-k)	2.4
Paddy transport (i-k)	1.1
Rice transport	1.6
Queuing	3.5
Paddy storage	0.2
Rice storage	0.0

Notes:

(a) As explained earlier, drying cost may be overstated and handling cost understated.

(b) Paddy transport (i-j-k) refers to field to procurement centre to mill route, whilst paddy transport (i-k) refers to the direct field to mill route.

considerable saving in net industry loss of $M2.4 million. A conventional cash flow analysis shows that the internal rate of return (IRR) of the semi-bulk handling system is 13.72% (Table 4). If we were to be somewhat less conservative in our estimates, such as in determining the savings accruing from change in handling cost, we believe that the IRR obtained would be much higher. Hence, we conclude that a semi-bulk grain handling system for Tanjung Karang is an economically viable proposition.[6]

Sensitivity of Model to Changes in Parameters

The sensitivity of the model to the following changes was tested. Using the semi-bulk version with 66% rice recovery rate as the 'base', the following changes were inflicted one at a time, separately:

(i) drying cost reduced by 10% from $M40.25/tonne to $M36.22/tonne;

[6]This is discussed in further detail in another paper presented at this workshop (see the paper by Mohayidin et al.).

TABLE 4. Sum of discounted industry gain from introduction of semi-bulk handling system

Social discount rate	Semi bulk
0.08	23 586 184
0.09	21 929 550
0.10	20 452 176
0.11	19 130 342
0.12	17 943 881

Notes:

(a) Capital cost involved for semi-bulk system = $16 million.

(b) IRR for semi-bulk system = 13.72%.

(ii) milling cost reduced by 10% from $M24.20/tonne to $M21.86/tonne;

(iii) purchase price of paddy reduced by 10% from $M408.30/tonne to $M367.47/tonne;

(iv) rice recovery rate reduced from 66% to 65%;

(v) reorganisational change involving closing down of the GK4 mill and 19 procurement centres that are underutilised in our model results.

Changes (i) and (ii) are changes that might follow technical innovations. Drying cost reduction is also possible if the initial moisture level of the incoming paddy is low. Change (iii) refers to change in paddy prices as a result of changes in either the subsidy level or the guaranteed minimum price. The rice recovery change can come about through better drying and handling procedures and hence is tied intimately to moisture content and other quality parameters. The last change is a long run change and is for testing effects of organisational changes suggested by our results. The sensitivity of the model to the above changes, as reflected in the value of the objective function, is as shown in Table 5.

It is not surprising that the model should be sensitive to the price of paddy since cost of paddy constitutes about 82% of the total cost (Table 3). What is surprising, however, is the large effect that a change in recovery rate of only 1% (from 66% to 65%) can have on the objective function. The change in objective function of 11.56% is almost as large as the

TABLE 5. Sensitivity of economic model of Malaysian rice industry to parameter changes

No. Parameter	Magnitude of change	Value of objective function	% change in objective
Base run		5 928 426	
(i) Drying cost	10% reduction	5 795 133	– 2.25
(ii) Milling cost	10% reduction	5 696 092	– 3.92
(iii) Price of paddy	10% reduction	3 463 683	– 41.57
(iv Recovery rate	66% reduced to 65%	6 613 689	+ 11.56
(v) Reorganisation	1 mill closed; 19 procurement centres closed	6 791 643	+ 14.56

Notes:

(a) Values are in Malaysian ringgit ($M). During October 1987, $M2.50 = US$1.

(b) For the 'base run', before changes were inflicted, we used the 'semi-bulk version' with rice recovery rate of 66%.

change (14.56%) resulting from a major reorganisational overhaul, such as closing down a mill and 19 procurement centres. Since the last three changes (Table 4) are the important ones, we will go into detail as regards changes in the various cost components for only these three, as shown in Table 6.

The following observations emerge from an examination of Table 6.

(i) Reducing the price of paddy by 10%, either via the guaranteed minimum price or the paddy subsidy, merely decreases the paddy cost item, with the other cost components and paddy flows remaining the same. Because paddy cost (including subsidy item) constitutes over 80% of total cost, paddy cost remains the single most sensitive determinant of the magnitude of net industry loss.

(ii) Comparing run (iv) with the base run, reduction of rice recovery rate from 66% to 65% increases the costs of all components, because a larger quantity of paddy is now required to satisfy the given demand for rice. What is significant here is that paddy storage cost increases by over three times, indicating a build up of stocks of both paddy and rice in the postharvest system. That a 1% change in rice recovery rate can cause so large a change in paddy stocks is surprising.

(iii) Similarly, for the case when a mill and 19 procurement centres are closed down, there is a build up in stocks of paddy. In this case also, there is an increase in transportation cost of about $M600000, because of longer, more roundabout paddy routes. However, as noted earlier, the change in net industry loss is not so great (about 14.6%) when compared with the impact of a 1% change in rice recovery rate (about 11.6%).

(iv) The model provides fairly consistent results and this gives us confidence that it can be used to explore other possibilities.[7]

Implications

We have treated the changes separately, whereas in reality they are interrelated. For example, the incentive features in the price structure for paddy are intimately linked with drying cost and rice recovery rate.

An incentive system that rewards good quality paddy could well result in drier paddy coming into the postharvest system, resulting in lower drying cost and an improved rice recovery rate. Moisture in paddy is only one of the indicators

[7] For example, to investigate the significance of nonlinearities in drying and milling functions.

TABLE 6. Optimal solutions of economic model, obtained by varying key parameters

Variables	Returns/Costs (% of total cost)			
	Base run	run (iii)	run (iv)	run (v)
Purchase cost of paddy	25 791 843 (62.1%)	23 327 100 (59.7%)	26 199 273 (62.1%)	25 839 479 (61.0%)
Subsidy payment	8 813 920 (21.1%)	8 813 920 (22.6%)	8 953 075 (21.2%)	8 830 274 (20.8%)
Milling cost	1 297 524 (3.1%)	1 297 524 (3.3%)	1 352 833 (3.2%)	1 332 362 (3.1%)
Drying cost	2 323 336 (5.6%)	2 323 336 (5.9%)	2 357 260 (5.6%)	2 335 302 (5.5%)
Handling cost	60 362 (0.1%)	60 362 (0.2%)	61 315 (0.1%)	60 474 (0.1%)
Paddy transport	1 650 413 (4.0%)	1 650 413 (4.2%)	1 624 195 (3.8%)	2 267 373 (5.3%)
Rice transport	710 943 (1.7%)	710 943 (1.8%)	710 073 (1.7%)	784 046 (1.8%)
Queuing	845 073 (2.0%)	845 073 (2.2%)	858 421 (2.0%)	846 636 (2.0%)
Paddy storage	18 815 (0.0%)	18 815 (0.0%)	68 517 (0.2%)	86 541 (0.2%)
Rice storage	15 189 (0.0%)	15 189 (0.0%)	27 669 (0.0%)	8 157 (0.0%)
Total cost ($M)	41 527 418	39 062 675	42 212 681	42 390 635
Rice income ($M)	35 598 992	35 598 992	35 598 992	35 598 992
Net loss ($M)	– 5 928 426	– 3 463 683	– 6 613 689	– 6 791 463
Quantity paddy involved (t)	60 362	60 632	61 315	60 474

Notes:

(a) Returns/costs are in Malaysian ringgit ($M). During October 1987, $M2.50 = US$1.

(b) Run (iii) Price of paddy reduced by 10%. Run (iv) Rice recovery rate reduced from 66% to 65%. Run (v) Mill and certain procurement centres closed. The changes were inflicted on the 'base run' one at a time, separately.

of quality. It appears that unripened grains are now becoming increasingly important.[8] This is because harvesting by combine harvesters is a fairly indiscriminate operation compared with the traditional method of harvesting by sickle where ripe and unripened grains can be easily discriminated. Given that rice recovery rate is so critical an issue in terms of its influence on net industry loss, paddy quality and the correct price incentive to bring about paddy quality are therefore of paramount importance. Conversely, technical improvements in, for example, drying and milling that bring about only a 10% reduction in their respective costs become comparatively insignificant.

The other important implication of our results is that there is some redundancy in the number of procurement centres in Tanjung Karang. Many of them could be closed down with little

[8]According to members of the Kedah Rice Millers Association.

adverse effect in terms of increasing net industry loss. This point becomes important when we consider setting up drying facilities in procurement centres. Not all centres may have space for such facilities. Since many of these centres are redundant, not all the centres need therefore be considered for drying facilities.

Finally, a few words are needed on how this sensitivity analysis fits in with the overall objectives of ACIAR Project 8344, so as to put this paper into proper perspective. The ACIAR model was formulated to capture all the diverse elements in the Malaysian postharvest industry, in order to understand how the various elements are interrelated and to enable suggestions to be made as to how the net return of the industry might be increased. One such suggestion is to introduce bulk handling facilities into the industry. As part of the process of using the model to study such changes, calibration, validation, and sensitivity analyses are standard procedures.

Conclusion

The main results of our sensitivity analyses are as follows.

(i) The price of paddy is the most sensitive parameter in effecting changes in net industry return. This finding is to be expected, given that price of paddy constitutes about 80% of total processing cost in LPN complexes.

(ii) The model is very sensitive to the rice recovery rate. A change from 66% to 65% rice recovery rate increases net industry loss by 11.6%. Factors such as paddy moisture content that affect rice recovery rate therefore become important in efforts to improve return to the rice/paddy processing industry.

(iii) Closing down a mill and 19 procurement complexes increases net industry loss by 14.6%, which is not large compared with the magnitude of the change resulting from alterations in the rice recovery rate. This seems to suggest that benefits may be obtained from a reorganisation of existing procurement centres, a reorganisation that would fit in nicely with the simultaneous introduction of bulk handling facilities.

In general, the ACIAR model gives fairly consistent results from the sensitivity analyses. We are confident that the use of the model to explore other possibilities would yield fruitful results.[9]

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[9]This is currently undertaken by Mr Salleh Yahya as part of his Masters degree requirements.

Policy Analysis and Bulk Handling of Paddy in Malaysia: Agenda for Reform of the Malaysian Rice Economy

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Abstract

In this paper, we discuss the policy and institutional changes that we think are needed in the Malaysian rice industry so that introduction of bulk and storage methods can proceed rationally in an economic environment conducive to providing sufficient incentive for renewed commercial investment by the private sector in the industry.

We propose an agenda for changes in both policies and institutions identified as constraints to improvement in the performance of the Malaysian rice industry. Our agenda is designed to meet the Government's objectives of increased private sector participation in the Malaysian rice industry for which both efficiency and equity considerations are preserved. The policy changes not only meet these necessary conditions but also are sufficient in the sense that they are realistic, achievable in a given time frame, and are practical.

ECONOMISTS have for a long time demonstrated how subsidies through price support programs are both inequitable and inefficient as means of providing income support for low income farmers (see, for example, Johnson 1987). When a price support program is also supplemented by an inefficient and ineffective mechanism for procuring paddy, then it is little wonder that changes required to improve performance are always frustrated. Such is the current policy for procuring paddy from farmers in Malaysia. Furthermore, regulated prices of rice act as an additional disincentive for private millers to invest in new and modern facilities of handling and storage. From the viewpoint of both farmers and millers, the current rice policy acts as a disincentive to improvement of the industry. On the contrary, farmers resist change because the incentive provided to improve quality for paddy does not offset their private costs.

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At the outset of our study, the Malaysian authorities administering the paddy and rice industry recognised the need to include an examination of grading and quality control systems as well as the potential for introducing improved technology. The results of the study reveal that the payoff from policy changes in relation to procurement of paddy is many times higher than the payoff from investment in technical change. Recently, the Government has recognised the need to reduce Government intervention in the industry through proposals to float higher quality grades of rice to satisfy unfulfilled demands of consumers for better quality rice. These reforms are certainly welcome for consumers and the processing sector, but need to be accompanied by a comprehensive policy package if the whole industry is to benefit.

We believe that the introduction of modern bulk handling technology in the Malaysian rice industry can proceed rationally and efficiently if, at the same time, policy makers recognise that there is a real need to provide an economic environment in which commercial investors can make the necessary investments. In this environment, the public sector regulates and monitors changes in the performance of the industry while private sector participation increases.

Proposed Agenda for Reform

Immediately

(i) Float prices of rice for all grades above A3 and B3. The grade 3 rice can be considered as the 'poor man's grade', and its price must be controlled, protected or even subsidised for equity considerations. The number of grades above grade 3 and their respective prices would be determined by the market. We would hope that this move would increase remuneration in the rice processing sector, thereby stimulating private investment and decreasing the load on LPN's processing capability. Rice millers would compete for better quality paddy to produce superior grades of rice, stimulating competition and incentive in the production of better quality paddy.

(ii) Improve or remove the present permit system in the distribution of rice. Millers will provide LPN with fortnightly or monthly sales and distribution information. The present permit system is costly and is a hindrance in the rice distribution trade.

(iii) Increase the penalty on low quality paddy. *Unless the penalty on low quality paddy is increased, the incentive to deliver good quality paddy will not arise*. For example, paddy at 25% moisture content should be penalised at least 16%, to cover both the full resource cost involved in drying and the loss in weight due to drying. The principle here should be to penalise farmers who do not take *even the simplest minimal care* to produce reasonable quality paddy.

(iv) LPN should provide technical assistance to private millers to help them develop their facilities. The proper role of LPN should be monitoring, research, and extension aspects of the rice industry and not direct competition with the private sector in paddy purchase and paddy processing.

Short Term: 2–3 years

(i) Planned removal, over a three-year period, of the price subsidy of $160/tonne. We believe that a reduction of $33^1/_3$% each year would cause little hardship. Concurrent with the removal of the price subsidy, a structural adjustment assistance program would be implemented targetted to help the adjustment of those low income farmers who are assessed to be commercially non-viable over the long term. The adjustment program will also provide income support and carry-on finance to eligible farmers, as well as provide longer term commercial loans to farmers who wish to develop and build up their farms by amalgamation. The program would operate similarly to the rural adjustment scheme in Australia (Heap 1980).

(ii) Provide loans to the private milling sector to assist in implementing modern grain handling and storage technology.

Longer Term: 3–10 years

(i) Reduce participation of LPN in rice milling and storage by leasing out LPN complexes to the private sector. As an incentive to the private sector, all capital equipment in LPN plants should be regarded as sunk and offered for lease by tender to the private sector, on condition that the private sector will provide all necessary investment to introduce modern grain handling technology of paddy over a five-year period. LPN will also provide technical assistance to the private milling sector through direct extension programs.

(ii) LPN will retain the sole right to import rice. Import policy on rice will eventually become the sole instrument for regulating the domestic rice industry in Malaysia.

(iii) Farmers' cooperatives or companies with farmers having shares should be encouraged to participate in the paddy processing sector so that farmers can have a stake in the postharvest industry. The cooperatives should be run on a commercial basis by professional management teams.

(iv) The floor price of paddy will be retained in nominal terms only. There is no provision for it to be increased. A system of arbitration on grading standards should be established for cases where growers and millers cannot agree on quality.

(v) All controls over retail price of rice will be abolished.

Basically, these reforms fall into two categories:

1. *Price Reforms.* The removal of price subsidies on paddy and the abolition of all controls over retail prices of rice will promote efficiency at all levels of the industry.

2. *Institutional Reforms.* The phased withdrawal of LPN from active involvement in procurement, processing, and storage of paddy will necessitate major changes in the operations of LPN. LPN will continually regulate and monitor the performance of the rice economy and will be the sole importer of rice. Funds generated from the leases received on current LPN facilities and from imported rice will be used to provide income support and assistance to low income farmers to adjust out of farming or to bring about farm amalgamation. A Structural Adjustment Assistance Unit will be established to undertake these assessments.

Commercial Investment Opportunities

We are confident that our proposed agenda for changes in the Malaysian rice industry is practical, realistic, and achievable within the given time frame. Public sector participation in the industry is the main constraint on improved performance of the sector. The role of Government is to regulate and monitor changes and its withdrawal from active involvement in the industry, together with the necessary price reforms and institutional changes indicated above, will provide the environment needed for the private sector to invest in modern bulk handling technology on a sound commercial basis. The industry will become more efficient and the significant postharvest losses (up to 28%) will be reduced).

Under our proposed policy package, low income, commercially non-viable farmers are specifically targetted for adjustment assistance. Currently, there is no means of facilitating structural adjustment in agriculture. The plight of the low income farmer therefore persists. We believe that the paddy farmer is now sufficiently frustrated with the current system for him to readily accept the proposed program of structural adjustment, which assists adjustment out of farming and/or amalgamation of holdings into more commercially viable entities. In particular, efficient farmers are effectively constrained to build up their farms by the presence of price subsidies which lock up resources on inefficient and poorly managed farms. Under these proposals efficient farmers will also be eligible to apply for commercial development loans.

Implications for Introduction of Bulk Handling Technology

Our analysis has shown that bulk handling is technically feasible and economically viable for the central storage system.

With the reforms proposed there will be renewed interest in commercial investment in the paddy handling and storage subsector. For example, there is the possibility that private investors will establish commercial grain drying and storage facilities handling grain in bulk, trading in dried paddy, and/or provide custom drying facilities to farmers. This will not only assist in the alleviation of the massive under-capacity in drying and storage, but also introduce modern grain handling and storage technology. The net effect of these proposals will be to stimulate private sector participation in the paddy handling sector which is one of the government's stated objectives. Private millers will be ready to tender for the leases on LPN facilities and to invest in the facilities on a long-term commercial basis. The proposed reforms provide the necessary catalyst for a change to occur. Without these changes it is believed that the main benefits of introduction of modern bulk handling methods would be forfeited.

Conclusion

Governments must always remain mindful of the consequences of their own decisions and the responsibility which they take for them. Our study has already demonstrated that a change to bulk handling would provide both social and private economic net benefits. However, we feel that many of these benefits will be dissipated if public sector participation and price subsidies are not also reduced. Public sector ownership can be effectively argued only if there is revealed market failure and government intervenes to promote equity and competition. *In the case of the Malaysian rice economy, government participation has reinforced market failure and constrained competition.* We therefore think that it is essential that the Government conduct a rational debate on these issues and pose the question 'What changes do we want?' rather than 'Why do we want to change?'.

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Case Studies on Bulk Handling in the Humid Tropics—I Session Summary

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THE first paper in this session reported on the results of a study conducted in 1985 on the costs of transporting paddy from the farm to LPN complexes. Three functions were estimated to represent transport cost, namely:

- trucking cost;
- queuing cost; and
- road transport charges.

Computations showed that trucking cost is primarily a function of distance, exhibiting an inverse relationship with its average variable cost and average total cost. Queuing cost, on the other hand, was found to be positively related to the amount of paddy delivered and inversely related to the number of workers available at complexes to unload the grain from lorries and tricycles. Lastly, the road transport charges were reported to be directly proportional to quality of paddy delivered, distance, and expected queuing costs.

The costs incurred by milling complexes in the procurement, drying, and milling of paddy, as well as the administrative cost involved in processing, were considered in the second paper. The total average processing cost was calculated to be $M97.09 per tonne. Drying took the largest share of the total cost at 38% (energy was the major cost component). Milling cost was the second largest component of processing cost (28%). It was noted that, in terms of cost elasticity with respect to output, a 1% increase in milling output will reduce the milling cost by 0.78%.

Administration and procurement represented, respectively, 26% and 8% of total cost.

The study further noted that recently commissioned rice complexes had much lower total average costs than older ones.

The third paper in this first case study session presented a model of the paddy and rice industry in Tanjung Karang, Malaysia based on the current marketing chain. The model captures spatial, temporal, and quality aspects of the rice postharvest system. It was calibrated against the real industry situation in Tanjung Karang and the theoretical results obtained from the model were considered to be sufficiently close to actual data collected.

The fourth paper reported on a sensitivity analysis of the rice industry model covered by the previous paper. In descending order, the variables that the model

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was highly sensitive to were: price paid for paddy; milled rice recovery rate; drying cost; and milling cost.

The next paper demonstrated the economic feasibility of converting the rice postharvest handling and processing system in Malaysia from bag to bulk. This conclusion was based on benefit and cost comparisons in a partial and general equilibrium model. However, due to social and political constraints, a full bulk system (farm to LPN complexes) was deemed inappropriate at present. A semi-bulk system from the procurement centres to the milling complexes was recommended by the authors as a feasible alternative.

The final paper in this session proposed an agenda for reform of the Malaysian rice economy. Policy and institutional changes were proposed, in order to permit the introduction of bulk handling and storage to proceed rationally in a conducive environment. Items in the proposed agenda included:

- the deregulation of the price of rice above grade 3;
- increased penalty on low quality rice;
- gradual removal of the price subsidy for paddy;
- provision of loans to the private sector for increased investment in modern grain handling and storage technology; and
- gradual reduction of LPN market participation.

Case Studies on Bulk Handling and Storage in the Humid Tropics—II

The papers presented in this session of the workshop reported the results of studies undertaken as part of the ASEAN–EEC Grains Post-Harvest Technology Programme.

Bulk Storage Paddy Aeration in Concrete Silos: a Malaysian Experience

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Abstract

This paper reviews silo storage in Malaysia using concrete silos with and without roofs for safe storage of dry paddy for periods of up to 6 months. Factors affecting the optimum use of aeration for silo storage are described, based upon experimental findings. Suggestions are made on the proper use of the system and the further research needed to make the system more effective and convenient to operate and control under humid tropical conditions.

AFTER being harvested, threshed, cleaned, and dried, paddy in Malaysia is normally stored in sacks or in bulk. Each system has advantages and disadvantages. The choice between the two is dependent upon several factors, such as the scale of operations, existing facilities and local conditions, availability of capital, relative operating costs, and so on. Bulk handling and storage in general involves a large initial capital outlay. However, in the long run it may prove to be a sound investment.

With the rising cost of manual labour and the increase in scale of production, there have been moves towards bulk storage in Malaysia, though bag storage is still important. Bulk storage is in the form of either on-floor storage or in-bin/silo storage.

In either system, the grain must be protected against deterioration during long-term storage. The risk of deterioration is high in bulk storage due to the larger unit volume of grain involved. Bulk storage in bins or silos provides a safe 'skin' to the bulk of grain against outside infestations from pest. However, there are also inside sources of deterioration, for example, moisture migration, localised heating of grain, mould growth, and infestations from insects and mites already inside the system. Investigators and storage operators over the years have found that one of the most effective and economical methods of protecting grain from most of these internal sources of deterioration is the practice of grain aeration.

The main protective mechanism in grain ventilation is the ability and capacity to maintain uniformly low temperature and moisture conditions in the mass of grain. In the humid tropics, this means maintenance of a temperature close to ambient throughout the mass of grain, thereby minimising the damaging effects of temperature gradients and hot spots. Studies elsewhere have also shown that certain mould activity is reduced during ventilated storage. The absence of hot spots and reduced mould activity may have been the main mechanisms leading to the reduction in grain discoloration observed during experiments in Malaysia. The same beneficial effects could also be achieved to a certain extent by a process of bringing the grain into contact with air during grain turning. However, the latter process is tedious, time consuming, more costly, and may interfere with other activities at the grain installation.

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Development of Bulk Storage in Malaysia

The period 1960–70 saw intense activity to upgrade the rice industry in Malaysia. Specialised areas were selected for paddy production and heavy investments were made in improving paddy farm infrastructures, facilities, and services. Similar investments were also made in the downstream operations of paddy storage and primary processing.

The establishment of LPN (Lembaga Padi dan Beras Negara) in September 1971 heralded a more concentrated approach to building up the infrastructures for paddy storage and primary processing. Several centralised and integrated paddy drying, milling, and storage complexes were built in the four major rice growing areas. For bulk storage of paddy, two types of storage structures were introduced, namely, flat horizontal storages and the vertical concrete silos. At the integrated complexes, each type of storage has a designed gross storage capacity of 6000 tonnes, with a supplementary 4000 tonnes capacity in the form of bag storage. Hopper-bottom horizontal bulk storages were subsequently introduced. Comparative characteristics of the three systems are given in Table 1.

LPN Concrete Silos

Since 1971, LPN has constructed 11 concrete silo installations, distributed throughout the four major paddy growing areas. The first six installations had no roofs, while the last five were fitted with cap roofs.

The silos are made of reinforced concrete. Each cell (eight cells per installation) has an internal diameter of 9.150 m (30 feet), a wall thickness of 0.1524 m (6 inches), a height of 25.908 m (85 feet), and a rated storage capacity of 680 tonnes of dry paddy.

Each silo cell is equipped with three lines of silo thermometers spaced at 120° intervals around the wall. The thermometers have been designed for rapid measurement of internal temperatures. The temperature sensing device consists of thermistors mounted in a protective cable suspended in the silo. Each cable has six thermistors equally spaced throughout the height of the silo. In total, there are 18 measuring points distributed throughout each cell. The temperature at any measuring point in any cell can be read from a meter located in the complex control room.

The eight cells have a common loading and unloading system consisting of belt conveyors for horizontal movement and bucket elevators for vertical movement of grain. The silos are connected directly to the drying and milling systems in the complex via a system of belt conveyors and bucket elevators.

Following the encouraging results of an aeration trial carried out at Ulu Tiram Buruk during 1981–1984 and subsequent extension work in Sekinchan in late 1984, the aeration system has been progressively introduced to all LPN silos. By 1986 all cells had been equipped with aeration facilities as shown in Figures 1 and 2. Cells with cap roofs utilise the suction mode of aeration, drawing the air from top to bottom, thus utilising the slightly dryer air created by the solar-collector effects of the roof. The aeration mode is reversed in the case of cells without roofs, basically to prevent ingress of moisture from any hair-line cracks from the exposed silo roof and walls, especially when wet.

Suitability of Local Ambient Air for Bulk Aeration

Studies carried out by Teter (1981), Nour et al. (1983), Ibni (1984), and others have demonstrated that aeration of bulk stored paddy under local conditions is possible if aeration is carried out during periods of the day when the relative humidity of the air is low.

The Ulu Tiram Buruk trials showed that between 10 a.m. and 10 p.m. ambient air was suitable for bulk aeration. The data in Table 2 show further that relative humidity of less than 75% is available during all months of the year.

Experimental Work on Aeration of Bulk Storages

Malaysia had a limited experience in bulk storage aeration of its concrete silos. The introduction of aeration facilities in recent years has been due to necessity in maximising the

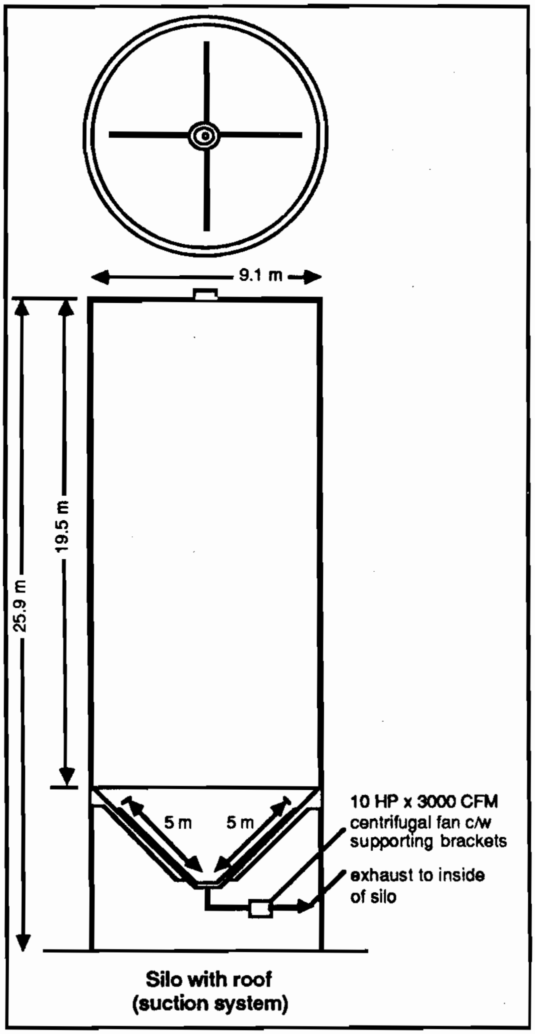

Fig. 1. Configuration of LPN aerated concrete silos fitted with roofs.

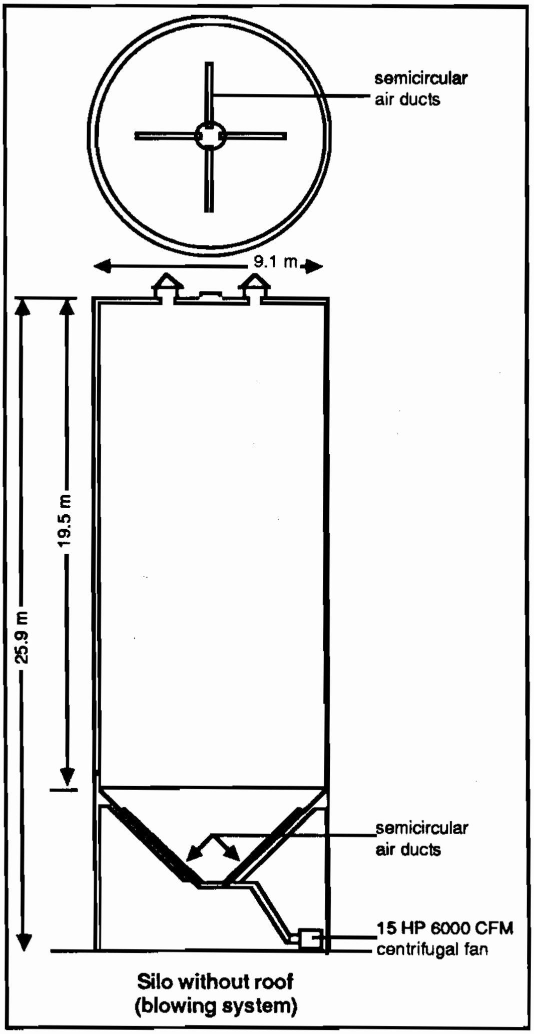

Fig. 2. Configuration of LPN aerated concrete silos without roofs.

utility of the available unaerated silos. Research activities undertaken in the past years in this particular field had been geared toward the urgent need of getting and testing a viable system, to arrest the losses incurred in silo storage.

Aeration Trials at Ulu Tiram Buruk

Aeration *versus* Grain Turning

The Ulu Tiram Buruk (UTB) system was tested over the period 1981–83 and has been reported on by Nour (unpublished data), Nour et al. (1983), and Loo (1985). Three aeration rates utilising selected ambient air were tested against the process of grain turning for storage periods of up to 4 months. Two of the aeration rates used, 0.3 m^3/tonne/min and 0.1 m^3/tonne/min, at total aeration times of 710 hours and 1205 hours, respectively, were found to be suitable and cheaper than grain turning. Grain discoloration, which is the main indicator of grain quality deterioration in local bulk storage of paddy was reduced to less than 2%.

TABLE 1. Comparison of various LPN bulk storage systems

Flat-bottom	Hopper-bottom (air-sweep)	Concrete silo
High construction cost (42.4% of total civil engineering cost)	High construction cost (49% of total civil engineering cost)	High construction cost (44.3% of total civil engineering cost)
Need manual labour to empty the grain	Can be emptied with aid of aeration fan	Self-emptying
Dusty and open	Enclosed (no dust problem)	Enclosed (no dust problem)
Semi-dried paddy (15–16% moisture content) can be stored for in-bin drying	Can keep only dry paddy of 13–14% moisture content (may be modified for wetter grains)	Can keep only dry paddy of 13–14% moisture content
Accessible and easy to inspect	Accessible and easy to inspect	Inaccessible and difficult to inspect
With aeration facility	With aeration facility	Without aeration facility in its original design

Germination rate, another indicator, remained at a high level of 85% to 89%. There was a slight drying effect (12.6% moisture content, wet basis to 11.9%).

The UTB trials also showed that aeration was simpler to manage and accomplish than grain turning. In any turning process, the other processes of transferring dry grain from the dryer tempering bins to the silos, from silo to silo, and from silos to milling bins are interrupted. The interruption could be for 121 hours on average, which would mean that complex's drying, storage, and milling operations would be severely affected. The risk of belt conveyor or bucket elevator failure was also high.

The other major disadvantage of grain turning is that, under local climatic conditions, no complex manager is prepared to fill non-aerated silos to full capacity due to previous experiences and their consequences. These silos were normally only one-third filled thus losing storage capacity and also wasting investment on the facility. With the introduction of aeration, net bulk storage capacity of the complex can be increased to its gross capacity of 6000 tonnes since the silos can be safely filled to design capacity.

Grain Temperature

Grain temperatures were generally stable at both the airflow rates used. Average grain temperature at midday when ambient temperature was highest (34°C) was in the range 32° to 35°C. As far as average vertical grain temperature distribution was concerned (Table 3), the top layers were slightly hotter (34–37°C) than the bottom layers (28–36°C). The temperature distribution was similar with both lateral and vertical modes of aeration, indicating a common source of heating. This was most likely heating of the silo outside wall by the sun since the top portions of the silos were exposed whereas the bottom portions were in almost total darkness for most of the time.

Insect Control

Further storage trials at UTB during 1984 indicated minor insect infestation in the paddy samples after $3^1/_2$ months of aerated storage. No infestations were detected in the initial grain sample (extensive sampling) before storage, indicating that infestation had probably resulted from hatching of eggs of insects and an increase in the population in the favourable environment (12% moisture content (wet basis) grain; temperature *c.* 34°C). Although the infestation was small, it nevertheless constituted a risk that had to be attended to.

Trials at Sekinchan

The Sekinchan aeration system, based on the 0.1 m^3/tonne/min flow rate UTB design was installed in late 1984 and was tested using paddy harvested at the end of 1985. Two silos were selected. It took a month to fill each one with dry paddy but aeration began as soon as the air ducting at the bottom of the silos was covered with grain. Aeration time was from 10 a.m. to 5 p.m. and the storage period for 6 months. Total aeration time was 1192 hours.

Maintenance of Grain Quality

The Sekinchan trial confirmed that selective aeration of bulk grain in concrete silos is safe and feasible under local climatic conditions.

There was no significant change in the percentage of discoloured grain between the start (2.5%) and end (2.4%) of the trial. Germination rate of paddy samples at the end of the storage period remained high at 91%. There was again a slight drying effect.

Average grain temperature at midday was 33°C, compared with average intake air temperature of 32°C (59% relative humidity) and average exhaust air temperature of 36°C (59% relative humidity).

Insect Control

A minor insect infestation was found in samples taken at the end of the trial. No insects were present in samples taken at the start of the storage period.

TABLE 3. Average vertical distribution of grain temperature in test silos at Ulu Tiram Buruk, Malaysia

Temperature probe level, top to bottom	Temperatures (°C) Airflow rate 0.3 m^3/tonne/min	Airflow rate 0.1 m^3/tonne/min
1	36.6	34.4
2	36.8	37.3
3	33.6	33.0
4	36.2	35.7
5	36.1	36.2
6	28.0	28.7
Average	34.6	34.2
Ambient temperature	32.5	30.0
Ambient relative humidity	59.5%	70.8%

Source: Nour, unpublished data

Note: the tests at the two airflow rates were undertaken at different periods during 1981, the higher flow rate in the middle of the year, and the lower at the end.

The Simpang Empat Perlis Silo System

The Simpang Empat Perlis (S.E.P.) system was installed in the middle of 1985. The system consists of blowing mode (bottom to top) aeration and utilises much higher airflow rates than at UTB (Table 4). The reasons for this, as mentioned briefly earlier, were as follows:

(i) the silos are exposed to the environment;

(ii) positive pressure created inside the silo cells will prevent the drawing in of moisture through any hairline cracks in the top cover and walls of the silos, especially when the structures are wet; and

(iii) there is a reduced risk of grain leakage into the aeration ducts.

TABLE 2. Percentage probability and total number of hours of ambient air suitable (< 75% relative humidity) for aeration through the year in Malaysia

Month	J	F	M	A	M	J	J	A	S	O	N	D
% Probability	40	50	45	39	25	23	30	28	22	23	22	31
Hours	346	323	306	232	164	151	148	155	132	141	150	260

Source: Ibni (1984)

No extensive storage tests were conducted due to time constraints. However, operational monitoring of storages for periods of a month indicated that the system was capable of maintaining grain quality, especially in terms of minimising grain discoloration. Total aeration time ranged from 94 to 110 hours for a month's storage. The aeration systems were manually operated when ambient relative humidity was below 75%.

General Findings and Recommendations

Feasibility of Bulk Aeration in Concrete Silos

1. Using the existing design of LPN concrete silos, in which no special facilities for grain turning are available, aeration has been found to be cheaper, more convenient, and does not interfere with or interrupt other processes in the complex.

2. All aeration practices carried out in the 11 LPN silo installations indicate that grain discoloration can be kept below 2%.

Design and Operational Implications

1. Aeration cannot control insect growth and development in the aerated bulk storage internal environment. A supplementary insect control system is therefore needed.

2. Airflow rates of between 0.1 and 0.3 m^3/tonne/min have been found to be sufficient.

3. A prescription of optimal aeration times (hours) per unit storage time has not been finalised. However, experience so far suggests that the airflow rates and times given in Table 5 were sufficient to maintain sound grain quality.

4. For operational and cost reasons, the vertical mode of aeration is preferable. It allows aeration to begin at the start of grain loading. Also, air ducting design, construction, and maintenance are simpler and cheaper (Table 4).

5. For silos with cap roof covers, the suction mode of aeration from top to bottom is recommended since there is a slight advantage from lower relative humidity of the ambient air used due to solar heating effects on the roof.

6. For silos exposed to the environment, a blowing mode from bottom to top is recommended. Positive pressure inside prevents moisture from wet surfaces (walls and silo top) being drawn in through any hairline cracks in the structure. The siting of the fan at the bottom of the silo reduces the cost of installation and makes inspection and maintenance easier.

Aeration Process Control

The present method of sensing environmental relative humidity using wet and dry bulb thermometers and subsequent manual switching on and off of aeration fans makes it difficult to optimise aeration potential. Records of aeration time utilised so far, show that only about 47% of the total potential aeration time (Table 2) was utilised.

This situation may improve as operators become more experienced. However, some form of automated control system is desirable. Such a system could then optimise not only daytime use but also early night time aeration when

TABLE 4. Types of aeration systems used in LPN concrete silos

Type of silo	Aeration mode	Cost of installation ($M)[a]	Fan power/pressure
With roof	1. push/suction	39 200	2 x 10 HP—900 CFM @ 2.5" W.G.
	2. suction	9 130	1 x 10 HP—3000 CFM @ 7" W.G.
Without roof	Push/blowing	9 088	1 x 15 HP—6000 CFM @ 9" W.G.

[a]Costs are in Malaysian ringgit ($M). During October 1987, $M2.50 = US$1.

TABLE 5. Summary of aeration times (hours) used to maintain sound grain quality in Malaysia

Storage period (months)	Location	Airflow rate (m^3/tonne/min)	Total aeration time (hours)
1	LPN Simpang Empat Perlis	0.2	94 to 110
3 1/2	LPN Ulu Tiram Buruk	0.3	710
4	LPN Ulu Tiram Buruk	0.1	1205
6	LPN Sekinchan	0.1	1192

temperatures are lower. It may also facilitate the development of alternative strategies of selective aeration using combinations of air temperature and relative humidity to achieve optimal storage conditions. It may be possible, for example, to overcome the present slight drying effect.

Future Research and Development Needs

1. More detailed studies on grain deterioration processes in a well-ventilated high temperature but lower relative humidity internal atmosphere of bulk dry clean paddy, in combination with other protective measures, such as the use of pesticides.
2. Development of a manual of operations and associated guidelines for aerated bulk storage of grain in humid tropical climates.
3. Development of an automated aeration process control system for the humid tropics.

Conclusion

LPN-MARDI experience over the past 5 years indicates that the practice of selective aeration of bulk stored dry paddy in concrete silos with low relative humidity (average 59%) but high temperature (average 34°C) ambient air has the capability and capacity to maintain sound grain quality for storage periods of up to 6 months. However, a supplementary control system is required to prevent insect infestation.

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Sealed Storage of Milled Rice Under Carbon Dioxide

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Abstract

This paper describes the sealing process and a subsequent preliminary controlled atmosphere storage trial on milled rice using carbon dioxide (CO_2) gas for insect disinfestation at the pilot 2000 t capacity storage at LPN Senawang, Negeri Sembilan. The storage design was based on the concept that airtight storage and a dehumidification system and fumigation facilities would permit prolonged storage of milled rice in an equilibrium relative humidity (e.r.h.) storage environment. However, preliminary investigations revealed that the reinforced concrete structure was permeable to moisture and vulnerable to humid tropical weather events, which invariably impede the functioning of the dehumidification system. A disinfestation trial using methyl bromide also failed.

Subsequent application of sealant improved the airtightness and stabilised the storage temperature and humidity. CO_2 treatment was found to be effective in controlling storage insects without affecting the quality of the milled rice. Further studies are needed to elucidate factors affecting the e.r.h. of the milled rice under sealed storage. The paper also discussed the constraints and other factors affecting the adoption of sealed storage technology under Malaysian conditions.

SEALED storage of milled rice is a new concept, thereby it warrants a cautious approach in its adoption particularly in humid tropical Malaysia. Nevertheless, the need to modernise the grain storage system, particularly moving towards pesticide-free methods of preservation, is inevitable. In its efforts to achieve this objective, the National Paddy and Rice Authority of Malaysia (LPN) built, in 1982, a pilot airtight godown equipped with dehumidification equipment. The concept was proposed and designed by a team of FAO/UNDP consultants in 1979. However, faced with some operational problems after a pilot storage experiment in 1983, a local research team decided to incorporate sealing as an additional structural component.

This paper describes a preliminary experiment involving storage of milled rice in a sealed dehumidified godown. The data presented should serve to guide future research on the practicality of the sealed storage system. The paper also discusses constraints to its adoption and potential benefits and costs for future consideration in moves towards bulk storage in Malaysia.

Background—Pilot Airtight Dehumidified Store

The 2000 tonne capacity airtight dehumidified godown at LPN's rice storage depot at Senawang was originally based on the concept that

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prolonged storage can be achieved when the humidity of the storage environment is in equilibrium with the grain moisture content at a given temperature. As previously described (Dhiauddin et al. 1984) the dehumidified godown is made of reinforced concrete and has an internal volume of approximately 4000 m^3 and floor area of 520 m^3.

The design specified that the godown be reasonably airtight and have an internal relative humidity of less than 70% to equilibrate with milled rice of moisture content 13% at temperatures of less than 30°C. The air dehumidification is provided for by a dehumidification unit consisting of an evaporator, a condensor, and a thermostat, built into an internal air recycling system. The internal air recycling system consists of an axial-flow fan, supplying air to ducts on the floor, roof, and front wall. The godown is also fitted with copper ducting on the roof to facilitate space fumigation with methyl bromide.

A trial involving bag-stack rice fumigated with methyl bromide at a dosage of 24 g/litre resulted in incomplete disinfestation, with heavier insect multiplication by the survivors. The store temperature reached 32°C, compared with the ambient 30°C in a conventional godown. The level of airtightness was not certain and moisture build-up in the concrete structure following heavy rain tended to exceed the capacity of the dehumidification system to lower the humidity to below 70%. It was decided to ensure that the godown was airtight by sealing it.

Storage Sealing

Sealing of storage is essential to achieve the dual objectives of ensuring airtightness and protecting the concrete against mechanical and corrosive damage and wear. More importantly, it enables gases such as carbon dioxide (CO_2) to be used as alternative fumigants to methyl bromide or phosphine which may leave unwarranted residue on the grain. For successful sealing, proper choice of sealant and its correct application are vital. The choice of sealant is subject to commonly accepted criteria covering its physical and chemical properties to provide good impermeability, strength to withstand adverse weather, flexibility to bridge all gaps and voids, and other properties specific to buildings structure and design (Sutherland and Thomas 1984; Woodcock 1984).

Sealing Specification

To achieve gastightness and water proofing, the approach adopted at LPN Senawang concrete storage was to seal both the external and internal roof and wall surfaces, and the concrete floor. Sealant *primer* with a coating thickness of 150 micron D.F.T. (dry film thickness) was used as an initial layer to bond the sealant to all concrete surfaces. Subsequent coatings used for various portions of the structure were as follows:

External roof and walls: acrylic sealant membrane of total coating thickness 150 micron D.F.T. Outermost layer with heat reflectant top coat of glossy white of thickness 150 micron D.F.T.

Internal surface of roof and walls: acrylic sealant membrane of coating thickness 150 micron D.F.T.

Exterior and interior concrete floor: one coat of water-based, single component epoxy floor coating. This was followed by two coats of two-component epoxy floor coating of hard water and chemical resistance.

Doors and air ducts: polyurethane foam was applied as an initial layer for all large gaps and voids. Pressure panels for doors, c/w frame back pressure bars. Outermost layer with sealant membrane of coating thickness 500 micron D.F.T. for pressure panels and air ducts.

Pressure test

The test standard for airtightness specified internal pressure decay to not more than one half of an induced pressure (a drop from 500 to 250 Pa or to 2.5 cm water gauge) over a period of 20 minutes, with the storage empty. This was conducted, and the pressure drop achieved (1.0 cm water gauge in 55 minutes) indicated satisfactory airtightness. The airtightness test for a storage filled with grain specified a pressure drop to half an initial level in not less than 5 minutes. This requirement was satisfied: the half-filled storage gave a pressure drop of 0.1 cm water gauge in 85 minutes.

The cost for the sealing process for the 2000 t capacity storage was $M68.50[1] per tonne of milled rice.

Methods and Materials

The sealing process was followed by an exploratory half-capacity scale trial to determine the storability of milled rice using CO_2 gas for insect disinfestation. The 3 months storage trial served to specifically evaluate:

(a) CO_2 decay pattern under humid tropical weather;

(b) efficacy of the CO_2 treatment to control insects

(c) operational problems related to sealed storage, research instrumentation, and application of CO_2; and

(d) effect of CO_2 treatment on rice quality.

Rice Storage

1000 tonnes of milled rice in 10 000 jute bags were stacked in 23 layers. Two vertical layers at mid-section of the stack were built in a way that facilitated post-storage sampling of marked bags at various positions within the stack (Fig. 1). The test rice was of B2 Malaysia Medium Grade (80% head rice).

[1]Costs are given in Malaysian ringgit ($M). During October 1987, $M2.50 = US$1.

CO_2 Application

Liquefied CO_2 from a bulk tanker was evaporated to the gaseous state through a heat exchanger. The industrial CO_2 was specified to be 99.5% pure with maximum moisture of 0.005%. Some 7.96 tonnes of CO_2 were required to purge the half-filled storage to the predetermined 80% CO_2 concentration. The purging operation was slow, taking 16 hours to complete, mainly due to frequent blockage of the vaporiser by condensed CO_2 ice. The CO_2 cost $M0.80/kg, resulting in a treatment cost of $M6.36 per tonne of rice.

Measurements

The CO_2 concentration within the store and the temperature and the relative humidity within and outside the store, were monitored twice weekly at 1400 hours. These measurements were achieved by extending to the external outlet thermocouple wires and PVC lines of 2 mm diameter, the latter for monitoring humidity and

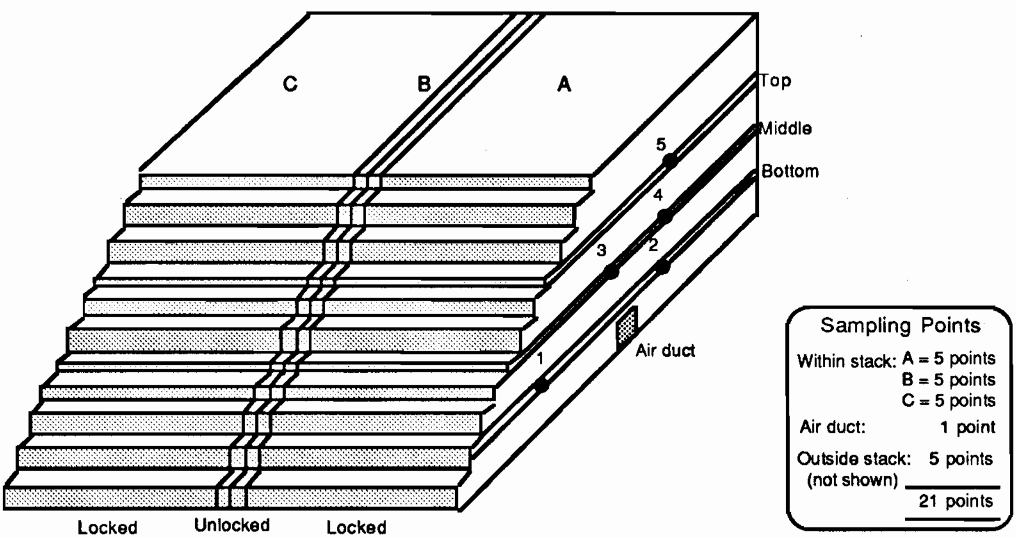

Fig. 1. Schematic drawing of bag stack in sealed storage, showing CO_2, temperature, and relative humidity sampling points.

CO_2 concentration. Measurements were taken at a total of 21 sampling points: 15 within the stack, 5 on the external surfaces and 1 in the airduct. The temperature was measured using a portable digital temperature recorder, and the CO_2 gas using a Fumiscope® gas conductivity meter. The accuracy of the Fumiscope® was frequently verified against a Kitigawa® CO_2 detector. A wet and dry bulb thermometer within a plastic casing was used for monitoring the humidity within the store but the ambient air humidity was measured by thermohygrograph. During each sampling for CO_2 concentration or humidity within the storage a suction pump was used to exhaust residual air or gas within the PVC pipe before taking the measurement.

Rice Samples

Pre-treatment rice samples were taken by probing 100 bags during stacking. Post-treatment samples were also obtained of probed grains from the surfaces of the stacks and from the marked bags in the unlocked layers. All samples from each sampling period were mixed and working samples obtained for analysis.

Rice Quality

Analyses of the effect of CO_2 treatment were based on the physical quality of the rice. Grain moisture was determined by the oven method (AACC method 44–19), bulk density by hectolitre device, and the whiteness using a Kett whiteness tester, model C–300 (calibration plate 86.2 ± 0.1). The rice grades were also analysed manually using the Malaysian grading system. Damaged grains consisted of both discoloured and insect damaged grains based on head rice samples. The proportion of yellowing was assessed from milled rice samples.

Insect Control

The effectiveness of CO_2 treatment in disinfesting rice was evaluated using test insects. Egg, larva, and adult stages of *Tribolium castaneum* (Herbst.), *Sitophilus zeamais* (L.), *Oryzaephilus surinamensis* (L), and the larva of *Trogoderma granarium* (Evert.) were inserted at two bag depths between bags at 9 locations (= replicates) around the vertical sides and top of the stack. Each insect stage from each species, together with 10–15 g milled rice as a medium, was caged in cylindrical mesh cages measuring 3 cm × 1 cm diameter. Three of these cages, each containing the three life stages of each species, were inserted into 45 cm long perforated brass probes. Ten adults or larvae were released per each insect cage, i.e. 90 individuals per life stage of each species were tested. The eggs, or the impregnated grains in the case of *S. zeamais*, were not counted but wholly transferred into the mesh cage after being sifted from the culture jars. Control insects were similarly prepared but inserted into an untreated rice stack stored in an adjoining conventional ventilated rice store.

Results

CO_2 Distribution

Current recommendations state that a CO_2 concentration above 35% must be maintained for at least 10–44 days for successful insect control (Annis and van S. Greve 1984; Jay and D'orazio 1984). The exposure time needed to obtain high levels of insect control is a function of CO_2 concentration, temperature, grain moisture content, and the species and life stages of the insects which are infesting the grain (Jay and D'orazio 1984). The results of the preliminary trial showed that CO_2 concentration was maintained above 35% for 7 weeks from the initial 80%, and that there was an average weekly loss rate of 4.7% CO_2 content during the 12-week storage period (Table 1). The weekly CO_2 loss rate (6.8%) was greater during the first month than during the second (3.0%) and third (1.8%) months. CO_2 concentrations within the stack and in the surrounding space within the store were evenly distributed throughout the storage period.

Temperature and Humidity

The mean temperature of the rice at 27.7°C was slightly higher than the average ambient temperature which averaged 26.2°C (Table 2). However, the temperature within the store was 4.6–6.1°C cooler than ambient air temperature measured at 1400 hours. The daily fluctuations of temperature and relative humidity within the sealed storage were observed to be minimal,

TABLE 1. Carbon dioxide (CO_2) concentrations in sealed milled rice store at LPN Senawang

Weeks after treatment	% CO_2 at various sampling points Outside stack	Air duct	Within stack	Average
1	79.2	79.0	79.0	79.1
2	68.1	68.1	68.1	68.1
3	59.2	59.4	59.6	59.4
4	51.7	51.5	51.7	51.6
5	44.7	44.7	44.7	44.7
6	39.7	39.8	39.9	39.8
7	35.0	35.0	35.0	35.0
8	32.4	32.4	32.5	32.4
9	29.5	29.5	29.5	29.5
10	26.7	26.7	26.7	26.7
11	24.2	23.8	23.8	23.9
12	22.0	22.3	22.0	22.1

compared with a 26–34°C daily range in temperature and 60–100% in relative humidity. The relative humidity of the CO_2 environment outside the stack averaged 77–78.6%, compared with 75.5% within the stack.

It was observed that the humidity levels were brought down to below 80% after two weeks from the start of the trial, when the dehumidification plant was switched on. The dehumidification system is therefore still needed as an integral part of the sealed storage system. Moreover, these findings indicated the need to further reduce the humidity to below 60%. This requirement arises from the need to achieve equilibrium relative humidity for rice with a moisture content lower than 13%.

Insect Control

No live insects were found in grain samples taken after the sealed store was opened. All the eggs, larvae, and adult stages of *T. castaneum*, *S. zeamais*, *O. surinamensis*, and the larvae of *T. granarium*, were dead. Test insects from the untreated stack showed better than 75% survival, with the exception of *T. castaneum* which showed high mortality, possibly due to this species vulnerability under adverse microclimate afforded within the insect cages (Table 3). Nevertheless, from the CO_2 treated samples, 2 adult *T. castaneum* were found to have emerged from the cages containing eggs; and 3–8% of the larvae of *T. castaneum*, *S. zeamais*, and *O. surinamensis* managed to complete their development to adulthood.

The CO_2 treatment also completely prevented new (F1) insect emergence, including *T. granarium*, which is the most difficult storage insect to control.

TABLE 2. Temperature and relative humidity (rh) within sealed storage under carbon dioxide (CO_2) treatment compared with ambient environment

Weeks after treatment	Mean temperature and relative humidity at 1400 h within sealed store: Outside stack (°C)	Outside stack (% rh)	Airduct (°C)	Airduct (% rh)	Within stack (°C)	Within stack (% rh)	Ambient (°C)	Ambient (% rh)
1	25.8		25.6	85.3	28.0	75.3		
2	25.1		25.0	80.0	26.8	68.0	33.4	51.4
3	28.3	73.2	26.8	74.0	28.1	72.8	33.9	56.6
4	27.3	58.3	27.0		28.2	54.0	33.9	54.3
5	26.7	79.0	27.0	76.5	28.2	80.9	33.0	64.7
6	25.9	77.5	26.5	79.0	27.6	78.1	34.2	52.6
7	26.2	80.0	26.0	78.5	27.4	77.4	33.3	57.5
8	26.2	80.0	26.0	80.5	27.8	79.0	31.7	64.2
9	26.1	81.0	26.5	82.0	27.9	82.0	30.8	66.9
10	26.3	78.0	26.5	76.0	28.0	78.5	30.9	66.7
11	25.6	82.5	26.0	85.5	27.9	85.0	30.4	70.0
12	25.2	79.5	25.3	77.5	26.9	77.0	30.2	71.0

TABLE 3. Mortality of caged insects resulting from carbon dioxide (CO_2) treatment compared with caged insects in an untreated stack

Insect	Mean mortality from initial test insects (%) CO_2 treatment Insect Stage Egg	Larvae	Adult	Remarks
T. castaneum	100	100	100	2 adults emerged from egg stage; 8% larval stage emerged as adults
S. zeamais	100	100	100	3% larvae emerged as adults
O. surinamensis	100	100	100	8% larvae emerged as adults
T. granarium	NT[a]	100	NT	
		Untreated		
T. castaneum	100	100	90	
S. zeamais	0	0	0	15× more live insects emerged as adults from test egg, larvae, adult stage
O. surinamensis	69	25	15	12 live adults emerged from egg stage; 25% more live adults from test adults
T. granarium	NT	23	NT	44% more insects emerged as dead/live larvae/adults

[a]NT = not tested

Considerable insect multiplication occurred in the untreated cages, most of the offspring surviving. It should be noted that mortality of the initially unknown number of eggs was assessed from the mortality of the subsequent stage(s).

Rice Quality

The moisture content of the rice after 3 months storage showed a significant increase, from an initial 11.3% to 11.8% (Table 4). However, 73 litres of moisture were collected over the 3 months of the trial at the external outlet of the internal air ducting. Whether this moisture condensed from the air or was desorbed from the rice is unknown. The uncertainty can be attributed to apparent moisture absorption, based on the recorded moisture content of the rice before and after storage, and the equally significant weight loss of 0.46 kg per hectolitre in the assessed bulk density of the rice.

The CO_2 treatment did not cause significant changes in grain colour in term of chalkiness, vitreosity, whiteness, and the proportion of yellow rice. No change in the proportion of insect-related damage was observed. Inconsistent results obtained from assessments for other qualitative parameters related to the sizes of the grains, such as proportion of broken rice and predominating and contrasting variety, reflects the dependability of manual analysis of grain quality.

Discussion

Sealing of the pilot LPN Senawang rice store succeeded in improving the airtightness and storage environment of the store. The resulting lower and more stable storage temperature and humidity improved the dehumidifying system, the function of which was otherwise impeded due to moisture accumulation within the concrete structure. More importantly, the sealed storage enabled research to be conducted on the practicality of controlled atmosphere storage of milled rice under humid tropical conditions.

As shown in this preliminary investigation, CO_2 treatment is effective in disinfesting storage insects. On a per application basis, the cost of the CO_2 ($M6.36 per tonne) is high compared with the cost of methyl bromide or

TABLE 4. Analysis of rice quality after 3 months storage under carbon dioxide (CO_2)

Parameters	Pre-treatment	Post-treatment
1. Moisture content (%)	11.34 ± 0.15	11.83 ± 0.37**
2. Bulk density (kg/hectolitre)	79.24 ± 0.56	78.78 ± 0.56**
3. Colour		
whiteness	39.32 ± 0.30	38.96 ± 1.28 n.s.
yellow grain (%)	0.10 ± 0.40	0.12 ± 0.06 n.s
From head rice		
vitreous (%)	96.68 ± 1.20	97.91 ± 1.11 n.s.
chalky (%)	2.72 ± 1.03	1.55 ± 0.81**
damaged (%) (discoloured and insect damaged)	0.60 ± 0.31	0.52 ± 0.30 n.s.
4. Grading		
From milled rice		
head rice (%)	80.88 ± 1.67	78.29 ± 0.9**
brokens (%)	19.12 ± 1.67	21.68 ± 2.06**
From head rice		
predominating variety (%) (medium)	81.97 ± 3.18	86.98 ± 4.08**
contrasting variety (%) (long and short)	18.03 ± 3.18	13.02 ± 4.08**

Note: n.s = not significant; ** = significant

phosphine fumigation ($M0.40 per tonne). However, for 12 months storage of 1000 t of rice in conventional storage and using current pest control practices, the total cost for pest management at $M13.0 per tonne is twice as high as sealed storage. This figure includes cost of fumigants, insecticides, all equipment, and labour. For effective pest control, repeated applications of under-sheet fumigation and insecticides are needed to protect the stack from reinfestation. This contrasts with the ease and safe application of CO_2 treatment and the assurance of rice free from residues at the end of the storage period.

Irrespective of the outcome of continuing studies on the feasibility of controlled atmosphere storage in Malaysia, there are two main factors that need careful consideration before widespread adoption of the system:

1. Capital cost. Sealed storage requires a high initial capital investment. The present pilot storage cost $M546 per tonne, broken down as follows:

Gastight godown	$441.00
Dehumidification plant	30.00
Axial fan; pressure vent	6.50
Sealing	68.50
Total	**$546.00**

These costs cover construction of new storage and the sealing process. It is envisaged that new horizontal storages built by LPN would be designed so as to be suitable for conversion into sealed grain storage with capital investment on sealing only.

2. Strategic or long-term storage. Another main criterion for decision on sealed storage is whether there is any need for storage of grains for periods exceeding, say, 9 months. This period is about the optimal time for safe storage of milled rice under conventional storage. As such, there is need to establish a practical storage policy, taking into consideration present

stock turnover for various grades, maintenance cost, supply and demand patterns at various storage centres, and the national policy on grain production and importation. With the establishment of a clear marketing policy which determines the scope and scale of storage operations, a long-term plan on storage method can be formulated. This would include consideration of whether there is need for sealed storages and their size and location if it is decided to adopt the technology.

Conclusion

Findings from preliminary experimentation on sealed storage of milled rice under CO_2 have shown that the concept is technically feasible for achieving safe, long-term storage under humid tropical climates. Continuing studies are directed to solving certain operational problems arising from its application on milled rice.

If the technology is proven, there will be a need for careful study regarding its adoption, taking into consideration present and future marketing policy which determines the scope and scale of storage operation, the national policy of grain production and importation, and the investment cost of construction of new sealed storages or of converting existing horizontal stores.

Although in sealed storage the grains are more convenient and economical to handle and store in bulk, there is no clear justification in most developing countries to convert from bagged to bulk as far as milled rice storage is concerned. As such, building a dual purpose bag/bulk store such as the one described at LPN Senawang may be a good investment covering likely future requirements.

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Maize Storage in Steel Silos at the Takfa Silo Complex of the Marketing Organization for Farmers, Thailand

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Abstract

Investigations on maize storage in steel bins under R–3 ASEAN–European Economic Community Grains Post-Harvest Technology Programme were made during the wet season harvest time in Thailand. Four steel bins each of 750 tonnes capacity were used for storing maize for 6 months. Under the semi-airtight storage conditions, unloaded maize was found to meet Thai Yellow Maize Standard quality requirements. The paper discusses the implications of the results for the implementation of bulk handling in Thailand.

BULK handling and storage of grains have been practiced for many years in Thailand. Paddy in bulk was transported by barges from local markets at the rice mills situated on the banks of the rivers. Many modern rice mills and storages have changed from manual to mechanical handling. There is very little information in the literature about the bulk handling of grains in Thailand because it is mostly a private sector operation. Government agencies have recently carried out a number of basic research programs on bulk handling. This paper reports on a research and development project sponsored by the Asean–EEC Collaborative Programme on Grains Postharvest Technology. The aim of the project was to improve silo practices for maize handling. There were three elements to the project:

- modification of silo bins and accessories;
- establishment of a small laboratory for physical analysis of grain;
- undertaking of a maize storage trial in order to set guidelines for silo operation.

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Materials and Methods

The R–3 project is still under way but 6 months experience in storing maize has already been gained.

Details of Silo Bins

Diameter of bins: 10.9 m (36 feet)
Eave height: 9.8 m above foundation
Effective storage height: 9.5 m
Capacity: about 886 m^3, i.e. 700 tonnes of maize (basis 780 kg/m^3)
Type of silo: flat bottomed, with two aeration channels. The silo is unloaded by gravity outtake up to the angle of repose and thereafter with the assistance of a sweep auger.

Handling of maize

Grain intake: Farmers delivered both bagged and bulk grain. Maize was checked twice for grading acceptance. The moisture content and visible quality appearance are two broad pricing differentials. Weight discounts were made based on moisture contents above 14.5% and the visible quality appearance.

Grain pre-cleaning and drying: Grain procured was passed through a pre-cleaner before going to the dryer. Grains with different initial moisture contents were kept in a tempering bin for 12–24 hours to let moisture become uniform. Drying was done in an LSU type dryer at air temperature 80°C. High moisture content grain (more than 22%) made two passes through the dryer. Grains were dried to about 15% moisture content.

Grain storage: Dry grain was moved to storage bins and treated with insecticide after 3 months storage. Grain was kept for 5–6 months over the period October to March (late rainy season to dry season in Thailand).

Unloading of grain: After 6 months storage, grain was unloaded and inspected. It met quality requirements for Thai Yellow Maize Export Standard. The final moisture content of the grain was too low, because of moisture equilibrium in the dry season.

Findings on Bulk Handling Practice

1. There was very little biological activity of the grain during storage because it had been treated with hot air of temperature 80°C during drying. The grain would have been dead before storage commenced.
2. Grain was not treated with insecticide at the beginning of storage, yet no insect damage was found in the unloaded grain. This supports the view that empty bins should be treated with insecticide before grain receival.
3. There were some 44 tonnes of dry grain remaining in the bins after unloading of the 2670 tonnes registered as stock.
4. The moisture content of the unloaded grain was 11.5–12.5%, lower than standard requirement (14.5% m.c.). The weight loss translates into a monetary loss during subsequent trading.

Discussion

The Marketing Organization for Farmers (MOF), in handling the R–3 Project on Bulk Handling of Maize, aimed to assess whether bulk handling would help farmers in terms of 'return to drying' and 'moisture discount'.

Standard for Thai Yellow Maize

1. Other coloured grain—not more than 1%
2. Slight damage and heavy damage—not more than 4%
   (limited heavy damage—not more than 1.5%)
3. Weevilled grain—not more than 2%
4. Broken grains—not more than 2%
5. Impurities—not more than 1.5%
   (must be isolated from oil seeds and toxic substances)
6. Average moisture content—not more than 14.5%

1. Return to drying' means the penalty for selling wet maize, in so far as 'returns to drying' are left to cover drying cost.
2. Traders buy maize at the standard weight of 14.5% moisture content and discount from the bid price to compensate for excess moisture content (above the standard moisture content notified). Moisture discount rate can be evaluated with the drying and handling charges as relating to:
   - value of shrinkage;
   - imputed drying and handling charge.
3. Value of shrinkage is the cost of total shrinkage that varies from the time and location as based on the price of maize in the market.

Total shrinkage = water shrinkage + dry matter loss (DML)

$$\text{Water shrinkage} = \frac{100\% - \text{initial }\%\text{ m.c.}}{100\% - \text{final }\%\text{ m.c.}} + \%\text{DML}$$

4. Return to drying equals the difference between receipts for maize sold dry and receipts for maize sold wet.

Receipts sold dry = price × dry grain at 14.5% m.c.

Dry grain at 14.5% m.c. = wet grain – (water shrinkage + DML) (or total shrinkage)

Receipts sold wet = price × wet grain sold

This perspective reveals the cost of the wet grain penalty imposed on farmers. In fact, the net profit from drying maize comes from value left after deducting drying cost from the 'return to drying'.

The 44 tonnes of maize which remained after unloading the full quantity of registered stock was said to be the extra profit gained by using the weight discount rate. This once again raises the question of what 'rate of weight discount' should be used? This and other questions relating to the implementation of bulk handling will be studied in forthcoming projects.

Study of Bulk Handling Equipment to Support the Handling of Paddy at KUD and Sub Dolog Task Force Levels in Indonesia

Anton Martono*

Abstract

Tests of bulk handling equipment for paddy were carried out at KUD Tani Binangkit and Rengasdengklok Task Force Sub Dolog Karawang, West Java during the 1986 harvest season.

The bulk handling equipment used was simple and could be made locally. It included spare parts and after sales service, and was designed for use at KUD and Sub Dolog Force levels. The bulk handling equipment tested consisted of 1 belt conveyor 10 metres long and 2 conveyors 7 metres long, 4 hand carts of paddy capacity 200 kg, a bulk trailer of 2 tonnes capacity, a mechanical sweeper, a hand tractor, hopper bins of 5 tonnes and 1 tonne capacity, an elevator, modified scales, and ramps.

The work carried out included construction and performance trials of the equipment, and observation of its operational capacity, problems, advantages, and working systems and efficiencies of several combinations of the equipment.

In technical terms, the use of belt conveyors, hand carts, bulk trailer, hopper bins, and elevators for bulk handling can be successful, and can smooth the processing of paddy, but the equipment needs modifications to improve its performance and overcome operating difficulties.

The data obtained have been analysed to compare different working systems. The data can also be used to develop improved working systems for future trials.

THE handling of paddy after harvesting, during transportation, drying, and transfer from the processing unit to the warehouse, is usually done by bagging the paddy after each operation. This bag handling system has some disadvantages: it needs bags that are relatively expensive and limits handling capacity. In some future processing complexes there will be a need for a faster, higher capacity system. The handling of paddy on the sun drying floor when rain is imminent needs a high transfer capacity to save the grain from damage.

As part of its research program, BULOG has, since 1978, been involved in a study of bulk drying and storage of paddy. This has included three trials, each with 2000 tonnes of wet paddy, which were mechanically handled, cleaned, and stored. These trials demonstrated the feasibility of drying wet paddy and storing it in bulk during the rainy season. This offers advantages to BULOG in terms of a reduced need for gunny sacks for handling and storage, and possibly a reduction in labour and time (Renwick and Zubaidy 1983; Kenneford 1984).

BULOG is now therefore examining the possible practical applications of bulk handling systems at KUD and Sub Dolog Task Force levels, and the incorporation of drying, cleaning, storage, and milling operations into these systems.

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All of these require some degree of bulk grain movement for filling and emptying, either manually by shovelling or by use of mechanical equipment such as bucket elevators, mobile augers, and belt conveyors.

The Paddy Marketing Chain at KUD and Sub Dolog Task Force Levels

The KUD (Village Unit Cooperative) buys paddy from farmers and small traders, irrespective of their membership of that KUD. KUDs rarely have their own transport, which is generally provided by either the small traders or by hiring vehicles from the private sector.

The paddy arrives at the KUD in lots of between 200 kg and 3 tonnes and at moisture contents often above 20%. All the incoming paddy needs to be dried.

Since the Dolog normally buys rice in milled form from the KUDs, the KUDs prefer to mill their own paddy. If paddy prices fall below the official floor price fixed by government, the Dolog activates the Task Force to buy at this floor price (discounted as necessary for quality factors and moisture content). The Task Force should buy direct from the farmers but in practice it tends to buy through traders because of the difficulties of sufficiently rapid collection from outlying areas with poor roads and scattered farms. The Task Force has its own facilities for drying and milling the paddy before passing the milled rice to the Dolog for storage.

Selection of Bulk Handling Equipment

Any introduction of new technology, especially at KUD level, would be best done on a slow and gradual basis, starting with very simple changes, so that the advantages and consequences can be readily identified and appreciated. At the same time, a cautious approach minimises the risk of an incompletely tested system giving unsatisfactory results and biasing operators against continued testing and use. Even if satisfactory results can be obtained, radical changes to a familiar system could result in hostility or reluctance by staff and workers to adopt the changes, especially if they involve a reduction in labour requirements.

Another commonly expressed concern among managers was that bulk handling would necessarily be expensive and beyond the technical abilities of prospective operators.

Decisions on the choice of handling equipment must be made in the light of three basic considerations: the material to be handled; the location and conditions of use; and external influences.

Paddy, the material to be handled, is very abrasive and any friction between grain and machine (cause by relative movement, e.g. sliding, scraping, or impact) causes wear to the machine and may damage the grain.

Consideration must be given to the finance available for purchase, operation, and maintenance of the equipment, and to the level of skills available among the intended users.

The first part of the project attempted to identify the most flexible systems and equipment, and test them in a number of combinations and at sites with differing operational requirements. From a consideration of the characteristics of the equipment, of the paddy itself, and of the requirements of the intended users, the most appropriate bulk handling equipment for use at both KUD and Task Force levels seems to be bucket elevators for permanent installations and mobile belt conveyors for general site use.

Belt conveyors are manufactured locally and have definite advantages over other types of conveyors in the handling of wet and dirty paddy. For maximum flexibility, these conveyors would be used in combination with hand carts for on-site movement.

The Paddy Handling System at KUD and Sub Dolog Task Force Levels

As noted earlier, the KUD receives paddy in lots of between 200 kg and 3 tonnes, in bags delivered by many suppliers, including farmers and small traders. The rate of receival is difficult for the KUD to regulate, averaging 10–15 tonnes per day during the harvest season. This incoming paddy usually has a high moisture content (over 20%). Average sun drying floor capacity is 5–15 tonnes and drying takes between 1 and 3 days depending on weather conditions.

After drying, the paddy may be milled by the KUD, sent to a private miller, or sold to the Dolog. Many KUDs have their own mills, of 0.7–1.5 tonnes/hour capacity and these are operated for up to 10 hours/day.

Within the KUD, a very simple system is needed, one that has maximum flexibility, low maintenance, easy operation, and minimum set-up and running costs. The system must provide for paddy movements between delivery vehicle, mechanical dryer, sun drying floor, mill, and godown.

Task Force centres are the responsibility of the Sub Dolog and are equipped with sun drying floors, mechanical dryers, milling units, and storage godowns. Each centre has its own fleet of 3 or 5 tonne trucks and buys wet paddy direct from farmers and small traders at collecting points up to 30 km away (average maximum distance). The trucks are despatched in the morning, return about midday, and are unloaded onto the sun drying floor, if there is space, or into the godown or mechanical dryer. They may then be despatched to collect a further load in the afternoon.

Each centre tries to limit its wet paddy intake rate to match the combined drying capabilities of its floor and mechanical dryers.

After drying, the paddy may be bagged and stacked temporarily near the mill. Alternatively, some Task Forces (and some private millers) store paddy in bulk between drying and milling. They do this by heaping it into a pile near the mill, using walls made of bags to retain the grain. After milling, the rice is bagged and despatched to the Dolog warehouse.

The study carried out was based on a feasibility study at KUD and Sub Dolog Task Force, which identified various possible handling systems. Trials were carried out to test the performance and suitability of various types of equipment for different applications.

The bulk handling equipment used consisted of 1 belt conveyor 10 metres long and two 7 metres long, 4 hand carts each of 200 kg capacity, a bulk trailer of 2 tonnes capacity, a sweeper, a hand tractor, hopper bins of 5 tonnes and 1 tonne capacity, a bucket elevator, and two sets of scales modified to weigh the loaded hand carts.

Bulk Handling Equipment Performance Tests

Belt Conveyor

Principles. A wide belt is tensioned between rollers, one of which is rotated to move the belt. Grain falls directly onto the belt and falls off as the belt passes over the end roller. Between the tensioning rollers, the belt may be supported by either intermediate rollers ('idlers') or it may slide along metal guides in a trough. Conveying capacity can be improved by lifting the edges of the belt to form a trough; this is done by angling the idler rollers.

Practice. Using belt conveyors for bulk handling at KUD Tani Binangkit and Task Force Rengasdengklok Sub Dolog Karawang proved to be technically possible, but during operations some problems were found.

The conveyors were heavy and awkward to manoeuvre. They were therefore difficult to move from one place to another, even though they had been fitted with wheels. Six labourers were needed to move a belt conveyor.

While paddy was being fed onto the belt conveyor, manually from hand carts or bags and during unloading from the dryer bin, there was considerable spillage and large amounts of paddy were trapped between the rubber belt and driving roller. Another problem was vibration which caused the belt conveyor to move during use, and thereby frequent adjustment of its position.

The main advantage of using the belt conveyor is its operational flexibility. It can be used for bulk handling of any type of grain at various locations and for operations such as loading and unloading bin dryers and trucks, and for transfer to and from warehouses, rice mills, sun drying floors, and other handling places. If a continuous loading feed can be arranged, a conveyor can operate at high capacities (around 10–15 tonnes/hour) and provide easy lifting of paddy. Conveyor belts do not cause grain damage, present no problems with stones, straw, and string in uncleaned grain, have low power requirements, are hard wearing, and require little maintenance. Local manufacture can be arranged and spare parts are readily available.

Bulk Hopper Bins and Elevator

Bulk hopper bins can be used in a bulk handling system to store paddy temporarily before it is cleaned or milled in the rice milling unit. The capacities of the hopper bins tested were 5 tonnes in Task Force Rengasdengklok, and 1 tonne in KUD Tani Binangkit.

The elevator to fill the hopper requires a power supply. At Rengasdengklok Task Force this power supply was from an electric motor running on the electricity supply to the site, but at KUD Tani Binangkit a generator was required.

The power problem must be solved for KUDs which are not supplied with electricity.

The use of hopper bins and supply elevators in the bulk handling system provided convenient off-floor storage for large quantities of paddy. The hoppers could, for example, be loaded during the afternoon then used to supply the mill on the following day. They were easy to use, and allowed more flexible use of labour force. They may also enhance the quality of milled rice because they permit a constant supply of paddy to the mill.

Hand Tractor, Trailer, and Sweeper

The hand tractor could be used either to pull a bulk trailer or to push a sweeper on the sun drying floor.

The trailer could be used to transfer bulk paddy from fields close to the KUD or processing centre or for transfer within the processing complex itself.

Bulk trailers have several advantages. They can transport large amounts of paddy, it is possible to use them for spreading paddy directly onto the sun drying floor and, having four wheels, they are stable when disconnected from the tractor.

However, they are difficult to manoeuvre, especially to reverse, when compared with, say, a small truck of the same capacity. Also, the tractor tyres can cause grain damage, the unit needs bridges in order to cross drainage ditches etc., and is slow. The sweepers tested were awkward to use and adjust, heavy, left large amounts of uncollected paddy, especially on uneven surfaces, and were not wide enough to sweep all the paddy in one pass. However, if these problems could be solved, the mechanical sweeper would provide a fast and easy way of collecting paddy. This would be especially useful at times when rain was imminent.

Hand Carts

Hand carts can be used to transfer paddy from the sun drying floor to the processing warehouse and from the bin dryer to the sun drying floor or the processing units.

The capacity of the hand carts used was 200 kg of paddy. Two labourers were needed to push them. Front unloading doors were fitted, making the carts easy to use for emptying and spreading paddy onto the sun drying floor. The advantages of hand carts are that they are cheap, easy to use, and flexible.

The Bulk Handling System for Paddy

The KUD or Sub Dolog Task Force normally buys wet paddy from the field in gunny bags or plastic bags, which are transported by truck to the processing centre at the KUD or Task Force. The grain may be sun dried or dried in a mechanical dryer.

Various combinations of bulk handling equipment for transferring paddy have been tested and compared with bag handling. Table 1 shows that it takes 23 man-hours to handle sun drying of 5000 kg of paddy and about 12 man-hours to load and unload the same amount of grain to and from a mechanical dryer. In contrast, a belt conveyor can load 2000 kg of paddy into a dryer in about 20 minutes when the grain is loaded directly from sacks onto the belt, or about 40 minutes if it is shovelled from the floor to the belt. Table 2 gives the average capacities of various bulk handling systems tested. The handling capacity of the equipment depends on the number of labourers available and the transfer distance involved.

Bulk Handling System at Village Level Cooperatives (KUDs)

The overall conclusion of this study is that mechanical bulk handling equipment as envisaged at present, with the possible exception of feeding hoppers, hand carts, and wheelbarrows, is not appropriate for use at village level in West Java.

TABLE 1. Times taken by six labourers to handle 5000 kg of paddy by conventional methods.

Sun drying	Time (minutes)
1. Opening sack and emptying out paddy	89
2. Spreading	20
3. Turning back	16
4. Collecting	36
5. Transferring to warehouse by baskets (35 metres trip distance)	69
Mechanical drying	
1. Loading by sacks	50
2. Unloading by baskets	69

TABLE 2. Average capacities of several systems for handling paddy in bulk.

Handling system	Average capacity (kg/hour)
1. Baskets	4214
2. Hand carts	4391
3. Belt conveyor loaded by shovel	4158
4. Belt conveyor loaded from baskets	4709
5. Belt conveyor loaded from hand carts	4519

Such equipment could become viable given the following circumstances:

- large increases in throughput at the average KUDs;
- sufficient technical ability is developed amongst KUD staff to carry out routine repairs and servicing of such equipment; and
- a change in the function of the KUDs that would justify subsidisation of the capital and running costs of such equipment.

In the current circumstances, alternative and cheaper approaches to increase drying and handling capacity should be explored. These are:

- improvements in the surfacing and finish of sun drying floors and improvement of the tools being used to spread, turn, and gather rice on the floors in order to reduce spreading and collecting times; and
- improvements in site design to reduce handling distances and the provision of better access to reduce movement times and difficulties.

Area Dolog Task Force

With considerable modification and training of operators, some types of mechanical handling equipment could be successful at Task Force level. For this application the possible increases in handling and drying capacities outweigh the economic problems. However, major problems in design, manufacturing, reliability, and training must be solved before any such equipment is introduced. The alternative approaches to increasing capacities outlined for KUDs are equally valid for Task Force units.

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Bulk In-bin Storage of Paddy under Malaysian Weather Conditions

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Abstract

This paper reports on a study of the potential of an in-bin drying system. The study indicated that paddy, after being partially dried to 17–18% moisture content by a conventional fast-drying process (through the use of LSU continuous-flow dryers), can be conditioned in the in-bin storage structures to a final 13–14% moisture content utilising the existing aeration facilities and a supplementary heat source. A 750 tonne bin, with a fan delivering air at about 1.02 m^3/min/tonne was used. Blowing air with a temperature of about 7°C above ambient conditioned the paddy to 13–14% moisture content in about 390 hours. Results of a comparative analysis of the quality of the product before and after storage are also presented.

At the Malaysian National Paddy and Rice Authority's rice mill complexes, different types of drying and storage systems are available, each with its own capabilities. It is suggested that these systems can be more effectively utilised through an integrated approach that would meet the demands and problems of wet paddy handling in Malaysia.

TECHNICAL development in any industry need not necessarily involve the purchase of new equipment. Optimisation of the utilisation and processing efficiency of existing systems can give rise to major technical developments.

In the government rice mill complexes in Malaysia, the conventional method of paddy drying is through the use of mechanical dryers in which the grain is dried to the final paddy moisture content of 13–14% (in this paper, moisture content of paddy is always expressed on a wet basis unless otherwise stated) before being stored and/or milled.

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In some of the government complexes, the storage system consists of a bulk in-bin storage system, sometimes referred to as the horizontal storage system. Unlike the earlier silos, the in-bin storage structures are equipped with aeration facilities. After being dried to 13–14% moisture content or less, paddy can be preserved during long-term storage by the process of aeration.

Grain can also be dried by blowing ambient air through it while it is in bulk storage. This method of in-store drying has been used elsewhere as reported by, for example, Nofsinger et al. (1979), Hearle (1979), Champ and Highley (1986), and many others. In the work of Nofsinger et al., for instance, the use of aeration at an airflow rate of about 4.5 cubic metres/minute/tonne (m^3/min/t) was found to reduce the moisture content of stored corn from an initial value of 24.8% to 15.5% in 24 days. This process of in-store drying using only ambient air is, however, a long, slow process and may pose problems in the tropics because of the climate. The drying time can be reduced, however, by the application of heat. This concept of paddy drying while in storage, using ambient air and a supplementary heat source, could be an alternative drying technology in Malaysia to solve problems of handling wet grain. The existing government in-bin storage system complements this technology. Earlier work by Adamczak et al. (1986) and Samsudin et al. (1986) showed that the use of the in-bin storage system as an in-store drying system has potential applications in the tropics under specified operational conditions.

This paper presents the results of an experiment to assess the technical capability of the in-bin storage system for in-store drying in Malaysia.

Materials and Methods

The experiment was conducted in 1986 using the second season harvested crop. One of the 750 tonne capacity in-bin storage systems at a National Paddy and Rice Authority (LPN) complex at Kangkong in Kedah was used in the trial.

The bin was initially filled above the level of the duct network with about 100 tonnes of dry paddy at 13–14% moisture content dried by a conventional fast-drying process in a Louisiana State University (LSU)-type continuous-flow dryer; this layer acted as a foundation layer. The bin was then filled to the top with intermediate moisture paddy of between 15 and 18% moisture content. The bulk consisted of about 50 tonnes of paddy at 15–16% moisture content and 550 tonnes of 17–18%. As was the foundation layer of paddy, the intermediate moisture paddy was initially dried to this level in a continuous-flow dryer.

Except during rain, the process of in-store drying was carried out continuously, using the existing bulk storage system. The system consisted of a bin of 21.3 m × 12.2 m × 5.3 m (length × breadth × height), a three-duct network and a fan with a capacity of about 1.02 m^3/min/t. A diesel-fired burner was used as a supplementary heat source.

Paddy was sampled while being loaded into the bin to an overall initial quality assessment.

Initial samples were also taken using probes after the bin had been filled. The samples were taken diagonally at three points and at three grain depths (1, 2, and 3 metres from the top) for quality analysis. The samples were again taken at intervals until the moisture content at all points reached about 13–14% or less.

The apparent velocities of the drying air flowing through the bulk were measured by use of an electronic rotating vane anemometer placed diagonally at three locations on the top surface of the bulk grain.

The temperatures and relative humidities of the ambient and drying air were monitored and recorded five times during daytime hours, at 10.00 a.m., 12.00 noon, 2.00 p.m., 4.00 p.m., and 6.00 p.m. The measurements were made using thermocouple wires and wet and dry bulb thermometers.

The diesel fuel consumption of the burner was also recorded during the field trial.

Results and Discussion

The experimental trial was conducted between 5 September and 12 October 1986.

The rationale for using a foundation layer of paddy covering the duct was to facilitate uniform air distribution within the bulk and to minimise paddy losses that might be incurred if the system broke down.

The average daytime ambient and air duct conditions recorded during the field trial are given in Table 1. Variations in the drying air conditions reflected variations in ambient air conditions. The drying air temperatures were about 6–7°C above those of ambient air, while the relative humidity of the heated air was between 53 and 40%. This is equivalent to 10–12% equilibrium moisture content. The reduction in the relative humidity of the drying air as a result of supplementary heating was about 3.0% per Celsius degree rise in temperature.

The relative humidities and temperatures of the ambient and air duct conditions at night were not measured but the influence of ambient air on air

TABLE 1. Comparison, for various times of the day, of ambient temperature and relative humidity and temperature and relative humidity of air used for in-store drying of paddy. The figures in brackets give the range in values.

Time of day	Ambient conditions		Heated air conditions	
	Temperature (°C)	Relative humidity (%)	Temperature (°C)	Relative humidity (%)
1000 h	29.2 (27.2–32.0)	73 (63–79)	35.6 (33.0–38.7)	53 (42–65)
1200 h	31.0 (30.0–32.0)	64 (62–66)	35.0 (37.0–38.7)	44 (42–46)
1400 h	33.0 (33.0–34.0)	58 (55–60)	40.0 (39.6–40.5)	39 (38–40)
1600 h	32.0 (31.0–33.0)	64 (58–71)	38.7 (37.8–39.6)	43 (40–43)
1800 h	30.7 (29.0–31.0)	68 (63–72)	36.9 (36.0–37.8)	46 (44–48)

duct conditions is likely to have been similar to that during the day.

Analysis of Moisture Content During Drying

Profiles of moisture content at three locations (far end, centre, and adjacent to the fan) were measured at three grain depths: 1, 2, and 3 m. Reduction in the moisture content was plotted against time, as shown in Figure 1. The plots show that the rate of moisture reduction during drying was, at all three depths, greatest in the grain mass closest to the fan. The rates were in the order: adjacent to fan > centre > far end. It took about 390 hours for paddy at the far end top layer to reach 13.4% moisture content, as compared with about 272 and 237 hours for the same layer at the centre and far end, respectively. At 391 hours the overall moisture differential between paddy at the far end and adjacent to the fan was about 2.8%. This reflects the magnitude of potential overdrying or underdrying that may be inflicted on the grain mass adjacent to the fan and at the far end, respectively.

No overdrying was evident at the far end of the bin (Fig. 1a), in contrast to the other two locations. When the top layer of paddy had reached 13.5% moisture content, the moisture content of the bottom layer was also maintained at 13.5%. Greater variability in moisture contents at all three depths was observed at the centre of the bin (Fig. 1b), where a maximum value of about 4.6% moisture differential was recorded between 1 and 3 m grain depths. The rate of moisture reduction of paddy adjacent to the fan at 2 and 3 m depth was found to be almost uniform (Fig. 1c).

Figure 2 gives the average moisture profiles at the three depths for the three locations. The average rate of moisture removal was about 0.16% per 10 hours of fan operation.

Figure 3 shows the variability in the moisture content of paddy at the three locations, for the same grain depth. The slow drying rate of paddy at the far end is clearly evident. The optimum moisture content of paddy at the far end can be reduced to only about 13.4%. The reduction in the paddy moisture contents at 2 and 3 m depths at the centre and adjacent to the fan reaches a plateau at 11.2% after 158 hours and remains constant (Figs 3a and 3b) for a long period thereafter. This moisture content may be likened to that of paddy in equilibrium with the drying air.

The apparent velocity of the air leaving the paddy surface adjacent to the fan was 0.04 m/second, the slowest for the three locations. This may provide the reason for the faster drying of paddy next to the fan.

Quality Analysis

The initial and final milling quality was analysed as tabulated in Table 2.

The average percentage of broken kernels was little affected by the in-store drying process with respect to its marketable grade where the percentage increase in brokens was less than 10%. The high percentage of broken kernels in the final sample reflected the high proportion of damaged grain in the initial sample.

Table 3 quantifies the effect of in-store drying on the incidence of discoloured grain kernels. Discoloration is one of the factors determining rice grade in Malaysia. There was an increase in the incidence of discoloration in the final sample and the variability in the percentage discoloration in the final product was found to be large (between 7.6 and 26.6%) as compared with the initial sample (8.0–10.0%). Grain from 1 m depth exhibited a higher incidence of discoloration. Unlike broken kernels, which can be separated easily by sieving or using rice graders, discoloured kernels require more

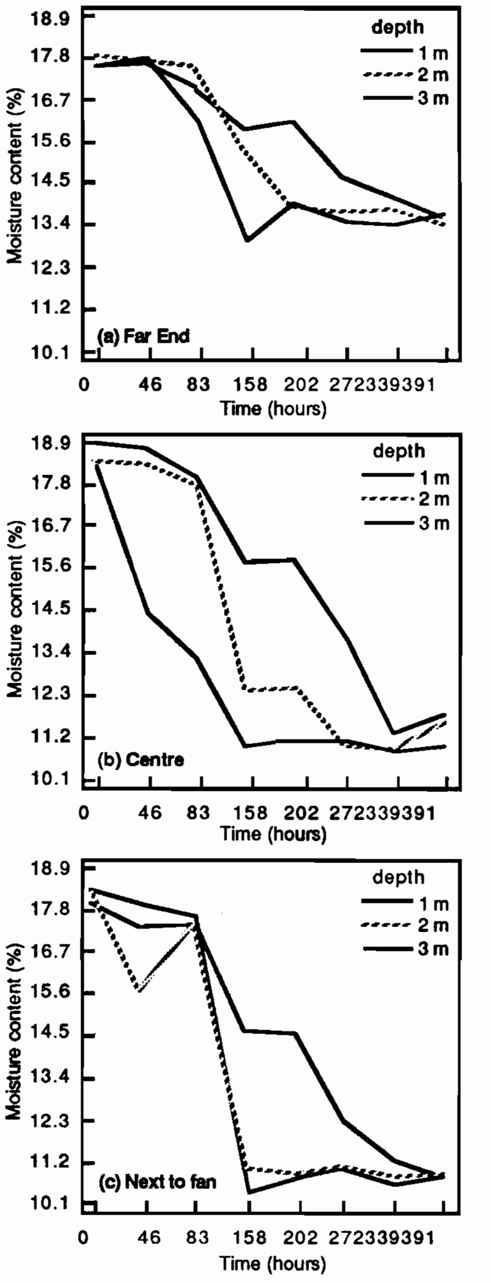

Fig. 1. Profiles of moisture content *versus* time in three regions of a 750 tonne capacity bin during in-store drying of bulk paddy: (a) profiles for the region of the bin furthest from the fan; (b) profiles for the centre of the bin; (c) profiles for the region adjacent to the fan.

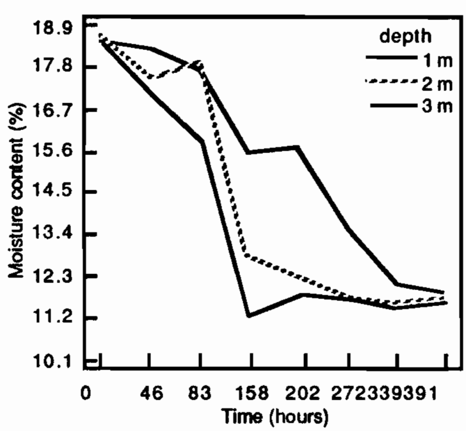

Fig. 2. Profiles of average moisture content versus time at three depths during in-store drying of bulk paddy.

TABLE 2. Milling characteristics of paddy before and after in-store drying. The head rice yield was calculated as a percentage of the milling recovery. Figures in brackets give the range in values.

	Milling recovery (%)	Head rice yield (%)	Brokens (%)
Initial sample	64.1 (63.8–64.6)	82.1 (79.8–83.6)	17.4 (16.6–20.2)
Final sample	64.3 (62.1–65.0)	80.9 (77.6–84.5)	19.1 (15.5–22.4)

sophisticated and expensive equipment to remove them. The occurrence of discoloration at the 1 m grain depth may be rectified by delaying the loading of the last 1 m of the bin. From Figure 1, the loading of the last 1 m, or an equivalent of about 136 tonnes of paddy (of intermediate moisture content), may be made 5 or 6 days after the in-store drying process has begun. It was also observed that a portion of the paddy in the bin, especially that just below the grain surface (0.5 m), exhibited some form of caking.

The initial and final germination rate of paddy was also measured. The results are given in Table 4. The viability of the paddy in the top 1 m was found to be markedly affected, with a reduction of more than 50% in its germination potential.

TABLE 3. Analysis of the effect of in-store drying on the incidence of discoloured grains. Figures in brackets give the range in values.

	Individual discoloration (%)	Overall discoloration (%)
Initial sample	9.7 (8.0-10.6)	43.2 (42.6-43.6)
Final sample	11.8 (7.6-26.6)	41.4 (40.0-43.3)

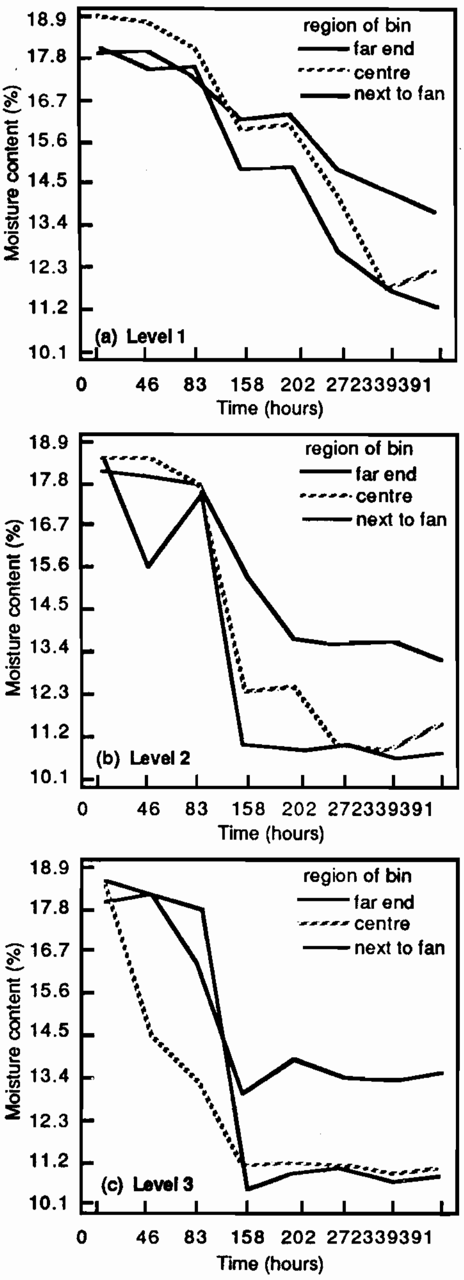

Fig. 3. Profiles of moisture content versus time at three depths in a 750 tonne capacity bin during in-store drying of bulk paddy: (a) 1 m; (b) 2 m; (c) 3 m.

TABLE 4. Analysis of the effect of in-store drying on paddy germination rate for samples taken from three depths in the grain bulk

	Overall	Different depths		
		1 m	2 m	3 m
Initial sample	75.5	n.a.	n.a.	n.a.
Final sample	64.8	34.6	83.0	76.7

n.a. = not applicable

Operational Cost and Efficiency

Table 5 summarises costs of the in-store drying experiments.

The average energy cost for drying a tonne of paddy was about $M6.20[1]. This is relatively low when compared with the cost of operating a flat-bed dryer of 30 tonnes capacity at an LPN complex, which is about $M12.80. Labour costs are estimated to add another $M0.90 to the cost of in-store drying, bringing the average total cost to $M7.10 per tonne.

The overall thermal efficiency of the system, calculated as the ratio of the heat required to evaporate the moisture to the net heat input from the combustion of the fuel (Hall 1971), was about 68%. This is comparable with the overall thermal efficiency of a direct heated air dryer in summer in the USA (Hall 1971) and as reported under Malaysian conditions (Rukunudin et al. 1983). The efficiency is greater for direct types of heater, low airflows, high initial moisture contents, high atmospheric temperatures, and thick columns of grain.

Conclusion and Recommendations

The use of in-store drying was found to be relatively effective in reducing intermediate moisture content paddy (17–18%) to a safe moisture limit (13–14% or less). There is therefore great potential for the in-bin storage system to be used for in-store drying and to be integrated with the existing mechanical drying system to increase drying capacity at LPN complexes. In-store drying has a relatively high overall thermal efficiency (about 68%) and low operating cost ($M6.20 per tonne). Bin loading techniques can be implemented to minimise grain quality deterioration, especially kernel discoloration in the top layer.

[1]Costs are given in Malaysian ringgit ($M). During October 1987, $M2.50 = US$1.

TABLE 5. Calculation of the costs of in-store drying of bulk paddy

Component of cost	Amount used	Cost[a]	Cost per tonne
Energy			
Electricity[b]	14 611.70 kWh	$M2630.10	
Fuel[c] @ 9 litres/hour	3 510.00 litres	$M1755.00	
Subtotal		$M4385.10	$M6.20
Labour			
2 labourers[d] @ $M8400.00 per year			$M0.70
1 technician[e] @ $M2400 per year			$M0.20
Total			$M7.10

[a]Costs are given in Malaysian ringgit ($M). During October 1987, $M2.50 = US$1
[b]Costed at $M0.18 per kWh
[c]Costed at $0.50 per litre
[d]Full time
[e]One third of time

The following recommendations are made:

1. ducting networks should be improved to avoid clogging and to facilitate more uniform air distribution within the grain bulk;
2. filling of the top 1 m of the bin should be delayed for 5 to 6 days after in-store drying has commenced;
3. gaseous preservatives may be added during in-store drying to counter potential growth of spoilage microorganisms; and
4. future in-store drying designs should incorporate slightly higher airflow rates.

Acknowledgments

The authors would like to thank the National Paddy and Rice Authority (LPN) for allowing its facility to be used in the field trial, and ACIAR for supporting the project. Thanks are also due for the assistance given by the research teams at Bukit Raya and Serdang.

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The Use of a Modified Light Pickup Truck for Bulk Handling of Paddy in Malaysia

Abdullah Ali*

Abstract

The original steel body of a light pickup truck was converted to a wooden tipper for the purpose of bulk handling of paddy from the field to the drying complex. The height of the body was raised in order to increase the pickup's capacity. Bulk handling was compared with bag handling in trials conducted in the Muda area, where paddy is harvested by the Laverda combine harvester. The results showed that the modified pickup could be used for bulk handling and that the handling costs were reduced by about 40% of those for bag handling.

A few years ago, much attention was given to the topic of bulk handling of grain in the paddy growing areas of Malaysia. Bulk handling was then identified as a step to reduce the long queues of lorries at the drying complexes. It was also identified as one of the appropriate alternatives to reduce postharvest losses and handling costs (Ahmad Robin and Dhiauddin 1984).

Pilot projects were initiated by the National Paddy and Rice Authority (LPN), the Malaysian Agricultural Research and Development Institute (MARDI), the Farmers' Organization Authority (FOA), and the Muda Agricultural Development Authority (MADA). Results of these pilot projects have been widely reported[1] as showing that handling costs were reduced significantly. However, the conventional lorries have to be modified in order to achieve their maximum capacities (Loo 1986). One of the modifications is the extension of the sideboards of the lorry. The other is the conversion of the tray to tipper operation (Abdullah and Loo 1986).

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[1] As, for example, in the New Straits Times of 5 October 1983.

Objective of Study

The study reported here describes the use of a modified light pickup for bulk handling of paddy from the field to the drying complex.

Since the study is still under way at the time of writing, the paper focuses on some of the preliminary results dealing with timing of harvesting and handling schedule and cost comparisons between the bulk handling under study and the bag handling methods currently practised in the MADA area.

Modification of the Pickup

The original steel-bodied pickup is shown in Figure 1. The load tray of the truck was 2075 mm long by 1645 mm wide by 300 mm high. It could hold about 600 kg of paddy.

The capacity of the original pickup was lower than that of the tank of the large combine

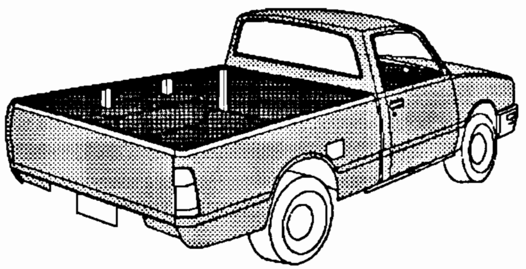

Fig. 1. Drawing of unmodified light pickup truck.

harvesters currently operating in Malaysia. The body of the pickup was therefore modified and converted to a wooden tipper (Fig. 2). The dimensions of the load tray are now 2360 mm long by 1690 mm wide by 600 mm high (an extension of 300 mm). The paddy carrying capacity is now about 1200 kg which is slightly higher than that of the tank of the Laverda M72R combine harvester (1170 kg).

Handling Trials

Trials on handling systems were carried out in the MADA area in August 1987 (wet harvest crop). A flow chart of the handling system is given in Figure 3.

The fields selected for the trials were adjacent to the road. The distance from the fields to the LPN drying complex was 5 km.

The paddy was harvested by Laverda M72R combine harvester. For the bulk handling trial, the grain was discharged directly into the pickup waiting at the roadside.

For bag handling, the grain was discharged onto a large plastic sheet spread on the ground. It was then bagged and loaded manually into a lorry waiting at the roadside.

At the LPN complex, the pickup/lorry had to wait for a time before weighing. After weighing, the paddy was graded at the grading bay. The pickup/lorry then emptied its load into the intake hopper or onto the drying yard. It then returned to the weighing bridge and thence back to the field to handle the next load.

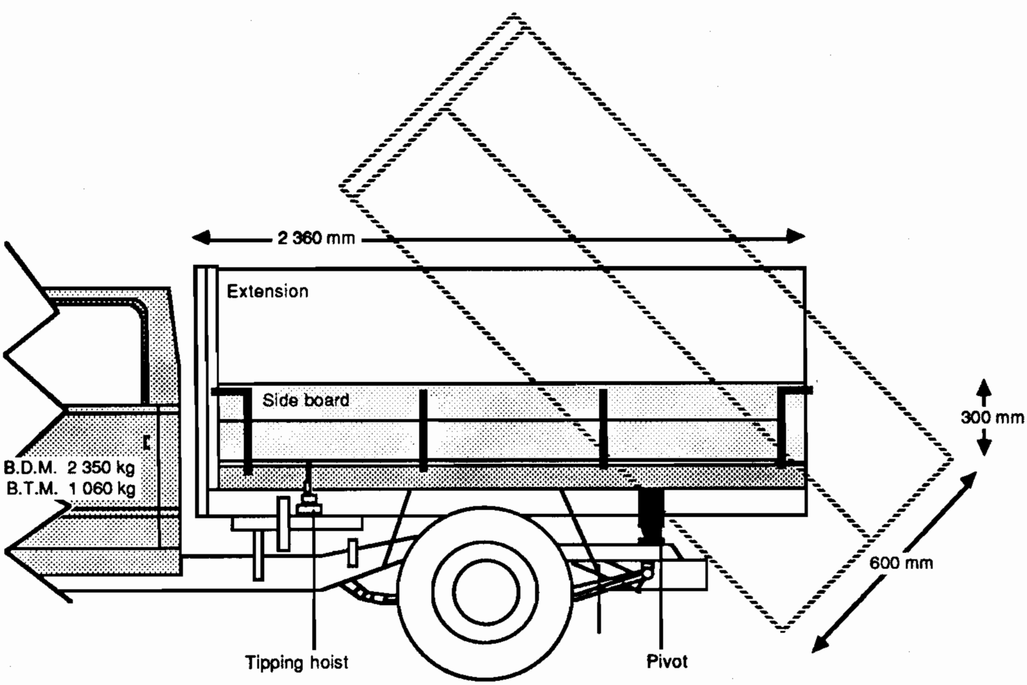

Fig. 2. Detail and dimensions of modifications to the tray of a lightup pickup truck for transportation of bulk paddy.

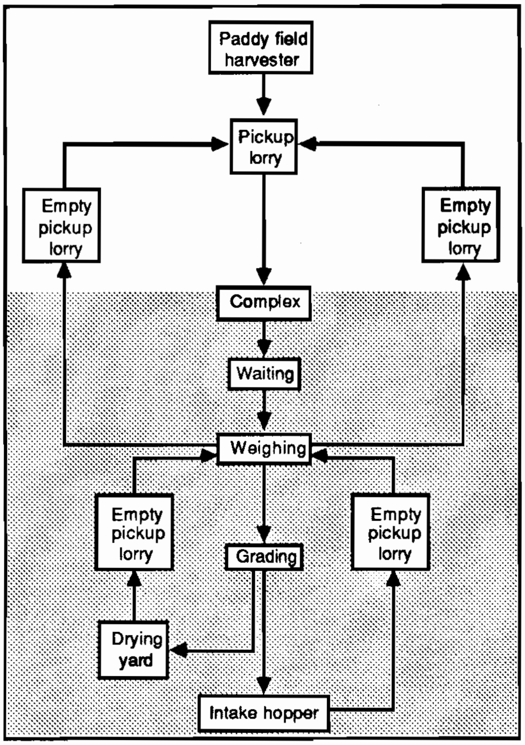

Fig. 3. Flow chart of the paddy handling system in the Muda area of north-west Malaysia.

Results and Discussion

The flows of harvesting and handling are shown in Figures 4 and 5.

The harvesting operation by the Laverda M72R combine harvester and the handling schedule of the modified pickup were very closely compatible. The combine harvester was not kept waiting with a full grain tank since the pickup could get back to the field in time (Fig. 4). The harvester and the pickup driver had enough time for 'breaks'.

Starting work at 9.30 a.m., the pickup could carry nine loads a day to the LPN complex before it ceased buying for the day at 6 p.m. The quantity handled was 1.5 times more than that handled by conventional lorry (10 530 kg *versus* 7020 kg).

The handling costs were reduced by $14.44 per tonne of paddy, or 40% (Table 1). This is an attractive result for farmers. A farmer with the average farm size of 1.97 ha and the average production of 6.8 tonnes (Wong 1986) could save $98.20 in handling costs.

Nevertheless, the use of the modified pickup is limited by a number of factors:

Area Limitation. The system is limited to areas adjoining the farm road. This means only a small fraction (13.3%) of the MADA area can be covered (Wong 1986).

Distance Limitation. The system is limited to a distance of 5 km from the field to the procurement centre. This means more pickups would have to be used for greater distances.

Combine Harvester Limitations. The pickup is modified to match only the Laverda M72R

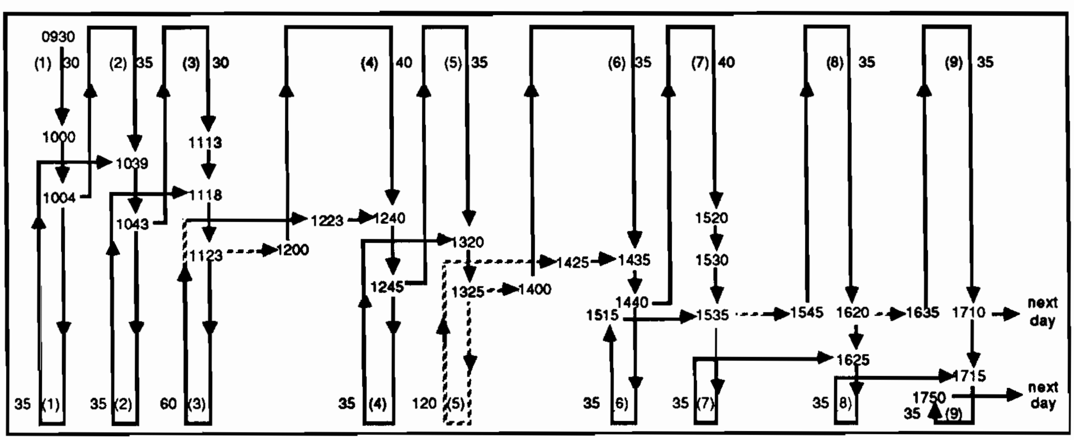

Fig. 4. Flow chart of harvesting and subsequent bulk handling and transport of paddy using a modified light pickup truck. Figures in brackets (1–9) denote the trip number. Also given are the time of day and the time in minutes taken to complete each trip.

TABLE 1. Comparative costs[a] of conventional bag handling of paddy and bulk handling using a light pickup truck.

Activity	Bulk handling	Bag handling
Bagging	0	$39.00
Loading	0	$39.00
Unloading	0	$23.40
Transporting	$234.00	$56.00
Total	$234.00	$257.40
Cost/tonne	$22.22	$36.66

[a]Costs are in Malaysian ringgit ($M). During October 1987, $M2.50 = US$1.

combine harvester in terms of handling capacity. This means more pickups have to be used for combine harvesters with bigger tank capacities.

Queuing Limitation. The handling schedule will be disrupted if the pickup has to queue at the LPN complex. In the event of queuing, the pickup would not be able to get back to the field in time to handle the next load and the harvester would be kept waiting with a full grain tank. More pickups would therefore need to be used.

Social Limitation. Like other bulk handling options, the use of a light pickup eliminates the manual bagging, loading, and unloading operations. This means the source of the income of those people currently doing those tasks is removed.

Conclusion

The use of a modified light pickup truck for bulk handling of paddy from the field to the procurement centre reduces cost of handling. It is an attractive option to farmers, but it needs further evaluation before its adoption can be promoted.

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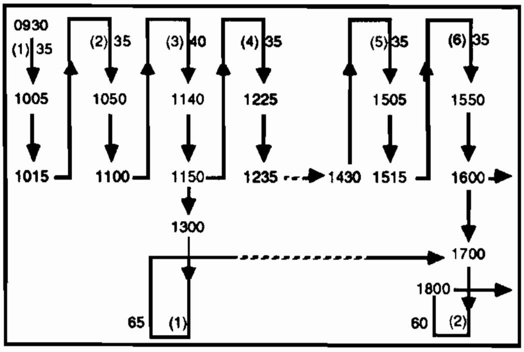

Fig. 5. Flow chart of harvesting and subsequent bag handling and transport of paddy using conventional lorries. Figures in brackets (1–9) denote the trip number. Also given are the time of day and the time in minutes taken to complete each trip.

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Case Studies on Bulk Handling in the Humid Tropics—II Session Summary

Chairman: Jose Santos*
Rapporteur: Emily Leong†

THIS session presented further case studies relating to the introduction of technological innovations in bulk handling in Malaysia, Thailand, and Indonesia, broadening the workshop's coverage of this aspect.

By and large, the papers presented studies undertaken to seek technical solutions on various facets of bulk handling. Whilst the speakers have highlighted preliminary research findings and discussed technical constraints, the need for further research and development work in the various study areas is clearly evident from the consistent recommendation made with each of the papers presented.

In the first paper, Dhiauddin bin Mohd Nour and co-authors reviewed the silo storage technology in Malaysia and described LPN–MARDI's experiences over the past five years on the introduction and optimum use of aeration facilities in concrete silos. Design and operational implications of bulk aeration were discussed, and findings have indicated that the practice of selective aeration of bulk stored paddy in concrete silos with low relative humidity (average 59%) and high temperature (average 34°C) ambient air has the capability and capacity to maintain sound grain quality for storage periods up to 6 months. However, further R&D efforts are needed to make the aeration system more effective and convenient to operate under the local environmental conditions.

In the second paper of the session, Mr Rahim Muda described the sealing process and the controlled atmosphere storage trial on milled rice using carbon dioxide (CO_2) for insect disinfestation in a 2000 tonne storage facility of LPN. The application of sealant has made the storage more airtight and has stabilised storage temperature and humidity, while the CO_2 treatment has been found effective in controlling storage insects without appreciably affecting the milled rice quality. Constraints and criteria in the adoption of the sealed storage under local conditions were highlighted and further research is currently being examined to alleviate operational problems and the other factors affecting milled rice quality under the sealed storage process.

Observations on the quality of maize harvested during the wet season and stored for a period of 6 months in 750 tonne bulk steel silos at a Ministry of Food silo complex in Thailand were presented by Likit Porntheeranarth. Some provocative thoughts on the application of appropriate economic parameters and terms in bulk handling operations in the commercial and trading circles in Thailand were posed by the speaker.

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Mr Anton Martono, from Indonesia, described the development and testing of simple, locally manufactured bulk handling equipment for paddy. This work has been carried out at the KUD or village cooperative unit level in West Java. The bulk handling equipment developed includes belt conveyors, a 2-tonne bulk trailer, hand carts, a mechanical sweeper, hand tractors, hopper bins, elevator, modified scales, and ramps. While initial performance test results on the various pieces of equipment have been satisfactory, further design modifications are needed to improve their performance and overcome operational difficulties.

The fifth paper, delivered by Ibni Hajar Rukunuddin and co-workers, highlighted the need for integrating the diverse drying and storage systems which exist at various LPN rice milling complexes in Malaysia, so as to effectively tackle the problem of wet paddy handling. The results of an investigation on the potential use of an in-bin storage system for drying were presented. There are indications that paddy, after being partially dried through the use of LSU continuous-flow dryers, can be conditioned in an in-bin storage and drying system to a 13–14% moisture level, utilising existing aeration facilities and a supplementary heat source. The integrated in-bin storage drying system has been found to have a relatively high overall thermal efficiency and a low operational cost. Further R&D work to improve the system using, for example, selective higher airflow rates and gaseous preservatives is being considered.

In the final paper of the session, Mr Abdullah Ali reported on a study in which a modified light pick-up vehicle has been used for bulk transportation of paddy from the field to a selected LPN drying complex. Whilst preliminary results on comparative handling costs of bulk versus bag handling demonstrate a cost reduction with the use of the pick-up prototype, further studies are needed to firm up its applicability and suitability.

General Socioeconomic and Technical Considerations

Sociological Factors as Determinants of the Extent of Change in the Postharvest Subsector: Is Bulk Handling Economic Outside of Recent State-Sponsored Land Development Areas?

B. Fegan*

Abstract

Bulk handling technology may be restricted to the land development schemes of Peninsular Malaysia. Elsewhere, it is likely to be adopted only by new complexes, most likely parastatal, in surplus producing regions. Private entrepreneurs in the regional export trade are unlikely to find conversion to bulk handling attractive for existing storages. A large proportion of total national harvest will continue to be handled in sacks, including probably the whole traded harvest in deficit and balance regions and the whole of intraregional trade in surplus regions. Comparative data about the country-specific comparative costs and grain saving for well-managed bulk and sack handling are necessary before we can predict whether handling in bulk will compete with handling in sacks, without subsidy, in countries with low wages and expensive capital.

BULK handling technology is capital-intensive and labour displacing. It is an economically efficient system in a country like Australia where grain producing regions have low population density, scarce labour, high wages, and relatively cheap capital. Except for some recent state-sponsored land development schemes in Peninsular Malaysia, Southeast Asian grain producing regions have high population density, plentiful underemployed labour, low wages, and scarce expensive capital. Bulk handling technology in producing areas of old and dense population may be economically inefficient in comparison with handling in sacks. Its labour displacing effects will contribute to rural unemployment, underemployment, reduced wages, and migration to the cities. Insofar as the heavy investment in bulk handling facilities merely replaces and throws idle existing facilities efficiently handling grain in sacks, it would divert scarce capital from more profitable investment from the point of view of private entrepreneurs or more productive development investment from the point of view of the state. Its justification must lie elsewhere than simple comparison of economic efficiency in the sense of either economising in the use of scarce and expensive factors, or the economic welfare of the people directly engaged in grain handling.

Scientists and administrators justify new technology proposed by projects sponsored by ACIAR and other agencies on the grounds of savings in grain quantity and quality. Bulk handling has begun with the combine harvester loading into trucks in the paddyfield in Malaysian development areas like Muda; elsewhere, bulk handling may begin with threshed paddy from the field or farm gate; or it

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may not begin until paddy has reached medium or large storage and milling operations oriented towards regional export. Wherever handling in bulk begins, paddy and rice will be handled thereafter until some downstream point near the consumer where rice is handled in sacks or packages. Outside the rare regions of recent state-sponsored and heavily subsidised settlement, the full chain of bulk handling technology beginning at the field or farm gate is uneconomic and probably technically impractical.

Bulk handling in densely settled areas can begin only downstream from the farm, after small traders or village cooperatives have first collected, sorted, and delivered grain in sacks to central private or parastatal storages. But bulk handling makes technical and economic sense only for that proportion of a region's production that is surplus to its own consumption and traded to distant deficit areas. There are diseconomies in transferring incoming bagged paddy to bulk for handling within store, then paddy or rice back to sacks for sale in small lots to local grain traders. This points to a persisting intraregional system handling sacks plus a new extraregional bulk handling system for the regional surpluses generated by improved irrigation, multiple cropping, and the seed-fertiliser revolution.

In long-settled areas of dense population the regional surplus is generally under one-third of total production. Many rural regions that concentrate on other crops have some localised rice production but may be in rice balance or deficit, with no surplus suitable for bulk handling. Surplus regions have a large internal rice trade in addition to household storage. Aside from small rice farmers and labourers who sell some paddy at harvest but buy rice later, a great proportion of village households have zero or insufficient incomes in rice. In addition, market and administrative towns with some light manufacturing, education, religious, transport, and service functions consume part of local production.

It is important that research in grain saving does not concentrate exclusively on the bulk handling system that will deal with only a minor proportion of the national grain harvest. Most grain will continue to be handled in most areas in sacks. Research and extension must not neglect preservation of grain in the sack handling system.

Scientists and technologists have had some remarkable successes in adapting to the humid tropics technological elements developed for different natural conditions. A further stage involves either scientists adapting this technology to the economic, political, and social conditions facing various potential users in the ASEAN countries, or alternatively, where policy makers perceive introduction of the technology to fit their interests, they may try to change conditions to facilitate its adoption. That is, both technology and society will be selectively changed to fit the economic and political interests of those who sought it: powerful bureaucratic, political, and business interests.

In each country, elements of the new technology that may be uneconomic to private entrepreneurs will be adopted if that can be made to benefit the politically most powerful interest groups. An interest group is politically powerful if it can influence state policy to make a possession or activity more profitable than it would be under free markets. That is, a powerful interest group is one that can influence the state to allocate to it economic rents, the difference between its income under monopolies, subsidies, and controls, and what would have prevailed under free markets. State intervention subsidises the powerful group by transferring income and wealth from less powerful groups—either directly, in the controlled prices the less powerful face, or indirectly, by allocating state revenues ultimately derived or diverted from them. Bulk handling may be adopted where powerful interest groups will benefit, whether or not there is a real increase in available grain and whether or not the technology uses scarce factors more efficiently or worsens the welfare of the powerless.

No satisfactory scientific literature exists to show quantified losses from each cause in handling systems using sack handling technology efficiently. Such data are needed to guide strategic priorities for grain saving research. It is not possible to distinguish estimates that are rhetorical flourishes to justify decisions made to benefit powerful interest groups from those that attack real grain losses at source. Published projections of grain saving combine worst-case estimates of current losses from all causes with best-case projections that all can be saved by investment in postharvest technology.

Some postharvest losses could be avoided or reduced by preharvest changes in organisation but not saved by postharvest technology. Some savings are specific to bulk handling technology that is unlikely to be adopted for the majority of grain produced. Some losses could be avoided cheaply by changes in state policy, or in organisation. Some technological changes will not cause a real saving in grain but divert scarce capital from other development, while merely redistributing income from less to more powerful interest groups.

Published projections of net national or social benefit from bulk handling technology fail to offset the full cost on foreign and domestic account of the technology. Projections in terms of global net producers' benefit and net consumers' benefit are misleading because they fail to distinguish on each side which interests would gain and which lose between local and foreign, state and private, capital and labour, rich and poor.

Many causes of 'losses' are unlikely to be affected by proposed technology. Phantom 'losses' in parastatal grain stores involve write-off to 'deterioration' of discrepancies in quantity and quality between real and book stocks. A large proportion of these 'losses' may be caused by corruption and poor management in parastatal grain handling. There is no indication that private handlers complain of similar losses to the extent they seek technology to avoid them, though some may use creative accounting when adjusting their books for presentation to tax authorities.

Some real losses are caused by state policy discouraging use of existing or new drying technology by offering farmers the same price for paddy wet or dry at parastatal storages. Some are caused by state policy replacing many dispersed medium private storages by a few large central storages, causing shortages of farm to storage transport that in turn increase real losses by extending the time wet grain must wait on farm or in a queue. Some are caused by low-incentive management systems in oversized parastatal storages failing to use existing technology to the standard achieved in private organisations.

Large real losses could be saved by organisational improvements that do not require expensive new technology or increased farm sizes. In ordinary wet- season conditions timing is crucial. Grain begins to deteriorate if there is delay on farm between reaping, threshing, and drying. Technology further downstream is too late. Manipulating irrigation schedules between laterals and sub-laterals to stagger the harvest period could break local bottlenecks in reaping, threshing, and drying labour and machines and transport. Savings due to improved timing would be increased by facilitating agents to custom hire labour gangs and machines outside their home district.

Large weather losses caused by damage during flowering, lodging, and floods cannot be saved by projected or foreseeable postharvest technology. But they might be reduced if research described recurring local weather and flood patterns. These could guide cooperation between irrigation and extension agencies to manipulate irrigation schedules and variety recommendations, so as to discourage farmers planting crops that would harvest when bad weather is probable.

Natural scientists and technologists are, by training and professional socialisation, disinclined to take into consideration the institutional patterns into which their products will fit or the social consequences of adoption of their product. Cooperation between scientists and technologists in the ACIAR projects has successfully adapted to the humid tropics elements of grain saving technology developed for regions with different climate and biological problems. That success comes from applying the central method of hard science: reducing a problem to one in which all factors are held constant except one experimental variable, in order to make precise observations. Findings from natural science then define the problems for which applied scientists and technologists design solutions in the form of machines, chemicals, and processes. But in practice scientists and technologists unconsciously carry in their minds the institutional patterns of their own society, defining problems and solutions as if they were to fit into the institutional patterns familiar to them. In particular, scientists from a high wage country unconsciously assume that labour is scarce and expensive. In countries where labour is plentiful and cheap but capital is scarce, such solutions are not economically efficient and by displacing labour may worsen economic welfare.

ACIAR-designed technology will be adopted where it advantages decision-makers: entrepreneurs or politicians and administrators. If free market conditions prevailed, entrepreneurs in each of the differing Southeast Asian production regions would take apart the elements designed to fit as components of the integrated system peculiar to Australian institutional conditions. They would selectively adopt those elements most profitable to their operations.

But the state intervenes in the politically sensitive rice industry in pursuit of a range of political and social goals (Fegan 1987). What grain handling technology suits the coalition in control of the state will therefore be as important as what profits private entrepreneurs. Even where parastatal grain handling organisations do not exist, the state will set the regime of regulations and subsidies or taxes that favour entrepreneurs adopting particular technologies.

Regional and National Determinants of Rate of Change

Rice surplus regions within countries are more likely to shift to bulk handling than rice balance and deficit regions. Adoption of bulk handling technology will be highest in production areas that have large farms and local surpluses, generating demand for high volume off-farm storage and transport to distant deficit areas. However large the local harvest, where a small proportion is surplus to the consumption needs of the farm, the village, and the market region of a town, most intraregional transactions are small and best handled in sacks. The adoption of bulk handling technology will differ between recent land settlement schemes and long-settled areas.

Recent State-Sponsored Settlement Schemes

Areas with the largest farms and local surpluses are recent settlement areas, especially where the state funded technical irrigation and planned land development and settlement. Farm size is relatively large, population density and the proportion of landless households low. The monocrop economy and lack of town life stimulate local youth to migrate to the cities, leaving a relatively older population in the villages. These conditions generate labour shortage at harvest, a relatively high harvest wage, and demand for mechanisation of harvest. Large combine harvester machines are technically feasible since the land in settlement schemes is level and well drained, farms compact and consolidated rather than fragmented, while paddyfields are large and rectilinear.

Farm mechanisation, rural depopulation, and urban migration of the young are accelerated where the state maintains a paddy price well above that of the world market, and/or subsidises irrigation, fertiliser, inputs credit, farm machines, and fuel. Such state policies make rice farming profitable enough to attract entrepreneurial capital into farming. Commercial farmers put together large operational areas by a combination of ownership, mortgage, and renting. They use covert arrangements where state regulations forbid land accumulation or reserve land for a particular ethnic group.

This policy-generated set of socioeconomic factors produces an institutional framework similar to the Australian pattern, and therefore most favours adoption of the full package of ACIAR technology. It is rare outside the land settlement schemes of Peninsular Malaysia. That country has also the highest internal paddy and wage prices in the ASEAN region. It has the greatest capacity to subsidise the rice industry, because of high state revenues from exports of non-rice commodities. The pattern of technology adoption feasible in heavily subsidised settlement schemes may not be transferrable to old production areas in Malaysia, let alone to production areas in other countries.

Old Production Areas

Irrigated land with sufficient water for two or more crops at the end of the 1960s was estimated by the International Rice Research Institute (IRRI) at 10% of the total riceland in Southeast Asia, with another 10% having single crop irrigation. Some 60% of riceland was rainfed and 10% inundated by stream flow. The remaining 10% was non-bunded upland. Since then, irrigated area has increased but the proportions may have remained about the same because of clearance of marginal rainfed land.

In all but the deep water inundated land, the seed–fertiliser revolution has increased yields. Varieties with shorter growing periods have permitted increased cropping intensity, creating drying problems where one crop harvests in wet weather. Sale of part of increased harvests plus the need for cash to pay for inputs have drawn rural populations into the cash economy to an unprecedented degree.

Some long-settled rice balance and deficit areas have become recent surplus exporters, generating need for more storage and transport capacity. In these old areas the institutional patterns favour selective adoption of single elements of the ACIAR technology but not the full complex. Crucially, farm size remains small, population density and the proportion of landless households in the villages is high, there is little labour shortage at harvest, and wages are low.

These conditions do not favour adoption of labour saving reaping and threshing machinery under free market conditions. Their introduction may worsen welfare of the rural poor by reducing both the number of days worked and the daily wage, redistributing income from labour to capital. This may create rural unrest and accelerate migration to the cities. Light reaping machines were designed by IRRI in the late 1970s in a cooperative project with the People's Republic of China. They spread in Central Luzon in the Philippines in the early 1980s when credit for machines was subsidised. A recent IRRI study by B. Duff and others shows that they proved not viable when subsidies were removed.

Central Luzon is an example of a surplus region of old settlement. At harvest, farmers use paddy to pay: harvest labour and threshing machine services; deferred wages to a permanent farmhand, or for custom machine cultivation; rent or land amortisation; debt for inputs; irrigation fees; village dues; consumption debt to village traders and moneylenders; deferred payment for services like barbering and transport to town for high school students. After putting aside paddy for seed and household consumption, the marketable surplus of each farmer is small and he may not sell it all at once, holding some paddy to await a favourable price. Although a large volume of paddy leaves the villages, it passes through many small transactions, accumulating in the hands of some of the recipients above, and of successively larger traders. These grade it by variety, cleanness, discoloration, and wetness. Some reclean and dry paddy and may hold it for a price rise before trading it on.

Bulk handling is not appropriate in this institutional setting until the paddy moves downstream to large private or parastatal storers and millers who handle any surplus destined for export from the region as rice. In old settlement areas of dense population, a large proportion of paddy that is sold by villagers at harvest time is not surplus to the area. It is repurchased by villagers as rice in a couple of months, or by townspeople and specialists. It moves in and out of storage in small transactions.

That is, long-settled production regions will have parallel grain handling systems: an intraregional system handling grain in sacks and a regional export system that may handle in bulk if this is profitable to entrepreneurs, or suits the state. These systems will probably remain separate because of the inefficiencies of moving paddy and rice from sack to bulk and back, because of the management, accounting, and paperwork problems parastatal systems would have in handling myriad small transactions, and the antipathy of farmers and small traders to that paperwork.

Where the surplus production area is not far from deficit areas, milled rice from the intraregional system will be exported in sacks whenever the market is favourable. The regional export system is likely to have an entrepreneurial subsector handling special varieties with premium price and high milling standards, oriented to the urban elite market. Because of the low traded volume of some premium varieties, this subsystem may continue to handle grain in sacks.

Conversion Costs versus New Capacity

In long-settled production areas there is already large total storage capacity for bagged grain on farm, in the warehouses of landowners, moneylenders, bulk-making small traders, and in the medium and large private and parastatal storer/miller systems. The capital cost of converting to bulk handling may exceed the capacity or willingness of private entrepreneurs to invest, given the returns to competing uses of capital. From the point of view of the small to medium bulk-making trader, whose operation depends on turning over traders' capital frequently at relatively low margins, investment in bulk handling equipment would tie up trading capital and reduce turnover. From the point of view of private medium-to-large storer/miller complexes, investment in bulk handling is unlikely to significantly increase storage capacity on existing premises. Thus, the investment would be attractive only if the savings in grain quantity plus anticipated savings in quality, times the price spread for quality, exceeded the amortised cost (taking into account any subsidised interest rate available for technology) and the difference between running costs of handling grain with capital as against labour. But the investment items are many, including plant to load, unload, and weigh bins and trucks, to move and stack bins, to protect bulk stored grain from pests, and to feed the mill. The change in operations may require structural alterations in premises that have grown haphazardly rather than to a plan, in response to site shape and the history of the entrepreneurial family's success. The plant items and wider passageways for plant access reduce valuable storage space. Investment in the capital items would tie up capital that could otherwise be invested in extending storage using existing labour-intensive technology.

Since grain handling labour is cheap and pay is commonly by piecework, costs in the existing system are calculable and strictly tied to volume. Bulk handling needs not only capital investment but new kinds of skilled labour plus new accounting and management skills and systems.

Given these constraints to conversion of existing private storages, it seems probable that, in areas of old settlement, bulk handling will be restricted to new storages built to handle the recent production increase. Private traders will not rush to invest even in this restricted use, unless the technology pays for itself quickly by savings within storage. This is because the full advantages will not be realised until transport delivering paddy and removing rice converts to bulk handling. That in turn depends on bulk-making paddy traders upstream and wholesalers downstream installing bulk loading and unloading equipment.

If this analysis is correct then in areas of old settlement bulk handling will be installed only by parastatal grain handling authorities that do not face the discipline of making a profit on investment and that are subsidised in their capital and running cost by a wealthy state. The test of whether bulk handling has real economic benefits will not be in the heavily politicised grain handling systems of Malaysia and Indonesia, or even the Philippines. Thailand's grain industry has the least state intervention and until recently has had negative subsidies. If bulk handling is adopted by Thai private grain handlers then the ACIAR technology will have demonstrated that the bulk bin is a robust technology that can compete with the sack without subsidy.

All handling systems will selectively adopt other elements of the ACIAR technology that benefit their decision makers. Some technology items will advantage only bureaucratic and political decision makers. Others will advantage these groups or entrepreneurial decision makers indifferently. The carbon dioxide based pest control procedures appear relatively scale neutral, have low capital costs, and are adaptable to bulk or sack handling. Their costs appear to be less than the grain saved or the cost of competing methods.

In a paper (Fegan 1987) presented at an earlier conference, I predicted that grain dryers designed for medium-scale integrated store-miller operators would be adopted first by those who specialise in quality milling for premium varieties. The logic was that loss of the same physical volume of premium grain means a higher money cost. But this consideration may be small: many premium varieties are photoperiod-sensitive and harvest in the early dry season when mechanical drying may be unnecessary. Premium variety storer-millers will, however, readily adopt other quantity and quality saving technology.

The Pursuit of Quality

Also at the previous conference, I proposed that to achieve full use of existing and new quality-saving methods, all the separate actors from retailer to farmer must be pulled into a system by a string of incentive. The strength of the pull is set by the price differential between high and low quality milled rice of ordinary varieties. State intervention may weaken the strength of the pull for quality by favouring farmers with a paddy floor price insensitive to low quality or by favouring consumers with a ceiling price for rice insensitive to high quality. Transmission of the pull for quality back down the line toward farm level depends in addition on the development of cheap tests that can predict the storing and milling quality of paddy. Without these, paddy buyers cannot pass to sellers a price incentive to produce for quality.

Where tastes and the distribution of income are such that a large proportion of consumers is content with a high proportion of brokens, the retail price spread for quality will be small and the string will not pull well. Millers will not have an incentive to strive for high quality or pass on through storers to farmers a price incentive to strive for paddy of high milling quality. In such markets, the pursuit of milling quality will be restricted to the premium varieties subsector of the total production and handling system. Where the country is a regular exporter, the sharp price differentials in the international market will produce a specialised sector pursuing quality milling.

The parameters that define rice 'quality' are set by consumer tastes in high income countries, rather than by objective factors such as recovery rates, storing quality, or nutritional value. It is doubtful that in rice deficit or balance countries pursuit of aesthetic quality is a worthwhile state priority for expenditure of scarce investment capital. A regular rice exporting country like Thailand achieves high milling quality with traditional technology for at least the small proportion of total production that is exported. Occasional exporters like the Philippines and Indonesia should not be over-impressed by parastatal monopolies making a loss on rice sold abroad at a discount for percentage of brokens. State investment or subsidy necessary to pursue aesthetic 'quality' throughout the country would be diverted from more pressing development needs. Since the loss to the nation is in the export sector, investment in the pursuit of quality should be restricted to production areas that regularly produce varieties aimed at the export market.

Conclusion

Bulk handling technology in Southeast Asia may be restricted to the land development schemes of Peninsular Malaysia. Elsewhere, it is likely to be adopted by new parastatal complexes in surplus producing regions to handle regional surplus. Private entrepreneurs in the regional export trade are unlikely to find conversion to bulk handling attractive for existing storages. A large proportion of total national harvest will continue to be handled in bags, including probably the whole traded harvest in deficit and balance regions and the whole of intraregional trade in surplus regions. Comparative data about the country-specific comparative costs and grain saving for well-managed bulk and sack handling are necessary before we can predict whether handling in bulk will compete with handling in sacks, without subsidy, in countries with low wages and expensive capital.

Areas Requiring Research

ACIAR's research project has had as its priority adapting bulk-handling technology to the humid tropics weather and biological conditions. It has justified the research at home and in the ASEAN countries by its grain saving potential. However, if grain saving is the objective, then we still do not have quantified data on how much real grain is lost, to which causes, in parastatal and in private operations, or whether loss was due to inherent defects in existing technology or to human failure to use it properly. Without hard data to identify the real problems, ACIAR and its collaborators cannot set rational priorities for true grain saving research, which may need to include upgrading management systems and personnel as well as technology. Responsible administrators and profit-oriented investors are likely to invest scarce capital in technology only if its promoters can identify present losses that could be saved at lower cost.

1. The best way to identify the source of real losses is to enlist the cooperation of associations of private grain handlers in Thailand and the Philippines. Private traders have an interest in identifying which inherent defects in technology, and which human failure to use it, cost them how much money.

2. To predict demand for technology and influence parastatal and private decision makers, we need to know the comparative capital and running costs of handling the same quantity of paddy in sacks *versus* bulk, for a medium and for a large operation, in sample long-settled surplus production regions of each country. Calculations should present, for each technology, the optimum and the average standards of management and use of technology, using data from (1).

3. The sack handling systems will continue to handle intraregional trade and may compete with bulk handling for regional surplus handling. As the majority of the grain produced will not be handled in bulk, research must continue on how to conserve grain handled in bags.

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Technical Assessment of Integrated Procurement, Drying, Storage, and Pest Management Systems

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Abstract

Decisions made in one sector of a total grain management system must be supportive of activities at all other points in the postharvest chain.

This paper gives considerable emphasis to the establishment of appropriate national standards and grades, and the maintenance of grain quality appropriate to those standards. Procurement systems must use objective methods to assess quality, and handling systems must be so integrated as to ensure that the end product reflects the application of quality assessment.

The importance of heat management in paddy drying is discussed and the generally accepted definition of heat-damaged kernels given a new interpretation. Technology and associated management practices now exist which, when applied, greatly minimise the incidence of many defects in quality. Expanded extension services and training programs are needed both to introduce the technology and to improve current management practices. A fully integrated postharvest management system necessarily includes a transportation component. This component is seen as the weakest link in the chain.

THE use of the word 'integrated' in technical discussions within the grains postharvest subsector seems to be amenable to a number of definitions or connotations. It appears that we now talk of an 'integrated pest management system' as a system which stands alone but is total in its approach to the problem of grain pests. In other words, the system incorporates all aspects of pest management in such a way that the system user is ensured of total control over infestation and damage.

Hence, an integrated procurement system must be one which gives the procurer total information in relation to the quality standards of the commodity being procured. It is a system which incorporates all of the essential measurements of quality characteristics and, of course, quantity, providing the tools for such measurement and the basis for judgement. It must involve evaluation in terms of monetary value or worth and therefore must contain the essential element of market information. It will ultimately be a very complex system because it will of necessity have a socioeconomic component if not indeed such a base. We shall try to deal with it shortly.

What then is an integrated drying system in this context? It is one which has been developed around the need for drying in the maintenance of marketable quality. Grain drying is inextricably connected with storage and it is very difficult to discuss an integrated or total system of grain drying without involving ourselves in the

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associated storage system. I therefore propose to discuss these two components of what has now become part of a grain handling system as a single entity, giving perhaps a second meaning to our word 'integration'. We are now combining, joining, uniting, or integrating the functions of drying and storage to achieve a wider objective.

Indeed, as we examine and assess these individual components of a grain handling system it becomes obvious that no single component should be permitted to develop in isolation, but rather developed in the context of an integrated whole.

What is the use of a drying regime aimed at maintaining grain quality for milling purposes if we have no provision for short- or long-term safe storage against the elements or protection against infestation by insects, rodents, or other pests? What is the value of a procurement system which measures intrinsic qualities and predicts acquired qualities if we do not have a fully integrated grain handling system to follow procurement? The questions are rhetorical because the answer is obvious. I am simply trying to impress on you the viewpoint that procurement, drying, storage, and pest management systems must be considered by those concerned or involved in the grain industry as a fully integrated or total grain management system in order to ensure that decisions made in one area will be supportive of both ongoing and preceding activities and not counterproductive, as well they may otherwise be.

Digresssing briefly to an example that takes us back a step or two in the chain of integration, and which I may have referred to at a previous workshop: in Laos, an Australian assistance project has provided an efficient irrigation system in Vientiane Province which, if properly used, could double rice production in the area that it serves. In other words, it makes double cropping available. Unfortunately, the irrigated crop is harvested in the rainy season and there was no integrated plan to provide appropriate drying and storage facilities for this second crop. I believe that any technical assessment of the irrigation system cannot ignore the social and economic effects of failure to integrate the irrigation component with the total grain management system.

Procurement Systems

Accepting that the term 'procurement system' implies that buyers (government or private) acquire the grain from the sellers (farmers/producers) under an officially endorsed set of guidelines, we should then examine what these guidelines ought to contain. From a technical viewpoint we are talking about standards and grades and, because my work experience has been limited to paddy and milled rice, I have necessarily confined my comments to paddy rice. Further, it is my contention that we should consider only national standards and grades set for the internal marketing of paddy (which is, in any case, not generally recognised as an export commodity). Indeed, in some countries it is sensible to establish regional standards and grades (perhaps written into the national system) to accommodate vastly different varietal and other characteristics. National standards can be properly established only with a full understanding of the total conditions under which the paddy is produced: climatic, economic, agronomic, social, and even political. Also, just as importantly, they must take into consideration the whole ambit of postharvest facilities that are currently available and perhaps likely to become available in the particular country in the foreseeable future.

The design and introduction of an effective and workable set of standards and associated grades for paddy demand detailed knowledge and understanding of the immediate postharvest facilities and practices which include:

- storage of unthreshed paddy;
- threshing practices;
- storage of threshed paddy;
- drying;
- transportation facilities; and
- the marketing system.

All of these were discussed in a paper (Baird 1987) which I presented to a previous international workshop on technological change. That paper also discussed the selection of grade characteristics, and these are critical in any technical assessment of a procurement system. The characteristics that ought to be selected for the allocation of grade under any set of standards are those which can be objectively measured and relate to the subsequent demands (in respect of defined quality) placed upon the buyer by the consumer. In circumstances where paddy is to be milled purely for domestic or local consumption, the characteristics selected and the grade parameters may be quite different from those that would be appropriate to particular export markets.

From a purely technical viewpoint an effective procurement system for paddy rice will include a quality assessment system based on the following quality characteristics:

- varietal purity;
- moisture content;
- impurities;
- immaturity;
- damaged and discoloured grains;
- red rice;
- milling recovery (potential); and
- head rice yield (potential).

All of these characteristics, given time and equipment, can be objectively measured. One of the major problems, however, lies in the time taken at the procurement point to carry out the procedures for this quality assessment. Hence it is necessary, in most instances throughout our region, to select those measurable characteristics which are most relevant to the final market place and over which there is clearly defined downstream management control, viz. drying, storage, infestation, etc.

Any procurement system recognises moisture content as a prime measurable grade factor. The results of storage of paddy containing excess moisture are well known. Moisture content is readily and rapidly measurable with a wide range of available equipment. However, moisture content itself cannot be recorded and simply set aside in an integrated procurement system. In the event that paddy is procured at a moisture level safe for storage, there is, of course, the further question of whether safe storage can in fact be provided following procurement, and for how long. Even more important, perhaps, is the measurement of milling recovery and head rice yield, for these are highly dependent on not just the moisture content of the paddy at procurement or at the time of milling, but upon how paddy has been dried. Stress inflicted by the drying regime will be clearly reflected in these measurable characteristics. These stresses are normally quite evident as cracks in the husked paddy, but milling yield and head rice yield have, to date, been determined only by laboratory or test milling procedures. These determinations do, of course, reflect other quality characteristics which may or may not obscure or exacerbate the effect of drying stresses. The use of the crack detector developed in Japan would appear to have considerable value in the overall control of the drying process, particularly when that process has been carried out off the farm (i.e. commercially).

When paddy rice is acquired by the procurement agency in a 'wet' condition, we have an even more classic example of why procurement must be fully integrated with the next phases of drying and storage. The procurement system must not only establish the moisture content of the grain; it must also be so constructed as to fairly compensate for excess moisture, in the knowledge that the drying and storage regimes which will follow procurement will ensure the maintenance of the potential milling quality as revealed by the quality assessment procedures carried out at the time of procurement.

The level of impurities is another assessment vital to the 'downstream' operations of our management system. It must be assessed at procurement, not simply for the reason that the buyer sees no value in buying waste or noxious material, but for reasons of efficient use of drying and storage facilities. Mechanical and in-store drying systems are seriously compromised by the presence of straw, chaff, grass, weeds, foreign seeds, and indeed a wide range of foreign materials or impurities. Apart from interfering with the free and even airflow necessary in all drying systems, valuable storage space can be lost to useless materials. The procurement system can and should be designed so as to allow this quality characteristic to be objectively assessed. In general, the prehistory of paddy rice (in respect to its purity) offered for procurement can be well assessed by the level of heat damaged grains, and it is a natural corollary that its future grade, with respect to heat damaged grains, can be assessed by reference to its current level of foreign materials or impurities.

The measurement of the level of immaturity is another important factor in an integrated procurement system. It reflects many things relating to earlier stages of the production chain, including varietal purity, varietal suitability, and farm practices. But it is also an indicator of potential milling recovery and ultimate consumer acceptance. Again, immature rice is wasteful in respect to drying and storage.

For practical purposes it can be assessed by thickness grading. The system does not give absolute accuracy but provides an excellent comparative test and should be regarded as an essential quality assessment factor.

Because inadequate facilities and incorrect or badly monitored drying and storage regimes can and do result in heat damage and discoloration, our procurement system would be incomplete if it did not measure the incidence of this quality defect. Although some of the defects often originate in the growing crop, through the attack of certain insect pests and the incidence of climatic conditions beyond human control, most of them are brought about through mismanagement in the postharvest stage. I hasten to state here that I use the term 'mismanagement' in a purely technical sense. No individual or organisation can be held responsible for failure to use facilities which they either do not possess or have no access to. Nevertheless, it is necessary that we highlight the fact that the technology and management practices which greatly reduce the incidence of these quality defects do exist. There are undoubtedly many opportunities for expanded extension services and training programs both to introduce the technology and improve the management.

The subject of damaged and discoloured grains is a very complex one that has received a great deal of attention from entomologists, microbiologists, physicists, chemists, and engineers involved in grain postharvest technology. Yet, when we measure this characteristic at the procurement level (by whatever means) we invariably do so using a definition that is either far from adequate or grossly misinterpreted. A widely used definition of 'damaged and discoloured kernels' describes these as being: 'whole or broken kernels of rice which are distinctly damaged and/or discoloured by heat, water, fungi, insects, or any other means. The category includes yellow or fermented kernels and parboiled rice kernels in non-parboiled rice'.

Because most of our drying practices use heat either to effect or to accelerate the drying process, and because so many of these practices are inadequately controlled, I am suggesting to you that the mismanagement of heat in paddy drying is the greatest single contributor to heat damage; but we do not measure this form of heat damage 'damaged and discoloured kernels'. It passes us by until we report milling recovery and head rice yield, which can prove to be disastrously reduced through the misuse of heat and a lack of understanding of the thermodynamics of rice drying. You will note that I have been specific in referring to rice drying, not grain drying, because I am relating the drying of paddy rice to a very specific end product: whole milled grains.

Of course, heat *per se* is not the only contributor to this highly important procurement factor: it is only one component of the dynamics of rice drying. However, in the great majority, if not all the farm or commercial drying practices in humid tropical areas, it plays a fundamental role, and not to ascribe this form of damage to heat is therefore akin to not blaming the fall from the cliff for the broken bones, but the sudden stop at the bottom.

As stated at the outset, drying and storage are so inextricably connected that I believe that any discussion of the practical application of rice drying systems must include the associated storage systems. The same applies to any technical assessment of drying systems.

Storage Systems

Storage systems can be considered at two stages of our grain management system: before drying, and after drying.

A number of variables govern the selection of a pre-drying storage system, but perhaps we can confine ourselves to two sets of circumstances: hand harvested paddy, with subsequent hand or stationary machine threshing; paddy mechanically harvested by combine harvester thresher. Where rice is hand harvested and threshed in the field it is inevitably accumulated there in sacks of from 40 to 75 kg capacity, for purposes of transportability. Generally, the grain is not held in sacks for any length of time before being subjected to some form of drying regime, usually sun drying. It is appropriate to mention here that it is during the interval between harvesting (cutting) and threshing that a great deal of paddy suffers severely from heat and water damage. This applies to cut paddy allowed to lie in the wet fields, and to field piles of cut paddy awaiting threshing.

Provided that the sun is shining, the paddy will be dried and finally rebagged and placed in covered storage (where it may or may not be subjected to immediate infestation pressure by insects and rodents) to await presentation to a buyer or procurement officer. Alternatively, it may be marketed directly after drying without any on-farm storage. Commercial bagged paddy storage is usually waterproof but not rodent proof and is generally heavily infested.

In some areas, including Malaysia, wet paddy with high levels of impurities (mostly straw) is packed into sacks and delivered to the procurement authority without drying. The consequences are well known.

There have been a number of attempts to build and encourage the use of dryers for bagged rice. For a number of reasons, these have not been satisfactory. It is likely that the drying air blown through the stack travels through the interstitial spaces between the sacks rather than the grain itself. The effectiveness of such dryers is also hampered by high levels of impurities in the paddy, and by the fact that most of the energy is used up in the drying and wetting of jute. The general answer to problems with bag stack dryers has been to increase the temperature of the input air above appropriate limits, thereby causing damage to the grain.

When paddy is harvested by combine harvester/thresher, one or other of two situations seem to be most common: the first is as seen in certain areas of Malaysia, where the paddy, having been combine harvested, is dumped in bulk in the field (usually with an excessive amount of trash from the combine), bagged wet and delivered to the National Paddy and Rice Authority for cleaning, drying, and storage. The other circumstance, which is by far more acceptable, is when the paddy is discharged from the combine into bulk transport bins and delivered, in bulk and within 24 hours, to a cleaning, drying, and storage facility. The first situation includes a period of unpredictable length during which the paddy is virtually bulk stored in the field, with or without cover: a damaging period of pre-drying storage. The second situation does not belong to this category of pre-drying storage as the time interval is short.

There is, however, a third situation for combine harvested paddy in which the paddy is bagged directly from the combine and stored with or without cover in the field before movement to a drying facility, whether this be solar or mechanical, private, or governmental.

There can be no useful technical assessment of pre-drying storage. It is a practice which inevitably causes grade deterioration and every effort must be made to eliminate or minimise it.

Drying Systems

The term post-drying storage implies that the grain is placed into storage after drying to a safe condition with respect to moisture movement, mould development, and suitability for milling. It is fortunate that these requirements come together at about 14% moisture content. Storage of dried paddy in the humid tropics has, of course, been predominantly in bags, but because this workshop is dealing with bulk handling and storage I shall confine myself to consideration of the bulk situation.

First, let us list the major drying options available to the industry:

- sun drying;
- aerated static bed with supplemental heat; and
- mechanical drying, continuous-flow systems.

Sun drying is effected by spreading the bulk grain on a smooth, flat, surface, manually turning or raking it periodically for maximum exposure to the sun.

Aerated static bed drying with supplemental heat may be a small or large batch method. Small batch dryers are normally used for relatively shallow depths of grain (up to 1 m). Large batch dryers generally handle deep beds (up to 5 m) of grain and their use is more generally known or referred to as in-store drying. In-store drying without supplemental heat has application under certain specified conditions but is not widely practised in the humid tropics.

Continuous-flow, mechanical or column drying is by far the most universally accepted method of handling high moisture paddy in bulk. There are a number of variations in method which basically relate to the mechanical method used to expose the grain to the heated airflow. The variables used in determining the amount of moisture removed are static capacity, airflow rate, temperature of the process air, and grain flow or discharge rate. The initial moisture content of the paddy and the judicial selection or fixing of these variables will determine the time taken for drying or the number of passes through the dryer.

Varietal differences also play a role in the selection of drying parameters but it is not my intention to devote any of this paper to the specifics of efficient continuous-flow drying of paddy. It suffices to say that the system has limitations with respect to the amount of moisture that may be removed in a single pass through the dryer. Hence, paddy with a high initial moisture content may require as many as five passes, though rarely more than three occur in practice. Intermediate tempering facilities must be provided as part of a multipass drying system.

The best use of continuous-flow, mechanical drying facilities in the humid tropics for the commercial storage of paddy is now seen to be a combination with in-store drying, using high aeration rates with supplemental heat. This is covered by other papers in these proceedings.

Another mechanical drying method which has great potential for many parts of the ASEAN region is the batch recirculating system, in which tempering between recirculation takes place within the drying unit. This system has particular application in situations where there is a large variation in moisture content between procurement lots. A battery of batch recirculating dryers ensures prompt and appropriate treatment for each lot, as the batch holding capacity is never over-large.

The technical development of rice husk furnaces linked to efficient heat exchange units with adequate temperature control has opened the way for the extensive introduction of the combined mechanical/in-store drying regimes that have been identified and refined as part of the ACIAR Grain Storage Research Program.

The proper use of this technology will ensure safe storage and quality maintenance of paddy in the humid tropics, provided that the storage is well designed and takes account of requirements for input and discharge of paddy, storage time, aeration management, pest control, and the monitoring of quality or grade characteristics.

All of these requirements have been dealt with in detail by other speakers to this workshop.

Conclusion

The procurement, drying, storage, and pest management systems available to us today in the rice postharvest subsector have reached a very high standard of technical efficiency. They come together in an integrated form as a total grain management system into which we must incorporate the vital transportation component. It is perhaps this last component which requires our greatest attention because when it breaks down so does our total integration. I have endeavoured to highlight to you that quality assessment throughout every phase of all these operations is absolutely vital to the technical assessment of the integrated system.

It is also the single unifying factor: for of what use is the end product to producer or potential consumer if it is unfit for human consumption or incapable of supporting the farm economy?

Reference

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From Field to Port: the Logistical Operation

G.K. Rand*

Abstract

Bulk handling and storage of harvested crops are subsystems of the total logistical operation of transferring crops from the farmer's field to the final consumer or, in the case of exported produce, the port.

The design of such a logistical system should specify transport modes from farm to storage facilities, and from storage to customer or port, and the number, location, size, and type of storage facilities. In determining such a specification, transport and storage costs, and the decision-maker's objective and area of responsibility need to be taken into account.

In analysing such a system it is important to consider how restricted the choice of locations should be, how complex the cost functions should be, what planning horizon should be considered, and whether the existing facility location and sizes should be taken as given.

Three examples of location analyses are given, from the Nigerian oil palm industry, and the grain industries of Bangladesh and Brazil.

A logistical system which is being operated needs to be controlled. Brief reference is made to the choice of performance measures.

IN the context of bulk handling and storage of grain in the humid tropics, logistics can be defined as the process of strategically managing the movements and storage of grain from suppliers to customers. In general, the object of logistics is to deliver the product, in the required quantities, when required, in acceptable condition, to the location where needed, at the lowest total cost. The responsibility of logistical management is to design and administer a system to control the flow and strategic storage of grain to the maximum benefit of the enterprise. Readers are referred to Bowersox (1978) for a detailed general discussion of logistics.

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The emphasis is therefore on both the design and control of a logistical system. A system will work effectively only if it is both designed correctly, taking into account constraints that exist and, once installed, controlled effectively, ensuring that it is working to the designed specification.

The definitions given in the opening paragraph indicate the all-embracing nature of logistics. It includes the following activities: procurement (to ensure supplies), transport, storage and processing, information supply, and finance. Decisions that will need to be made may include choice of transport mode and size, the scheduling of transport to reduce the length of queues at processing facilities, and choice of type, level, and location of storage and processing facilities. The information required will concern sources of supply and demand (location, quantity, time), and financial information (purchase and selling prices, transport costs, wages). Performance data should also be collected to allow control measures to be adopted.

Grain logistical systems have been described elsewhere, for example by Fegan in another paper in these proceedings, and by Ghazali (1987). Grain is taken from the field to intermediate storage, such as procurement centres, and is then transported to drying, milling, and storage facilities. In the wet season particularly this movement needs to take place quickly after harvesting because of the rapid deterioration of harvested grain in the humid tropics. From the mills, the grain will be sent to customers and possibly to a port for export. An analysis of such a system will require cost models to be created for transport and facilities, as described in papers by Muzafar, and Ghaffar and Hassan, in these Proceedings.

The Decision Maker's Objective

The design of the system will depend on the decision maker, and the decisions under his control. An issue debated at a previous conference (Champ et al. 1987) was how government intervention in the marketing system might affect the validity of logistical models which had been proposed. Some speakers argued that a competitive market can solve the coordination problem in grain transportation and so there is no apparent value to gain from modelling the logistical system. Others argued that government involvement in grain handling is needed to ensure efficient coordination.

However, both private enterprises and governments should be concerned that the decisions they make should be effective. Whether the decision maker is concerned with a part or the whole of the system, attention should be given to evaluating the alternatives that exist, so that the decisions made achieve the benefits intended.

The design of the system will also depend on the decision maker's objective. The most frequently assumed objective in the design of logistical systems is to minimise the total costs. This is appropriate only when the revenue is not dependent on the system, because then, when revenue is assumed fixed, minimum costs are equivalent to maximum profits. When delays in processing cause losses in production, as is the case with paddy and other grains, it is appropriate to maximise profits or net revenue, as is described by Salleh et al. in another paper in these proceedings.

It may be appropriate to consider whose profits are being maximised. If farmers pay for transport to the procurement centres, as may be the case in some agricultural systems, it will be to their benefit for there to be many procurement centres, because they would then be, on average, nearer to the farms. However, if there are fixed costs associated with procurement centres it would be in the interest of the organisation providing them to have fewer of them, thus reducing cost. Nevertheless, there may not necessarily be a conflict of interest, because a smaller distance from farm to procurement centre may reduce deterioration and subsequent postharvest losses.

A similar situation existed on a sugar estate in Kenya, when an analysis of the optimum harvesting cycle was carried out. The longer the crop grew, the more sugar cane was harvested, though there was a decline in the tonnes of cane per hectare per month after approximately two years. There was also a decreasing return in the conversion to sugar with an increase in the age of the crop at harvest and, of course, a delay in the start of the next crop. For the sugar estate it was possible to evaluate the harvesting cycle for both the first crop and the subsequent crops, called ratoons, which gave maximum sugar yield per unit time. The farmers were paid by weight of cane harvested, which potentially gave rise to a different optimum cycle, when the maximum cane yield per unit time was evaluated. In fact, the cost curves were shallow enough near the optimum for the cycles to be the same from the point of view of both the estate and the farmers, and for both the first crop and ratoons, which was contrary to the perceived wisdom.

Analysis of Locational Decisions

An important part of the design of the logistical system will be to determine the locations of the various facilities required. The designer will want to answer the following questions:

- How many facilities should there be?
- Where should they be?
- Which farms/markets should they serve?
- How big should they be?

Some of the models relevant to this issue were discussed at a previous conference (Koo 1987; MacAulay 1987; Ryland 1987).

It is appropriate to discuss some of the choices presented to an analyst when faced with modelling locational decisions. These and others have been dealt with at greater length elsewhere by Rand (1976).

1. How restricted is the list of potential locations?

It has become traditional to distinguish between an infinite set approach to location (i.e. allowing no restrictions as to where facilities may be located) and the feasible set approach, where a list of possible facility locations is specified.

Advocates of the infinite set approach consider the main advantages to be that it does not require the preselection of potential locations, but in practice it may not be possible to locate facilities at the 'optimal' locations. Furthermore, for multi-site selection the infinite set approach does not guarantee an optimal solution, because the usual algorithms are iterative, requiring the generation of many solutions using initial locations, and then the choice of the best solution. In addition, there is no direct procedure for determining the number of facilities. The multi-site algorithm would need to determine the best solution for a different number of facilities, and then the total cost of the different solutions, including facility costs, would need to be compared.

In grain handling and storage systems it is probable there are relatively few sensible locations for facilities and, in these circumstances, a feasible set approach will probably be the right choice. Using a feasible set approach allows costs specific to location to be incorporated, and permits greater freedom for the choice of transport cost model. Moreover, the approach allows direct answers to be given to the questions posed at the beginning of this section.

2. How complex should the solution search procedure be?

Linked with the choice between the infinite set and feasible set approaches is the choice of the mathematical algorithm to be used. A trade-off exists between the complexity of the search procedure and the sophistication of the cost functions. This is illustrated in Figure 1.

The feasible set approach allows more complex cost functions to be used, but the use of a feasible set inevitably reduces the thoroughness of the search. A potentially fruitful approach is to use the feasible set approach to produce a short list of location combinations by the use of mathematical programming or heuristic techniques, and then to evaluate the short list using simulation programs such as those described by Moore in his paper on port handling facilities in these proceedings. The GMAT simulation model, which has been used for planning the grain handling and transport system in Victoria, Australia is presented in Bennett and Kent (1983), and Smith and Stoney (1983).

3. What planning horizon should be considered?

Most location studies have been concerned with a static situation. When it is expected that the total quantity of a particular grain harvested in a region may increase over time, it will be more appropriate to use a model to provide strategic decisions for the location of a set of

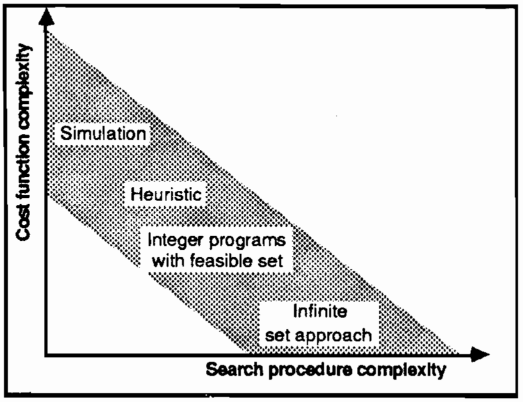

Fig. 1. The relationship between complexity in search procedures and cost functions.

proposed facilities and their implementation over an n-year period. The objective then may be to maximise the ratio of net return to total assets over the economic life of the facilities. Such a model is likely to be extremely complicated.

An alternative which may prove useful is to consider the robustness of locations to the possible future (see Rosenhead et al. 1972). By considering the supply pattern expected in n years time, it will be possible to determine the optimal number of additional facilities. It would then be possible to generate a number of potentially good combinations of locations (say costing within 5% of the lowest cost). The robustness score of each location is the proportion of these good combinations in which the location appears. Then the location with the highest robustness scores should be chosen first, and the exercise repeated and other locations added as the need arises.

4. Should existing locations/capacities be included in the model?

It is rare for an analyst to be presented with the initial location problem, where no facilities exist (the so-called 'greenfield' situation). Usually, there will already be a number of facilities in existence. Where these involve large fixed costs it will generally be sensible to regard the capital as sunk and assume that these facilities will continue to exist. In other situations, it may be appropriate to ignore the present site configuration and consider the implementation of the 'greenfield' solution when compared with the present locations. This may be the case, for instance, when considering the location of procurement centres, which may not have expensive fixed assets associated with them.

A similar argument may apply to the capacity of existing sites. There is a choice, not only for existing sites but for all feasible locations, of including a capacity in the formulation of the model or of creating an uncapacitated model. It will frequently be useful to run the model without capacities included. This will allow the analyst to discover whether the capacity at an existing facility is insufficient and, if so, by how much. If capacities are included in the model this will not be discovered so easily, if at all. With this information the analyst can evaluate various alternatives, such as increasing the capacity, moving to a nearby site, or serving part of the catchment area from a neighbouring site.

Some Examples

To illustrate some of the preceding points, summaries of three relevant papers are given in this section.

1. The Nigerian Oil Palm Industry

Ademosun and Noble (1982) describe a model to identify the set of locations for oil palm processing units in Nigeria. The location decision implies the allocation of plantations to processing units, and hence their size.

The infinite set approach was used to minimise the total cost of transportation of fresh fruit from plantations to processing units, transportation of mesocarp oil from processing units to the oil markets, transportation of palm kernels from the processing units to the kernel depots, and processing cost. The use of the infinite set approach was justified because there is no large area in the oil palm producing and consuming zone in Nigeria which is unsuitable for the establishing of a processing unit. Thirty-four plantations, eight oil markets located at state capitals, and four kernel depots located at major ports, were considered. The mathematical formulation of this problem is given in an Appendix.

The solution procedure involves an iterative process following a choice of random initial locations for the processing units, in which processing units are allocated to markets and kernel depots, and plantations are allocated to processing units. The total cost is then compared with that obtained in the previous iteration. This iterative procedure has to be repeated for different numbers of processing units, to determine the number of units which leads to the minimum total cost. The optimal number of processing units was found to be 10, but the cost curve is very shallow about this point.

In Nigeria, the favoured policy is for each state to control its own agricultural resources. To establish the penalty cost associated with this policy the model was modified to ensure that each plantation was allocated to the market in its state capital. The increase in cost was found to be insignificant.

2. The Bangladesh Grain Model

Pruzan (1978) describes how a nationwide logistics problem was tackled in Bangladesh. The term of reference for the project, initiated by the Bangladesh Ministry of Food and Civil Supplies and supported by the World Bank, specified that 'the capacity and location of additional storage facilities of all types (terminal silos, gathering/distribution silos, or flat storage units at Central Storage Depots and Local Storage Depots), should be determined through the application of appropriate systems analysis techniques to ensure that the new facilities, integrated with the existing facilities, will provide a complete system with minimised capital, operating and transport costs'.

The solution procedure used was based on a mixed integer programming model using a network formulation of the problem. It considered 58 potential locations for major storage facilities (MSF) in the form of either a flat storage unit called a 'godown', a cement silo, a steel silo, or the rehabilitation of existing facilities. The main purpose of the model was to distinguish cost-effective structures of the grain storage system from costly, ineffective structures, and not to directly provide an 'optimum solution', because of the great uncertainty about production and demographic forecasts, unclear policies regarding the future rationing and procurement systems, and the uncertainty surrounding future costs of transporting, handling, and storing grain.

The major recommendations based on the model output were that there should be 20 sites with an MSF, that preference should be given to rehabilitating existing flat land storage units as opposed to new inland silos, and that preference should also be given to manual technology as opposed to the use of bulk handling and storage. Only two sites were recommended for rehabilitated MSFs based on bulk storage, while 13 sites were recommended for rehabilitated MSFs with storage in bags. Two new import/export silos were recommended. It was estimated that savings in handling and transport costs and storage losses would result in an internal rate of return of 20% on the investments required.

3. The Brazilian Grain Industry

Monterosso et al. (1985) are concerned that the historical 'think big' strategy, which has been followed in most Latin American and African countries, is misconceived. The main reason for this, it is suggested, is that storage decisions have been made without consideration of transport costs, with an emphasis being placed on gaining economies of scale from storage construction. One result of this strategy has been unnecessarily high transport costs.

The authors formulate the problem as a plant-size location problem, and develop a program to search for efficient patterns of storage location, using Fulkerson's (1961) out-of-kilter algorithm as a subroutine. They argue that the network flow formulation of the problem provided a logic and results that could be easily understood by decision makers.

Three Brazilian production areas were investigated. They were selected to represent a wide range of levels of development, transport-storage problems, and tenure conditions. The areas selected were the soybean and corn producing areas of the southwestern and Campo Mourão microregions of the state of Paraná, and a rice producing region in central-western Maranhão. The results from all three areas showed that lower cost could be obtained from a greater number of units of smaller average capacity, and contradicted the widely held premise that collector storage units should be located on good roads, provided the roads are not so bad that larger trucks are unable to travel on them.

Performance Control

Any system that is being operated needs to be controlled to ensure continued effectiveness. Various performance measures need to be collected on a regular basis, probably weekly. These performance measures should be of two kinds: first, productivity measures, which are the ratio of real output to real resources consumed, such as tonnes processed/man hour or tonnes delivered/vehicle day; and second, utilisation measures, which are the ratio of capacity used to available capacity.

It may be appropriate to distinguish between productivity efficiency and productivity effectiveness (Armitage 1987). Measures of productivity efficiency seek to measure the efficiency with which individual activities are conducted. However, there may be a more productive way to carry out the activities, even though the current operation is being performed in an efficient manner, so it may also be appropriate to measure productivity effectiveness.

For example, consider two hypothetical rice stores which have 10 men working for 10 hours per day on processing incoming rice. Rice may be received in two different forms: in bags or in semi-bulk form. Suppose that a tonne received in bags takes three times as long to process as a tonne received in semi-bulk form. An efficiency measure should recognise the existence of different inputs and the effect on productivity.

On a particular day suppose that store A processes 10 tonnes of rice in bags and 70 tonnes of rice in semi-bulk form, and store B processes 50 tonnes of rice in bags. Thus the stores process the equivalent of 100 and 150 tonnes of rice in semi-bulk form respectively. The stores efficiency scores, using the measure

Equivalent tonnes processed/hours worked

are 1.0 and 1.5 respectively, which indicates that store B is more efficient than store A. However, an effectiveness measure,

Actual tonnes processed / hours worked

gives scores of 0.8 and 0.5 respectively, which demonstrates that store A is more effective, perhaps because of greater success in persuading suppliers to use semi-bulk handling systems.

Managers of different aspects of the logistical system should be assessed on the basis of the measures used. They should know what they are, the measures should match the objectives of the enterprise and some control procedures, such as cusum charts, should be used to determine when deviations are significant.

Conclusions

The aim of this paper was to describe some of the key features in the design and control of logistical systems for grain in the humid tropics. The references cited indicate that many of the component models, which together form an integrated model of the total system, are already in existence. This applies particularly to the rice and paddy industry in Malaysia.

The reduction of postharvest losses is an important issue to which effort should be devoted. The logistical difficulties which have bedevilled the famine relief operation in Sudan and Ethiopia have made headline news in recent years. But these problems are not confined to countries which experience severe drought. Many countries fail to distribute agricultural produce adequately and experience regular losses of crop. These losses can be high. In Zambia, for example, 12 000 tonnes of the 1985 maize crop remained stranded in one district of the Northern Province as the rainy season approached (Cooper 1986).

It is to be hoped that this workshop, of which this paper represents a small part, will encourage the research that will enable integrated models to be developed, which in turn will lead to improvement in postharvest performance.

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Appendix: Location-Allocation Model for the Nigerian Oil Palm Industry

Objective: Minimise $C = C_f + C_m + C_k + C_p$

where

C_f = cost of transportation of fresh fruit bunches (FFB) from the plantations to the processing units,

C_m = cost of transportation of mesocarp oil from the processing units to the oil markets,

C_k = cost of transportation of palm kernels from the processing units to the kernel depot,

C_p = cost of processing fruit bunches at the processing units,

subject to the following constraints:

(1) Each plantation i (i = 1, 2, ..., p) sends its FFB production w_i to one, and only one processing unit j (j = 1, 2, ..., u).

d_{ij} = 1 if plantation i is allocated to processing unit j
= 0 otherwise

and

$$\sum_{j=1}^{u} d_{ij} = 1 \text{ for all } i$$

(2) The capacity of any processing unit j, Wj, cannot exceed some maximum value W_{max}.

$$W_j = \sum_{i=1}^{p} w_i d_{ij} \leq W_{max} \text{ for all } j$$

(3) The total amounts of mesocarp oil supplied to each market m (m = 1, 2, ..., M) by processing unit j, w_{jm}, is the amount of oil extracted from all the FFB supplied to the processing unit.

$$\sum_{m=1}^{M} w_{jm} = \sum_{i=1}^{p} r_i w_i d_{ij} \text{ for all } j$$

where r_i = the quantity of oil extracted from 1 kg of FFB harvested from plantation i.

(4) The total amount of kernels supplied to each kernel depot k (k = 1, 2, ..., K) by processing unit j, w_{jk}, is equal to the production of kernels by that processing unit.

$$\sum_{k=1}^{K} w_{jk} = \sum_{i=1}^{p} q_i w_i d_{ij} \text{ for all } j$$

where q_i = weight of kernels obtained from 1 kg of FFB harvested from plantation i.

(5) $w_i \geq 0$ for all i

$w_{jm} \geq 0$ for all j and m

$w_{jk} \geq 0$ for all j and k

Each of the transport costs can be expanded as follows:

$$C_f = a_1 \sum_{i=1}^{p} \sum_{j=1}^{u} w_i k_{ij} d_{ij}$$

$$C_m = a_2 \sum_{j=1}^{u} \sum_{m=1}^{M} w_{jm} k_{jm}$$

$$C_k = a_3 \sum_{j=1}^{u} \sum_{k=1}^{K} w_{jk} k_{jk}$$

where k_{ij} is the distance in kilometres from i to j and a_1, a_2, a_3 are the respective transportation costs per kg per kilometre return journey.

The processing cost, C_p, was of the form

$$C_p = F_1 + p_1 W_j \text{ when } 0 < W_j \leq W_{min}$$

$$= F_2 + p_2 W_j - p_3 W_j^2 \quad \text{when } W_{min} < W_j \leq W_{max}$$

where W_{min} and W_{max} are the capacities of the smallest and largest existing processing units.

Establishing Priorities for Research and Development on Bulk Handling in the Grains Postharvest Sector

J.V. Remenyi*

Abstract

Relevant criteria for priorities assessment are different for public and private sector decision makers. The former have a responsibility to guard net social welfare, while the latter respond to shareholders and investors. It is critical that public sector intervention should complement rather than compete with the private sector. As a first task, therefore, priorities assessment requires identification of appropriate roles for the private and the public sectors. In this paper it is argued that the public sector should be involved only where market imperfections (i.e. failures) or externalities exist and operate to reduce investments in research and development below optimal levels. Within areas of research or development where this is the case, economic techniques are available to assess opportunity, costs of funds, potential domestic resource costs and benefits, expected internal rates of return, and the distribution of benefits as measured by consumer and producer surplus estimates between consumers and producers at home and abroad. A central element in this process is an evaluation of relevant food sector policies, especially pricing and procurement, to ensure that existing postharvest grains subsector deficiencies are not the perverse outcome of existing inappropriate policies amenable to change or replacement.

THE task set for this paper is a daunting one, fraught with all manner of pitfalls and traps. Nonetheless, like the fool who rushes in where angels fear to tread, the paper addresses the topic directly.

The strategy followed has two parts. In the first, we examine the global question of what ought to determine the absolute level of public support for research on bulk handling of grains in the tropics. In the second part, we leave aside the question of government involvement to explore how competing research demands within grains postharvest research can be resolved or accommodated. In respect of each part, we argue that there are specific decision rules designed to achieve complementarity between the public and private sectors and socially optimal levels of investment in specific areas of research. Throughout, a multidisciplinary approach to problem identification, specification, and solution is advocated.

Establishing the Importance of Postharvest Research

Priorities assessment in research and development (R&D) is essential in a world of scarce resources. Central to this task is an acceptable and consistent procedure for choosing between competing claims on resources for R&D. This procedure needs to operate at several levels. First, there is a global concern to ensure that resources are allocated optimally across the economy. Two decisions are needed for this to occur:

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(a) what role for the public sector and what can be left to the private sector?

(b) what is an optimal level of investment in any given area of R&D; in the case before us, bulk handling of grains in the humid tropics?

Answers to these two questions are not easy or unequivocal. The answers will vary, depending upon the importance we attach to subjective factors that enter into the social-welfare equation. Fortunately, however, we have a useful starting point: the actions of entrepreneurs and investors reacting to profit opportunities in the market place. These are, necessarily, only a guide to R&D priorities because they do not account for the non-private (i.e. social or societal) costs and benefits of investment and risk-taking in R&D. These are at the heart of issues to be considered in addressing question (a) above, a task to which we now turn.

To the extent that net social benefits of investments in R&D exceed the net private benefit (i.e. profit motive), there will be under-investment by the private sector in R&D. The prevalence of this problem in R&D generally is the primary reason why governments issue patents and copyrights to inventors and innovators. Without this protection, competitors can benefit from technical progress without having to share in the burden of risk-taking and cost associated with what may well be a lengthy and expensive period of R&D. A cause-célèbre in the postharvest grain area that illustrates the problem is the small-farm rice thresher developed in the early 1960s at the International Rice Research Institute (IRRI), Los Baños, Philippines.

Because subsistence farmers are poor and find cooperative group activity difficult to sustain (the problems of communication are legion and the cost of overcoming them often prohibitive), there is a *prima facie* case for believing that there is less investment in the generation of small-farm technologies than may be socially desirable. The public sector can assist by helping to bridge this gap. There are numerous examples where this has happened, but in the postharvest grains sector the IRRI small-farm rice thresher is a well known case study with lessons relevant to the topic before us in this workshop.

Bart Duff's (1986) ex-post evaluation of IRRI's investment in R&D on the small-farm rice thresher is instructive for our purposes in several respects. First, development and manufacture of the rice thresher was a uniquely successful enterprise; it has matured beyond an 'infant industry' needful of public subsidies. Second, in this study, Duff found an overall annual internal rate of return of 57.6%, with a benefit-cost ratio of almost 12 at a discount rate of 20% per annum! By normal commercial standards these are impressive figures and indicative of how seriously below optimal was private investment in small farm engineering R&D. Third, Duff explicitly attributes this market failure to the lack of financial incentive and support that subsistence smallholders are able to generate among investors in agricultural R&D. Fourth, Duff concluded that left to the free play of market forces, a thresher for smallholder agriculture would not have been forthcoming as quickly, if ever, even though threshing was an important constraint on improved performance among smallholder rice farmers.

These are fundamentally important observations that provide the basis of the first of our decision rules or principles in R&D priorities assessment: i.e. public sector involvement in postharvest R&D is appropriate where the free play of private sector market forces cannot be expected to elicit a socially optimal level of investment in relevant R&D.

This decision rule tells us when government intervention is justified, but we are still left with another critical element to our global question that must also be answered: how much public sector involvement is needed? At the global level, the fact that we can identify an area of actual or potentially important market failure is not enough information on which to build a strategy for government action. Just as the success of the IRRI thresher does not imply the necessity of public support (i.e. subsidies or direct involvement) for agricultural engineering programs generally, so too the identification of specific divergences between private and social net benefits does not justify or necessarily require public intervention.

The answer to the question 'to intervene or not to intervene?' depends on the opportunity cost of resources needed for effective intervention. In the specific terms of our focus here, resources allocated to R&D on bulk handling of grains in the humid tropics have an opportunity-value in other research endeavours: consider, for example, the data in Table 1.

Imagine that you are the Director of Research, faced with internal rates of return (IRR) estimates across the six competing areas of research shown in Table 1. On the basis of these data, it is not at all obvious that the IRRI rice thresher would find support. One would be inclined to invest first in areas of R&D where the IRR is highest and continue to invest in those until investment opportunities greater than 57% per annum were exhausted.

Our second decision rule or principle follows directly from this example: i.e. priority ought to be given to the public funding of R&D in grains bulk handling so long as the opportunity cost of resources in that use is less than the expected net social benefit from their employment in grains bulk handling R&D.

Factors Enhancing the Importance of Grains Postharvest Services

Past and contemporary trends indicate that the bulk handling of grains in the humid tropics will become more important in the decades ahead than it is today. A generation ago subsistence agriculture was more widespread throughout the developing world and the cash economy not as dominant. A key indicator of this important change is the increase in the percentage of grains output deliberately produced for cash sale rather than for subsistence use or payments in kind to landlords and farm labourers. In the case of rice, which is the principal grain grown and consumed in Asia, the marketed surplus has increased from not more than one-third in 1950 to at least one-half in 1980. By the turn of the century this figure may well top two-thirds.

In parallel with an increase in marketed surplus, there has also been a rapid rise in the urban population of developing countries. In 1950 only 15% of Third World population was urban. By 1980 this proportion had doubled, and is forecast to rise to over 40% by the year 2000 (IWC 1985). Urbanisation has fuelled the demand for cash sales of grains and underwritten both the growth in marketed surplus and the volume of imports of grains by developing countries. These trends reinforce the need for bulk handling capacity and, by implication, to increase the importance and urgency of overcoming problems/constraints inhibiting more cost-effective operation of the grains postharvest services subsector in developing countries.

In addition to the increase in demand for cash sales of rice and other grains, urbanisation has also introduced important qualitative changes

TABLE 1. Estimated internal rates of return (IRR) to research investments in agriculture.

Area of research	Source	Period of investigation	IRR (% p.a.)
IRRI rice thresher (Southeast Asia)	Duff 1986	1966-84	57+
Pasture improvement (Australia)	Ruttan 1982	1948-69	58+
Rice improvement (Asia)	Ruttan 1982	1966-75	73+
Cotton improvement (Brazil)	Ruttan 1982	1924-67	77+
Rapeseed improvement (Canada)	Ruttan 1982	1960-75	95+
Farm management and extension (USA)	Ruttan 1982	1948-71	110+

into the market for purchased cereals. These qualitative changes relate to the processing and storage characteristics of cereals, and the demand for imported cereals and grain legumes, both of which have increased the value-adding capacity of the grains postharvest services sector. Urban consumers tend to be selective and demand more sophisticated processing of their rice. They will pay a premium for 'high quality' rice, defined as white, polished, and with few broken grains or other unwanted contaminants. In order to satisfy this need, there has been a growth in demand for postharvest services in grain cleaning, milling, storage protection, and transport. This has enhanced the importance of cost-effective delivery of postharvest services, while also increasing the potential loss in value-of-output during the various stages of the postharvest process. Research can help minimise these losses by improving technical efficiency in economically viable ways, and by increasing the robustness of the postharvest delivery system generally.

Global trends in output and consumption are reinforcing the rise in importance of the postharvest grain subsector in developing countries. Throughout Asia, grains output and consumption have been running ahead of population growth, with the result that the absolute volume of grains consumption is increasing by 40% per decade. Income growth has been an important factor fuelling this explosion in volume, part of which has spilled over into the markets for internationally traded cereal grains and grain legumes. In the 30 years to 1982-83 grains imports by developing countries increased five-fold, from 15 million to 74 million tonnes. A similar growth rate for developing country grains imports is expected to be sustained or exceeded in the next three decades. This will not only cause demand for shipping and port facilities, storage, and transport capacity to increase: the technology necessary to bulk handle safely and with a minimum of loss in volume and value will become more valuable. It will strengthen the claim that the grains postharvest sector has on scarce research resources by increasing the capacity of the grains postharvest sector to generate 'value added'.

There are many other factors that will influence the priority given to grains postharvest research in the tropics. Some of these, such as the spread of wet season harvesting in response to the expansion of intensified rice-based farming systems, will also influence the importance attached to particular components of the postharvest process. Grain drying is a case in point. Expansion in volume of output, trends in imports, and changing consumption habits influence the priority given to problems associated with handling a larger flow of product. Hence, transport and storage problems are highlighted for attention by researchers. Similarly, the spread of wet season harvesting has highlighted problems related to drying and grain handling in the rainy season. These and similar shifts in basic determinants of demand for postharvest services influence the importance attached to particular foci within postharvest grains research. This is the subject to which we turn our attention in the remainder of the paper. In essence, we are now looking for an answer to question (b), put at the outset of this paper.

Research Priority Setting Within Postharvest Research

The Importance of the Multidisciplinary Approach

Success in research requires not only the identification and testing of a viable solution to a problem, but also the prior specification of the right problem. Solutions to unimportant problems are not very interesting. The trick in the first instance is, therefore, to choose to allocate your postharvest R&D to important problems. How can this be done?

There are a number of approaches to this problem. The most commonly observable practice relies on extending research support for the serendipitous interests of talented scientists. The assumption here is that good scientists can be expected to do enough good work that support will, in time, prove to have been worth while. Another common strategy is the 'group' variant of the talented-scientist model. In this variant the aim is to support the leadership of a great and charismatic senior researcher (and his/her team) with a track record for getting research support and delivering results. Both represent intuitive approaches that are not without their merits.

These intuitive approaches to problem identification and priority assessment have their objective elements but, in more recent years, we have come to realise that there are also merits in taking an even more ordered, statistically objective, and multidisciplinary approach to the problem identification and research priority evaluation process. For example, it is not illogical to suggest that one might begin the process of postharvest research priority setting by looking at the results of postharvest loss assessment studies. It makes eminent sense, at least on the surface, to then recommend that the bulk of the scientific effort should be concentrated where the greatest losses appear to occur. One could be forgiven for believing that such a strategy will lead to the best possible allocation of R&D effort. Indeed, many a great and charismatic research leader has employed this procedure, or one very like it, to winnow the important from the less important problems in postharvest services delivery. There are, however, serious shortcomings to this procedure that only a conscious multidisciplinary approach can overcome.

Economists, sociologists, anthropologists, and other social scientists do not have a comparative advantage in engineering, food science, the physics of grain bulks, the chemistry of moulds, or other technical aspects of postharvest grains R&D. They do, however, have complementary skills to those of engineers and food scientists, the combination of which can result in a more holistic and meaningful interpretation of loss assessment data. For example, loss assessments do not necessarily point to the need for future research to be reoriented towards bulk handling. Such a change is indicated more by demographic, output, and foreign trade trends not necessarily reflected in current postharvest loss experiences. Similarly, where postharvest losses are the perverse result of policies that can be changed readily, research on technologies designed to overcome these losses may be of little long-term value.

In research priority assessment a certain degree of speculative futurology is unavoidable. The challenge is to 'harden' our crystal ball gazing by also using the forecasts derived from the established techniques of econometric analysis, and the results of policy studies that throw light on the root causes of observed losses in the postharvest sector. On the basis of these we can claim, with some confidence, that we have to hand the critical inputs essential for the segregation of researchable problems into categories marked 'important' and 'not-so-important'.

I trust I have not led you to believe that social scientists have a monopoly of the problem identification process. Nothing could be further from the truth. The steps involved call for expert scientific judgement as to which problems are more or less readily amenable to solution. These judgements are typically not the preserve of socioeconomists, but the opinion of informed scientists. These opinions are essential in research priority assessment as expertly assessed expectations of 'probabilities of success', given a specified time limit and budget. These judgements are the preserve of technical researchers rather than socioeconomists. In this respect the socioeconomists must rely on their scientific colleagues, while in the case of forecasting and policy analysis the reverse is the case. Success requires interdisciplinary cooperation.

The Congruence Principle

A useful starting point in research priorities setting is to establish objective, preferably statistical criteria for assessing the 'importance' of a potential research topic. For example, as a component of the human diet rice stands apart. On a global basis rice is at least twice as important as wheat as the primary dietary component for humans and ten times as important as coarse grains (i.e. maize, barley, millet, sorghum, and rye). *Prima facie*, therefore, the congruence principle suggests that rice research ought to be a higher priority than either wheat or coarse grains research, possibly twice that for wheat and ten times that for coarse grains.

In grains postharvest research these statistics about rice production and consumption are complemented by loss assessment studies that indicate postharvest losses by volume in rice are at least twice those in other grains. Strict interpretation of the congruence principle would require, therefore, that resources devoted to postharvest rice research ought to total not less than four times that given to wheat and twenty times that to coarse grains! Such a conclusion, however, need not result in an optimal allocation of research funds. We turn now to why this is so.

Risk and Reward in R&D Priority Setting

Postharvest losses are notoriously difficult to calculate. This is in part because there are not only physical losses taking place (as measured by volume or weight changes), but also losses in value as the market place discounts for the consequences of deterioration in quality (i.e. colour), contamination (i.e. moulds, fungi), ease of milling (i.e. hardness and cracking characteristics), and adulteration (with foreign matter or broken grains). Nonetheless, there is now sufficient past research available that we have at least indicative data to compare physical loss rates across grain types. There is also enough evidence to conclude that retail markets for grains (especially rice) will discriminate in favour of quality if allowed to do so. Alas, in a great many countries government regulation of food systems thwarts the free play of market forces, robbing farmers and entrepreneurs of the market signals and incentives essential to more efficient operation of the postharvest subsector.

In heavily regulated food systems, the risk and financial penalties associated with postharvest losses tend to be transferred to the public purse, and ultimately domestic taxpayers. In some cases, the lack of regulatory capacity and administrative sophistication needed to discriminate in favour of desirable quality characteristics (e.g. low moisture content) has led to the perverse result where suppliers are rewarded for eschewing good postharvest practice. In these cases, the impact of government policy is to set up the wrong set of incentives. If extant government policy increases the reward for adulteration and discounts the reward for quality control, the number of suppliers who will succumb to the temptations of moral hazard will increase.

The lesson here is that it is critical when assessing postharvest losses to ensure that the policies in place, especially those relating to pricing and subsidies, are the right policies. This can most easily be done by examining the pattern of incentives facing producers and the providers of grains postharvest services. The prevalence of wrong policies is, I believe, why it is not uncommon to find the contrary coexistence of 'evidence that the grains postharvest sector is competitive' and 'high levels of technical inefficiency' [see Barker et al. (1985), p. 182, and IRRI (1985)].

Excessive government control of marketing channels and marketing margins can render gross technical inefficiencies into economically efficient practices. The cost to society includes suboptimal levels of investment, lost economies of scale because of lower throughput, and loss of net benefits to society because prices to consumers are higher than they need to be, and less attention is devoted to R&D than would be the case without public subsidies to cover the cost of postharvest losses.

Is the Effort Worth the Candle?

The critical role of grain postharvest research is to increase the ability of millers, traders, and other suppliers of postharvest services to minimise postharvest losses in an economically viable way. Successful research can have impressive 'spillover' benefits for other areas of agricultural research insofar as gains from crop improvement and other research are 'protected' by successful postharvest practices. It is not unusual, therefore, for an element of urgency and naive hyperbole to surround the interpretation of estimates of potential gross benefits from reductions in postharvest losses. This result comes in part from the temptation to regard the postharvest system as a single stage between the producer and the consumer. The complexity of that stage is easily lost in altruistic and well meaning desire to cut percentage losses substantially; i.e. by a half or more. Consider, for example, the rhetoric of the Director General of FAO, Edouard Saouma: 'At a most conservative estimate of a loss of 10 percent in the cereals harvested in developing countries, a halving of that loss would provide some 40 million more tons of cereals and save around US$7,500 million in foreign exchange per year' (FAO, undated [1977?], p. 3).

Postharvest losses arise in part because the path from harvest to final use is complex and often lengthy. At each stage in the process there is potential for loss through waste, damage, or contamination. The loss at any one point may not be large, but the cumulative loss can be substantial. In rice, total postharvest losses in Asia are believed to be not less than 10% and possibly as high as 42% of paddy. The average for ASEAN is probably between 20% and 25% of output. If a half or even one-quarter of these losses is to be reversed, as Saouma urges ought to be done, where in the system would we seek to intervene to plug the leaks? The options are numerous, as is clear from the typical postharvest sequence for rice in Asia shown in Figure 1.

Losses in paddy (% by weight) at each stage in the sequence are estimated by Chandler (1979) as follows: harvesting and threshing, 5–15; cleaning and drying, 2–3; storage, 2–6; milling, 3–7; and handling and transport, 1–11. These figures add up to an estimated total postharvest loss of paddy of between 13 and 34%.

Other authorities broadly agree with these estimates, though FAO and the National Academy of Sciences (1979) of the USA report losses in the cleaning and drying stage of up to 11%. However, the point to be made remains; in such a fragmented and multi-stage process, it is difficult to achieve large gains by choosing to focus on only one source of loss. Moreover, since losses at each stage can be relatively small though the total be large, a competitive return on investment in postharvest R&D has to be associated with very high levels of 'probability of success' and subsequent 'adoption' of the solution by potential users.

It is not enough that research be successful. The results must also be adopted by potential users for the effort to be judged worth the candle. Since, in setting R&D priorities we are dealing with unknowns rather than ex-post realities, a hard-headed assessment of the risks associated with specified expectations is a critical element in the final decision-making process. The higher the risk, the higher must be the probability of success and the more rapid the adoption rate.

Distribution of Net Benefits

Value judgements are part and parcel of policy decisions. Research priority assessment is no exception. The most obvious way in which we find these judgements manifest in the R&D process is in the distribution of benefits from research between consumers and producers. Typically, the benefits from grains postharvest research are biased in favour of consumers, who receive better quality products at lower prices. This is fortunate since government policy is usually also biased in favour of consumers,

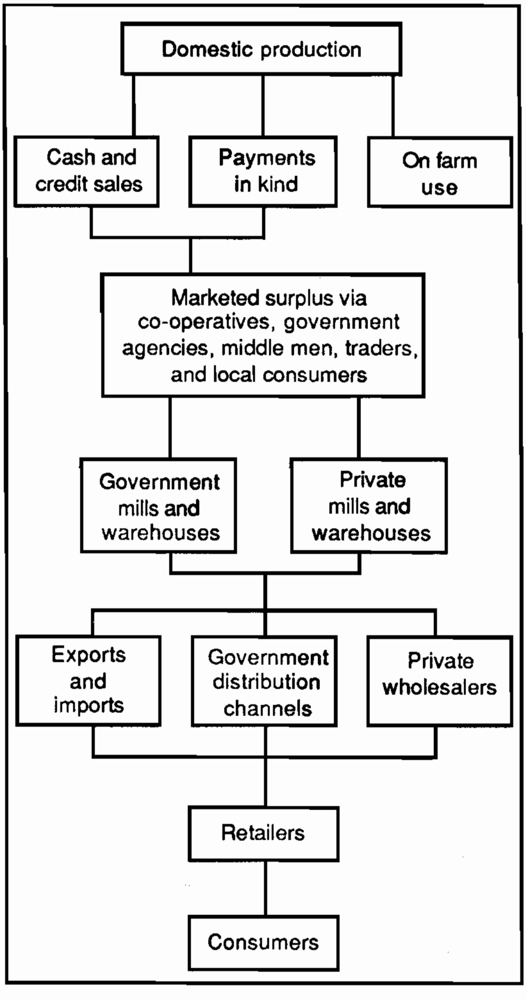

Fig. 1. Typical Asian rice postharvest chain.

which is one reason why government intervention in food systems is so widespread throughout the developing world.

The distribution of benefits between producers and consumers can be estimated using supply and demand curves to define consumer and producer 'surpluses'. The techniques used are discussed by others at this workshop and a practical example can be found in Davis et al. (1987). It is not my intention, therefore, to go over this material also. Rather, I will confine my remaining remarks to some closing observations.

Extensive research has been undertaken in the past few years on the economics of postharvest handling of grains in Malaysia and the Philippines. Some of the results of this research have been presented at this workshop. Without exception, the results confirm the central decision rule outlined above: i.e., that socially optimal R&D resource allocation decisions are critically dependent on establishing correct pricing and related economic policies in the food sector.

Without the right pattern of incentives, investment and consumption patterns will be distorted and the associated loss of output and value added in postharvest activities different from what is socially optimal. Any attempt to find a technological solution to such a situation is unlikely to result in a viable long-term development environment for the postharvest services sector. A more appropriate strategy is likely to involve closer attention to policy research, and genuine multidisciplinary cooperation in separation of researchable problems into an objectively defensible priority order.

A useful starting point in objective assessment of research priorities is congruence analysis based on the importance of the crop in production, consumption and foreign trade, plus data from loss-assessment studies. However, congruence analysis is not enough and the results of such studies must be adjusted in various ways.

Typically, loss assessments are physical measures of wastage and lost output. They do not include an allowance for lost value as the market discounts for quality deteriorations. Also, loss assessments do not necessarily point to essential long-term structural changes in the postharvest sector; structural changes that relate more to macroeconomic parameters than existing patterns of activity and practice.

A conscious and deliberate effort is required if adequate attention in research priority assessment is to be given to distributional issues. We have already noted that postharvest research is biased in favour of consumers. How should this influence our assessment if the bulk of these consumers are foreigners, as they are in the case of Thai rice exports? The answers are neither trivial or obvious. There are important spillover impacts of research that cross national boundaries, with opportunities for free-rider effects. It is not clear, therefore, that national postharvest research investment decisions can be divorced from consideration of what others are doing, access to the research results of other countries, and the importance of location-specific problems.

Finally, adequate account of each of these factors is not the preserve or comparative advantage of any one discipline. Rather, successful execution of the task demands multidisciplinary cooperation.

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General Socioeconomic and Technical Considerations Session Summary

Chairman: Tirso Paris*
Rapporteur: Hadi Purwadaria†

IN the first paper of this very interesting session, Dr Fegan argued that bulk handling technology is capital-intensive and labour displacing and is thus economically inefficient in areas with high population density, plentiful under-employed labour, low wages, and scarce expensive capital. Bulk handling will be successful in the regions with high rice surplus, labour shortage, small government intervention, and little subsidies. However, bag handling may remain appropriate for intraregional trade in surplus regions. Further, the paper argues that information and publications on efficient bag-handling systems should be made available to decision making groups.

Postharvest losses can be reduced by improving the organisation and management of the handling system. Targetted for improvement were the poor management in parastatal grain handling, and the state policies of introducing little drying margin and transforming small storage to large storage.

The speaker put the view that determinants of technological change are not only technical and economical parameters, but political as well. He proposed that research and extension must not neglect the preservation of grain in the bag handling system. Research should also be conducted to identify the real sources of losses, and to compare bulk handling and bag handling at the same volume of paddy.

During the discussion, various participants emphasised the advantages of a bulk handling system in terms of solving, for example, the problem of large production volume in the wet season. The speaker stressed that bulk handling may be appropriate to surplus regions, but it is questionable whether it would be for deficit regions.

Mr Baird, the second speaker, elaborated on the importance of an integrated approach to achieving quality standards and grades. He argued that procurement, drying, storage, and pest management systems must be considered as a fully integrated, total grain management system in order to accomplish end products which reflect the standard quality assessment.

The paper also discussed various characteristics of quality assessment for each postharvest activity. Various examples were also cited to highlight the necessity of the interrelationship among procurement, drying, storage, and pest management handling operations in achieving the high quality standards and grade.

The speaker argued that quality assessment throughout every phase of postharvest operations is absolutely vital to the technical assessment of the integrated system.

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There was comment from the floor on Mr Baird's remark that drying should be carried out off the farm. The speaker replied that farmers do not really have time to deal with drying. However, cleaning can be done on field, especially when combine harvesters are used.

In the third paper, Mr Rand described in some detail the components of a logistic system and methods of approaching the logistical operation as a system. He viewed bulk handling and storage as subsystems of the total logistical operation of transferring grains from the farm to the port, especially for products destined for export.

Prior to the assessment of the system for logistics, it is important to assess the design, and afterwards to apply controls to system performances based upon the design specification. The objectives of the system approach are to minimise the logistic cost, thereby maximising the profit, of providing services to farmers and consumers.

He discussed the design of a logistical system, which should specify transport modes from farm to storage facilities; from storage to customer or port; and the number, location, size, and type of storage facilities.

To apply the control on the logistic system, a determination of the performance measures is required. These are comprised of productivity measures and utilisation measures. The measures should be the basis for assessment of management performance and match the objectives of the enterprise.

There was a request from the audience for the speaker to amplify his recommendation on 'greenfield' location studies. It was argued that when facilities are in existence, their capital costs should be regarded as sunk, and that the study should evaluate what additional facilities, if any, are required, and where they should be located. The speaker agreed that it is a sensible approach in these circumstances, but that there are circumstances when lower level facilities are being located, where the greenfield approach may be appropriate.

Dr Remenyi, the fourth speaker, identified and discussed the macroeconomic and microeconomic issues in establishing priorities for grains postharvest research and development. As regards macroeconomics issues, the speaker argued that (1) the role of public sector should complement the private sector and market failure should be identified; (2) the determination of public investment in grains postharvest R&D should consider the opportunity cost of public funds, the importance of spillover effects, and the target of socially optimal investment; and (3) the trends in demand for grains postharvest services.

The major microeconomic factors identified by Dr Remenyi were: (1) priority setting by taking into account a multidisciplinary approach and the intuitive approach such as the congruence and the risk analysis; (2) the appropriate formulation of food sector policies; (3) the implications of fragmented claims of loss sources; and (4) the uniform distribution of net benefit to producers and consumers.

The speaker reinforced the need for bulk handling technology to consider not only the domestic level but also international and intraregional movements.

It was asked by a workshop participant whether consumers always gain from improvements and cost savings in processing, e.g. where there are fixed prices and marketing boards. The speaker agreed that intervention of this type created problems and emphasised the importance of correct pricing policies.

Another issue raised from the audience was that, while technological changes may result in substantial cost reductions at all stages of postharvest operations, the benefits accrued to the operator of each stage may not be proportional to the additional investment required. The speaker commented that this situation is a clear example of market failure and highlights the necessity to investigate new policies.

The Prospects for Bulk Handling in ASEAN Countries

Prospects for Bulk Handling in the Philippines: Socioeconomic Considerations

Tirso B. Paris, Jr.*

Abstract

The overall objective of this paper, which is based on the report of a joint Philippine-Australian grains postharvest subsector study, is to assess the prospects for bulk handling and storage in the Philippines based on social and economic considerations.

Empirical estimates of net social benefits from improvements in postharvest technology were obtained using a published model. Net social benefits refer to surpluses accruing to those who demand additional marketing services plus those benefits which accrue to those who successfully adopt the improved technology, less the cost of the improvements. Results of the analysis show that mechanical drying supported by bulk aerated drying/storage systems and a comprehensive integrated pest management program provide significantly increased net social benefits.

A cash flow analysis was conducted to compare gross operating margins and internal rates of return from improved postharvest systems over conventional systems. Various strategies of utilising a mechanical dryer and bulk aerated storage show that improved systems yield higher returns.

Social, economic, and technical constraints to adoption of improved postharvest systems, as well as implications of the improvements for equity, are also discussed.

The purpose of this paper is to assess the prospects for bulk handling from a social and economic perspective. The paper focuses on the Philippine situation, although the conclusions derived can be extrapolated to other Southeast Asian countries.

Bulk handling represents a relatively new approach to postharvest handling in the Philippines. Although there have been previous attempts to introduce bulk handling facilities in the country, these have, by and large, been unsuccessful in two senses: (1) where bulk handling facilities have been installed at National Food Authority (NFA) facilities, they are now either non-functional or non-usable; and (2) bulk handling has not been adopted commercially by private firms (millers and traders).

Bulk handling facilities usually comprise a set of complementary equipment including a mechanical dryer, tempering bins, and bulk aeration and storage bins. The scale of operations implied is large, which virtually excludes individual farmers and narrows the possible adopters to traders-millers or federated farmer groups.

In the Philippines, the scale of operations of traders-millers ranges from a volume of a few tonnes to over a thousand tonnes per year. The volume of grains handled usually depends on the capacity of transport, drying, milling, and

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storage facilities. The usual mode of operations of traders-millers involves travelling from one production area to another to purchase grain from individual farmers or small traders, drying and milling the grain in their own sun drying and milling facilities, and selling the milled rice or maize to urban centres.

The objectives of this paper are:

(1) to assess the social profitability of improved postharvest facilities, including bulk handling and storage equipment;

(2) to assess the firm level profitability of bulk handling and complementary equipment; and

(3) to explore the income distribution impact of bulk handling and storage equipment.

Framework of Evaluation

The overall conceptual framework for the study is based on a model discussed by Freebairn et al. (1982) for determining net social benefits of technological change in multiproduction processes. The variant of the model used in this analysis is concerned with only those benefits to suppliers of storage/drying facilities and those who need storage/drying facilities. In this case, the suppliers of drying/storage facilities are the traders-millers. Those who deliver to warehouses include both farmers and traders.

The modelling framework chosen for this analysis attempts to provide empirical estimates of net social benefits stemming from changes in postharvest technology. Net social benefits in this paper refer to surpluses accruing to those who demand additional marketing services plus those benefits which accrue to those who successfully adopt the improved technology, less the cost of the improvements.

The empirical model provides a relative measure of the expected increase in net social benefits over time stemming from the improved technology and hence may be used as a means for allocating priorities to proposed development activities.

The model requires information on demand and supply parameters and supply changes stemming from postharvest improvements (extent of reduction in postharvest loss), information on rates of adoption of the improvement, and *a priori* probabilities of the improvement, once adopted, being successful. These variables are the key parameters of any empirical evaluation of benefits accruing to society from improvements in postharvest technology.

Postharvest Losses

Studies on postharvest losses usually measure only quantitative losses (reduction in dry matter) and take no account of qualitative losses which reduce the value of the product from the level that it would otherwise have had had modern postharvest handling, drying and storage operations been available. It is widely accepted that controlled drying of high moisture grains as soon as possible after harvest is the most critical process in reducing losses and maintaining grain quality in Southeast Asia. Past studies show that, in the absence of drying, postharvest losses in paddy amount to 23%, in maize 15%, and in groundnuts 10%. These are the values that were used as benchmarks against which improvement in postharvest technology is evaluated. The absolute level of the social benefits from postharvest improvements is extremely sensitive to changes in these initial values.

In the absence of modern drying facilities, complementary quality maintenance technologies such as integrated pest management and aerated bulk storage have been shown to be of limited value in reducing losses. Consequently, the key factor in the overall analysis is the extent to which losses can be reduced by a combination of drying and other modern grain quality maintenance technology. Up-to-date postharvest technology operating efficiently on commercial quantities of grain can reduce postharvest losses to negligible levels. In the humid tropics, however, where there is a combination of high humidities and temperatures, previous experience indicates that the threshold value of postharvest losses is around 5% for rice and 2% for maize and groundnuts. On this basis, the estimated reductions in postharvest losses resulting from different postharvest activities are given in Table 1.

Rates of Adoption

Rates of adoption of new technology depend critically on the extent to which potential adopters of the technology see their own welfare

TABLE 1. Estimates (%) of reduction in postharvest losses from successful adoption of modern postharvest technology.

Crop	Activity Mechanical drying	On-farm drying	Dry bagged storage	Bulk aerated storage	Pest management
Rice	15	6	5	10	5
Maize	10	4	4	7	2
Groundnuts	5	3	3	4	2

improving by so doing. Unless the technology is tested, and supported by an effective information and communications program through increased site-specific research and extension activities, rates of adoption of improved postharvest technology can be expected to be virtually negligible.

Government intervention in the subsector, through regulation of prices of commodities to consumers and in paddy procurement, has reduced incentive to invest in improved postharvest technology. In addition, the large volume of paddy that must be handled, the high capital cost, and the lack of monetary incentives have reduced the adoption of postharvest technology. It is believed that these are the main reasons for the very slow rates of adoption of mechanical drying and bulk handling techniques in the Philippines. It is estimated that only around 5% of the total harvest is mechanically dried. Changes in rice industry pricing policy towards a freer and more competitive system will stimulate investment in modern postharvest technology, but these changes in themselves do not guarantee that the technology will be successfully adopted.

In general terms, investments in modern postharvest technology with higher initial capital requirements will have slower rates of adoption than those with lower initial capital costs. Hence, sealed storage of dry, bagged grain will have a relatively faster rate of adoption than bulk aerated storage systems.

Improved pest management methods, which have very low initial capital costs, will be adopted more quickly than sealed, bagged storage. The estimates of levels of adoption over time of the various activities are given in Table 2. These estimates are based on the assumption that technology such as sanitation/hygiene/pest management methods can be very quickly implemented simply by changing operating procedures. On the other hand, those technologies requiring greater inputs of resources have a relatively slower rate of adoption.

Probabilities of Success

Because of ineffective management and unavailability of labour and capital resources in required proportions, not all technology, even if it is adopted, will be successful. Some developments such as provision of mechanical

TABLE 2. Estimates of levels of adoption (%) over time of various modern postharvest technologies.

Activity	Year 1	2	3	4	5	6	...	10
Mechanical drying	5	7	9	11	13	15	...	20
On-farm drying	10	20	30	40	50	60	...	70
Dry bagged storage	5	9	13	17	20	25	...	40
Bulk aeration	1	3	6	9	11	13	...	18
Storage pest management	15	20	30	40	50	60	...	70

TABLE 3. Estimates of probabilities of successful adoption of various improved postharvest technologies in the Philippines

Activity	Probability of success (%)
Mechanical drying/bulk aeration	70
On-farm drying	10
Dry bagged storage	50
Bulk aeration	70
Integrated pest management	90

drying equipment at the farm level are of a high risk, speculative nature. Our assessment of the risk involved in adopting each of the proposed development activities is given in Table 3.

Model for Estimating Net Social Benefits from Improved Postharvest Technology

Economists have for some time used the concepts of consumer and producer surplus to evaluate the impact on economic welfare and distributional effects of a change in consumption or production. In particular, welfare impacts of changes in technology have been analysed by Akino-Hayami (1975) and more recently by Freebairn et al. (1982).

In Figure 1, the consumer surplus (CS_0) and producer surplus (PS_0) are shown for a market in equilibrium at prices P_0 and quantities traded Q_0. The surpluses represent the amounts producers and consumers have left after trading takes place and this depends critically on the relative slopes of the demand and supply curves. Figure 1b represents the changes which take place in the distribution of the surplus among producers and consumers when quantities traded expand as a result of an increase in quantity supplied stemming from an improvement in technology. Consumers gain the area P_0abP_1, while the benefit to producers is the area P_1bd less the loss in producer's surplus P_0ac. The change in gross benefit is the area abcd. To obtain the net effect on social welfare, any spillover costs and resource costs involved in the improved technology must be deducted from the change in gross benefit.

The above analysis demonstrates that to determine whether adoption of any new technology will be economic in terms of its net benefit to society as a whole requires comprehensive evaluation of consumption

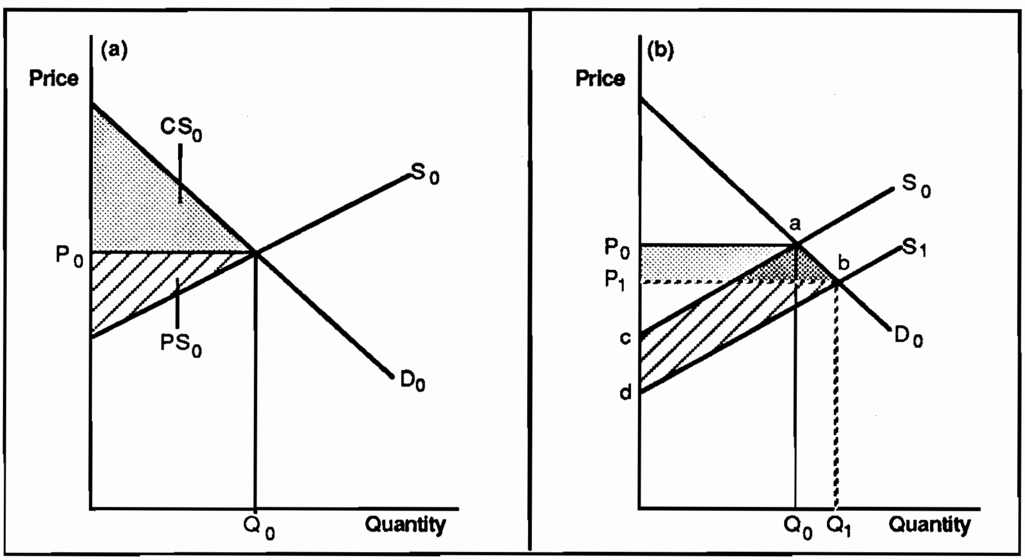

Fig. 1. Model for determining the net benefits stemming from an increase in supply of a commodity: (a) distribution of surplus between producers and consumers before change in suppply. (b) change occurring in distribution of the surplus when quantities traded expand as a result of an increase in quantity supplied, stemming from, for example, an improvement in pest control.

behaviour, responses of producers to changes in technology, and spillovers, as well as the direct costs of the new technology. The benefit cost assessment is summarised in Table 4.

Empirical Model

The empirical model used for analysing the expected increase in net social benefits from adoption of improved postharvest technology is discussed below.

The expected change in net social benefit $E(\Delta NSB)$ stemming from improved postharvest technology for a given region (r), commodity (i), and activity (j) over a given time period $(t = 1, \dots T)$ is expressed as follows:

$$E(\Delta NSB)(r,i,j) = \sum_{t=1}^{T} \frac{1}{(1+d)^t} (P_t \Delta GSB_t - \Delta C_t) \times (r,i,j) \quad (1)$$

where:

$\Delta GSBP_t$	=	change in gross social benefit
ΔC_t	=	marginal cost of the improvement
P_t	=	probability of successful adoption of the technology
d	=	social discount rate

The change in gross social benefit (ΔGSB_t) is given by:

$$\Delta GSB_t = \Delta CS_t + \Delta PS_t \quad (2)$$

where:

ΔCS_t = change in consumer surplus
ΔPS_t = change in producer surplus

Given any demand equation of the form:

$$Q^d_t = \alpha - \beta P^d_t \quad (3)$$

Consumer surplus is given as:

$$CS_t = 0.5\ (\alpha/\beta - P^d_t)\ Q^d_t \quad (4)$$

Similarly, producer surplus (PS_t) can be derived from a storage supply function of the form:

TABLE 4. Summary of benefits and costs in evaluation of improved postharvest technology

Benefits	Costs
To consumer: lower prices as a result of increased supply	To consumer: potential damage to resource base stemming from indirect costs to individual
To producer: aggregate income increased by expansion of supply and increased supply prices	To producer: (1) increased substitution of management inputs for conventional inputs (2) direct resource cost of increased use

$$Q^s_t = \gamma + \theta P^s_t \quad (5)$$

to give:

$$PS_t = 0.5\ (\gamma/\theta - P^s_t)\ Q^s_t \quad (6)$$

In equilibrium, the condition $Q^d_t = Q^s_t$ is imposed as consumers benefit from reduced demand prices with improved postharvest technology. Changes in consumer demand prices are used to evaluate consumer surplus. On the other hand, changes in farm supply prices are used to evaluate producer surplus.

Projected Production Changes

The model outlined above relies on the projection of production increases with and without postharvest improvements.

Without Postharvest Improvements

The projected production in any year (t) is given by the expected annual growth rate in production (g) from some base level as

$$Q_t = (1 + g)^t\ Q_0 \quad (7)$$

With Postharvest Improvements

The projected change in production from improved postharvest technology is determined from the projected production Q_t adjusted for the expected percentage rate of reduction in postharvest losses (L_t) and the rate of adoption in year t (A_t) to give:

$$\Delta Q_t = Q_t (1 + L_t) A_t \qquad (8)$$

so that the projected production with improved postharvest technology is

$$\hat{Q}_t = Q_t + \Delta Q_t \qquad (9)$$

Changes in Consumer Surplus

Changes in consumer surplus are calculated from:

$$\Delta CS_t = \hat{C}S_t - CS_t \qquad (10)$$

where: ΔCS_t = change in consumer surplus stemming from the improved postharvest technology

$\hat{C}S_t = 0.5 (\alpha/\beta - \hat{P}^d_t) \hat{Q}^d_t$, from equation (4)

Anticipated demand prices can be derived from the demand function to give:

$$P^d_t = \frac{\alpha - Q_t}{\beta} \qquad \hat{P}^d_t = \frac{\alpha - Q_t}{\beta} \qquad (11)$$

Substitution of P^d_t, $\hat{P}^d_t$, $\hat{Q}_t$ and Q_t in equation (10) gives the expected change in consumer surplus for any given change in improved postharvest technology.

Changes in Producer Surplus

Changes in producer surplus are calculated in a similar way using Q_t, $\hat{Q}_t$ and

$$P^s_t = \frac{-\gamma + Q_t}{\theta} \qquad (12)$$

$$\hat{P}^s_t = \frac{-\gamma + \hat{Q}_t}{\theta} \qquad (13)$$

inserted in the following expression:

$$\Delta PS_t = \hat{P}^s_t - P^s_t \qquad (14)$$

Model Results

The net social benefit accruing from improvements from mechanical drying of food grains was compared with farm drying using the model discussed above, and the estimates of rates of adoption, probability of success, and reduction in postharvest losses. The empirical estimates of net social benefits by region, for both rice and maize, are given in Table 5. The analysis reveals that the net social benefit of mechanical drying is about 4–5 times that of farm-level drying. This means that mechanical drying of wet grains is projected to have significant social benefits, particularly in commercial quantities in the private sector. Farmers or community groups could avail themselves of these improved postharvest technologies by the formation of group or cooperative drying/storage associations.

While mechanical drying, including the provision of tempering facilities, is a proven and viable technology, the other postharvest activities that could be improved were also considered. Bulk aerated storage was considered complementary to drying/storage activities. It is a proven and viable technology for medium-scale grain handling and milling establishments in Australia, Malaysia, and other tropical areas. Bulk aerated storage was compared with improved dry bagged storage (Table 6). The analysis reveals that net social benefits of this technology are higher than that of improved dry bagged storage, despite higher initial costs and lower rates of adoption. Bulk storage systems can be used as complementary drying facilities, with appropriate aeration systems gently drying the grain as it is held in storage.

The net social benefits from improved pest management programs were also considered relative to the status quo, in which pest management programs are virtually non-existent. The results of this analysis, assuming the grain has been dried, are given in Table 7. There is no doubt that this activity will bring net social benefits and improve the performance of the postharvest subsector.

The results of the analysis confirm the view that mechanical drying supported by bulk aerated drying/storage systems and a comprehensive integrated pest management program provide the

TABLE 5. Present value of net social benefits of mechanical and on-farm drying of rice and maize (in thousand Australian dollars[a]).

Item	Rice		Maize	
	Mechanical drying	Solar, farm drying	Mechanical drying	Solar, farm drying
Assumptions:				
Demand elasticity	0.75	0.75	0.75	0.75
Supply elasticity	1.50	1.50	1.50	1.50
Prod. price (PHP/tonne)	3500	3500	2900	2900
Price of service	700	700	700	700
Cost (PHP/tonne)	60	30	60	30
P success	0.70	0.10	0.70	0.10
Loss reduction	0.15	0.06	0.10	0.04
Ilocos	12 108	2 229	954	172
Cagayan Valley	16 669	3 069	4 491	811
Central Luzon	22 739	4 186	93	17
Southern Tagalog	14 692	2 705	3 189	576
Bicol	11 272	2 075	1 594	288
Western Visayas	16 519	3 041	462	83
Central Visayas	2 080	383	2 951	533
Eastern Visayas	6 395	1 177	3 087	557
Western Mindanao	5 274	971	2 384	431
Northern Mindanao	4 296	791	2 761	499
Southern Mindanao	8 694	1 601	15 309	2 765
Central Mindanao	10 765	1 982	10 237	1 849
Total	131 505	24 210	47 514	8 580

[a]The exchange rate used was \$A1 = 13 Philippine pesos (PHP)

optimal approach for development in the postharvest subsector of the Philippines food grain economy.

Cash Flow Analysis of Improvement in Postharvest Systems

It is important to be able to show how improvements in postharvest systems could affect the gross operating margins for potential investors. This section attempts to provide estimates of the financial benefits and internal rates of return that would flow to a trader/miller or a farmer-cooperative were they to adopt improvements in postharvest services.

The analysis uses as a benchmark a conventional system with a 2 tonne per hour rice mill. This is compared with several drying/storage options:

1. provision of a 4 tonne per hour throughput dryer
2. provision of a 4 tonne per hour throughput dryer plus 600 tonnes of bulk aerated storage with several possible drying strategies as described below.

The effective drying capacity of a 4 tonne per hour throughput dryer depends on the number of times paddy has to pass through it, as follows:

No. of passes	Effective capacity (tonnes per hour)
1	4.00
2	2.00
3	1.33
4	1.00

Assuming that the dryer is operated 20 hours per day at 4 passes, the total daily capacity of the dryer is 20 tonnes. Without a bulk storage facility, the dried paddy goes directly to the warehouse (or to the rice mill). With bulk aerated storage, however, more paddy can be dried since the bulk storage could temporarily hold either fresh paddy or partially dried paddy.

TABLE 6. Present value of net social benefits of dry bagged storage and bulk aerated storage of rice and maize (in thousand Australian dollars[a])

Item	Rice		Maize	
	Dry bagged storage	Bulk storage	Dry bagged storage	Bulk storage
Assumptions:				
Demand elasticity	0.75	0.75	0.75	0.75
Supply elasticity	1.50	1.50	1.50	1.50
Prod. price (PHP/tonne)	3 500	3 500	2 900	2 900
Price of service	700	700	700	700
Cost (PHP/tonne)	20	40	20	40
P success	0.50	0.70	0.50	0.70
Loss reduction	0.05	0.10	0.04	0.07
Ilocos	4 570	5 385	432	446
Cagayan Valley	6 291	7 413	2 036	2 101
Central Luzon	8 582	10113	42	44
Southern Tagalog	5 545	6 534	1 446	1 492
Bicol	4 254	5 013	723	746
Western Visayas	6 234	7 347	209	216
Central Visayas	785	925	1 338	1 380
Eastern Visayas	2 414	2 844	1 400	1 444
Western Mindanao	1 990	2 346	1 081	1 115
Northern Mindanao	1 621	1 911	1 252	1 292
Southern Mindanao	3 281	3 867	6 940	7 160
Central Mindanao	4 063	4 788	4 641	478
Total	49 638	58 484	21 541	22 223

aThe exchange rate used was \$A1 = 13 Philippine pesos (PHP)

Table 8 shows some possible strategies for utilising the dryer and bulk storage. Strategies A to C involve partially drying the paddy and subsequently holding it in bulk aerated storage. The dryer thus becomes available for drying additional paddy. With the bulk storage occupied, however, it would be necessary to completely dry (4 passes) the incoming paddy. Strategies D to G involve taking incoming paddy directly to the bulk storage thereby allowing the dryer to accommodate an additional 20 tonnes of paddy per day (at 4 passes). The paddy initially stored in the bulk storage is subsequently partially dried (that is, less than 4 passes) and then returned to bulk storage. Bringing the paddy to the bulk storage allows the complete drying of additional new paddy. Finally, the partially dried paddy in bulk storage is brought back to the dryer to obtain the four passes required for complete drying. It should be noted that as the output accommodated increases so too does the number of drying days.

The assumptions adopted for the cash flow analysis are given in the Appendix. In the conventional system, gross revenues are derived from the sale of rice and rice bran, priced at PHP6[1]/kg and PHP2/kg, respectively. Milling recovery rate is assumed to be 65% for rice and 8% for bran. Storage and other losses from the time of purchase up to the time of the milling are assumed to be about 3%. The latter constitutes a reduction in the total revenue. It was further assumed that the miller has to borrow, at 20% interest, one-fourth of the operating capital needed to purchase the paddy each season.

Under the improved systems, increased returns are expected to result from the following:

1. increased milling recovery from 65% to 68% for rice;

[1]Prices are given in Philippine pesos (PHP). At the time of this study, the approximate exchange rate was 20PHP = US\$1.

TABLE 7. Present value of net social benefits of integrated pest management of rice and maize (in thousand Australian dollars[a])

	Rice	Maize
Basic assumptions:		
Demand elasticity	0.75	0.75
Supply elasticity	1.50	1.50
Prod. price (PHP/tonne)	3500	3500
Supply price	700	700
Cost (PHP/tonne)	20	20
P success	0.90	0.90
Loss reduction	0.05	0.02
Ilocos	18 695	880
Cagayan Valley	25 737	4 146
Central Luzon	35 109	86
Southern Tagalog	22 684	2 944
Bicol	17 404	1 471
Western Visayas	25 506	426
Central Visayas	3 211	2 724
Eastern Visayas	9 874	2 850
Western Mindanao	8 143	2 201
Northern Mindanao	6 634	2 549
Southern Mindanao	13 424	14 131
Central Mindanao	16 623	9 449
Total	203 044	43 858

[a]The exchange rate used was $A1 = 13 Philippine pesos (PHP)

2. reduction in storage losses from 3% to 2% for mechanically dried rice, and from 3% to 1% for mechanically dried rice with bulk aerated storage; and
3. increase in price of rice due to superior grain quality by about 2% to 4%, depending on the type of improvements.

Costs are also expected to increase due to the operation and maintenance of the additional equipment as well as the adoption of integrated pest management. Specifically, these include depreciation, and costs associated with the operation of a mechanical dryer (rice hulls, electricity, labour, and repair and maintenance costs) and bulk storage (energy, and repair and maintenance).

Results of Cash Flow Analysis

Gross Operating Margins. Table 9 shows the gross operating margins of the different alternative drying and storage strategies in the first and subsequent years and the net present value, assuming a discount rate of 20%. Note that gross operating margins improve considerably as improvements in postharvest systems are adopted. Further increases in gross margins result from the adoption of strategies that will increase the amount of paddy that can be dried mechanically and this is made possible by the availability of an aerated bulk storage facility.

Internal Rates of Return. The profitability of improvements in the postharvest system (such as the introduction of mechanical dryers and aerated bulk storage) depends on the extent of the additional private benefits the miller obtains compared with his use of the conventional system. In this study, the profitability of an improvement in postharvest system was determined by measuring the internal rate of return (IRR) based on the *increment* in net benefits of the new system over and above that of the conventional system. A period of 10 years of useful life for both dryer and bulk storage was assumed.

Table 10 gives estimates of the internal rates of return for the various improvements in the postharvest system based on the initial assumptions. The figures clearly show that the adoption of a mechanical dryer would give a rate of return that is well above current commercial interest rates. When the adoption of a dryer is coupled with a bulk storage system, the IRRs are considerably higher and increase progressively as more paddy is dried due to the availability of a bulk storage system.

Sensitivity Analysis. The profitability of any improvement in the postharvest system is dependent on the relative strengths of the various factors affecting returns and costs. We examined how profitability is affected as assumptions relating to the following factors are changed: (a) milling recovery; (b) paddy price; (c) rice price; (d) percent of operating capital borrowed; and (e) interest rate. The results are presented in Table 11.

It was found that profitability is very sensitive to milling recovery rates. For example, given a 1% rather than a 3% improvement in milling recovery rate, investment in a mechanical dryer becomes unprofitable. Profitability of an improved system over the conventional system

TABLE 8. Effect of drying/storage strategy on the amount of paddy that can be mechanically dried

Strategy	No. of passes	Drying days	Tonnes mechanically dried
Dryer only	4	60.0	1 200
Dryer + bulk storage			
Strategy A	3–1[a]	67.5	1 350
Strategy B	2–2	75.0	1 500
Strategy C	1–3	82.5	1 650
Strategy D	0–4	90.0	1 800
Strategy E	0–3–1[b]	97.5	1 940
Strategy F	0–2–2	105.0	2 100
Strategy G	0–1–3	112.5	2 250

[a] Three passes the first time, followed by one pass.
[b] Paddy goes to the bulk storage immediately and subsequently dried twice, the first time with three passes, the second with one.

was not sensitive to the price of paddy, although it is clear that a lower purchase price for paddy will imply higher margins regardless of configuration. Profitability is, however, sensitive to changes in rice price due to the premium for better quality grain. Finally, the profitability rates (IRR) are only very slightly sensitive to changes in the proportion of operating capital borrowed as well as to the interest rate, since these affect investment in all types of postharvest systems.

The analysis presented here assumes that the total throughput of the miller/trader or cooperative remains the same regardless of the system configuration. If it is assumed, however, that the installation of a dryer/bulk storage system enables the miller to increase his throughput, he would be able to obtain considerably higher returns than from the conventional system even if there are no price premiums for better quality. Increased profitability in this case stems from the higher volume of paddy that is handled due to the availability of a dryer and a bulk storage system.

Impact of Postharvest Improvements on Equity

The previous section has shown that improvements in the postharvest system would

TABLE 9. Annual gross operating margins (in Philippine pesos[a]) of alternative drying and storage strategies

Strategy	Year 1	Years 2–10	Net present value
Conventional	5 055 420	5 055 420	21 194 707
Mechanical dryer only	4 272 434	5 272 434	21 271 200
Dryer + bulk A	3 738 053	5 538 053	21 718 131
Dryer + bulk B	3 810 996	5 610 996	22 023 944
Dryer + bulk C	3 883 939	5 683 939	22 329 756
Dryer + bulk D	3 956 882	5 756 882	22 635 568
Dryer + bulk E	4 024 464	5 824 464	22 918 902
Dryer + bulk F	4 102 769	5 902 769	23 247 193
Dryer + bulk G	4 175 712	5 975 712	23 553 005

[a]At the time of this study, the approximate exchange rate was US$1 = 20 Philippine pesos.

result in substantial net social benefits. It is of interest, however, to know how these net benefits would be distributed among the various participants in the postharvest subsector.

It is declared policy of the Government of the Philippines to promote equity and social justice. Given two projects that have more or less the same net social benefit, a project that confers more benefits on the poorer sectors of society would be given the higher priority. This concern for equity implies that a project proposed for implementation must either promote a more equitable distribution of income or it must not seriously worsen it.

It must be stressed that concern for equity does not necessarily mean that efficiency considerations be ignored. A project that results in greater incomes for all income groups, even if it results in a more skewed income distribution, may be preferable to another project that makes distribution more equitable but at the expense of lower incomes for all. Equity and efficiency must be considered hand in hand. The Philippine development plan itself states that 'political and economic arrangements shall shift from a system which provides incentives on the basis of accessibility to power to one which gives importance to efficiency and equity considerations'.

The estimates of changes in consumer and producer surplus due to postharvest improvements show that net social benefits accruing to consumers would be roughly seven times the change in producer surplus for rice and about six times that for maize (see Table 12). Based on these figures, it would appear then that the net social benefits are overwhelmingly in favour of the consumer. It should be emphasised, however, that this proportion is largely dependent on (1) the elasticities of demand and supply for postharvest improvements, and (2) price of paddy and rice. For example, if the same demand and supply elasticity levels are assumed and if the price of rice is twice that of paddy, the consumer surplus would only be twice the producer surplus. On the other hand, if rice and paddy prices are roughly equal and demand elasticity is half the supply elasticity, the consumer surplus would again be twice the producer surplus.

As shown in the cash flow analysis given earlier, postharvest improvements are relatively profitable to the investor on the basis of high internal rates of return. The question arises whether other participants in the postharvest sector would also benefit from the improvements. A factor which affects the distribution of benefits is the degree of concentration of ownership of the postharvest equipment. If the postharvest equipment is owned solely by a miller/trader, a large proportion of the benefits would accrue to the miller/trader. However, if the ownership rests in the hands of several farmers who are members of a cooperative, the benefits would have a wider distribution.

Any technological improvement results in a change in costs and returns. Who bears the costs

TABLE 10. Annual net benefits (in Philippine pesos[a]) and internal rates of return (IRR) of alternative drying and storage strategies

Strategy	Year 1	Years 2–10	IRR
Mechanical dryer only	–782 986	217 014	0.2360
Dryer + bulk A	–1 317 367	482 633	0.3401
Dryer + bulk B	–1 244 424	555 576	0.4284
Dryer + bulk C	–1 171 481	628 519	0.5245
Dryer + bulk D	–1 098 538	701 462	0.6307
Dryer + bulk E	–1 030 956	769 044	0.7409
Dryer + bulk F	–952 651	847 349	0.8865
Dryer + bulk G	–879 708	920 292	1.0445

[a]At the time of this study, the approximate exchange rate was US$1 = 20 Philippine pesos.

TABLE 11. Sensitivity of the internal rate of return of alternative postharvest systems to changes in milling recovery and rice price.

Milling recovery (%):	64	65	66	67	68
1.Mechanical dryer only		−0.4925	−0.0637	0.0942	0.2360
2. Dryer + bulk A	0.0701	0.0756	0.1674	0.2558	0.3542
3. Dryer + bulk B	0.1198	0.1256	0.2268	0.3311	0.4436
4. Dryer + bulk C	0.1685	0.1749	0.2873	0.4072	0.5412
5. Dryer + bulk D	0.2171	0.2242	0.3500	0.4888	0.6494
6. Dryer + bulk E	0.2625	0.2703	0.4107	0.5706	0.7618
7. Dryer + bulk F	0.3169	0.3256	0.4857	0.6751	0.9109
8. Dryer + bulk G	0.3692	0.3788	0.5607	0.7837	1.0729
Rice price[a]: (PHP/kg)	5.0	5.5	6.0	6.5	7.0
1. Mechanical dryer only	0.1435	0.1896	0.2360	0.2832	0.3316
2. Dryer + bulk A	0.2470	0.2997	0.3542	0.4110	0.4708
3. Dryer + bulk B	0.3175	0.3789	0.4436	0.5125	0.5864
4. Dryer + bulk C	0.3914	0.4636	0.5412	0.6253	0.7176
5. Dryer + bulk D	0.4702	0.5557	0.6494	0.7532	0.8695
6. Dryer + bulk E	0.5488	0.6494	0.7618	0.8890	1.0347
7. Dryer + bulk F	0.6488	0.7710	0.9109	1.0733	1.2650
8. Dryer + bulk G	0.7523	0.8999	1.0729	1.2795	1.5311

[a]Prices are in Philippine pesos (PHP). At the time of this study the approximate exchange rate was US$1 = 20 PHP.

and receives the returns greatly affects the distribution of income. In the case of improvements in postharvest technology, changes in income distribution would be affected by the nature of ownership of the raw materials, labour, transport facilities, the rice or maize mill and other postharvest equipment.

Table 13 shows the various costs and returns of postharvest improvements from the point of view of a miller/trader and the corresponding recipients. It is apparent that any change in postharvest technology will affect the income of not only the miller/trader but also the incomes of other participants in the postharvest subsector. While equity considerations dictate that the bias should be towards improvements that would favour farmers and hired labourers who have generally lower incomes, it must be stressed that, in order to attract investment into the postharvest sector, it must be financially attractive to the investors, whether they be private millers/traders or cooperatives. Hence, it is to be expected that benefits must accrue to millers/traders in order to obtain wider social benefits from improved postharvest systems.

TABLE 12. Average proportion of consumer surplus to producer surplus[a] following various postharvest improvements

Postharvest improvement	Rice	Maize
Mechanical drying	6.9242	5.7313
Sun drying	6.9335	5.7365
Dry bagged storage	6.9149	5.7275
Bulk storage	6.9133	5.7255
Pest management	6.9287	5.7281

[a]Given the assumptions on demand and supply elasticities, as well as product and input prices, the ratio of consumer surplus to producer surplus remains constant.

The fact that millers/traders are recipients of profits does not necessarily mean that they will reap all the benefits of improved postharvest technology. Insofar as investments in postharvest equipment will result in increased purchase of paddy or maize from the farmers thereby increasing competition, the increased demand for grain is expected to result in higher prices received by farmers.

Hired labourers are also expected to benefit from the increased volume of grain handled. With a larger volume of paddy handled, other things being equal, more persons will be

TABLE 13. Costs and returns in the postharvest chain and corresponding recipients.

Cost or return	Recipient/ beneficiary
a. Raw materials (paddy)	Farmers
b. Transport services	Owners of transport facilities
c. Total wages paid to haulers, mill operators, dryer operators	Labourers
d. Other operating costs	Input suppliers
e. Total sales less costs = profit	Owner of mill/post-harvest equipment

required to move the grain through the postharvest chain and this will have a positive effect on total wages paid. Labour requirements are not expected to decrease drastically even with the use of bulk storage and handling equipment. During the dry season, sun drying is expected to be availed of by millers and traders on account of its lower cost. Hence, labourers would still be needed and hired on the same basis as at present.

Transportation services are required to move the raw material to the mill and the milled product to the market. Other things being equal, increased volume will mean increased revenue and margins for transport firms. Although transport services can be provided by other firms, in practice most millers/traders also own transportation facilities. Hence, the extra benefits accruing to transportation firms due to increased volume may also be captured by the miller/trader.

It is expected that improvements in postharvest facilities will ultimately mean better quality products and lower prices to consumers. This is due mainly to the greater amount of rice distributed, even during the wet season, and less spillage and wastage.

From the foregoing discussion, it may be concluded that there are increased benefits to be gained from improvements in postharvest technology. The concern that the benefits will be limited to millers and traders is largely unfounded. The analysis has shown that the potential net social benefit from postharvest improvements will be shared by farmers, transport firms, millers and traders, hired labour, and consumers. The overall conclusion is that there will be no concentration of benefits in one particular group.

From a technical assessment, it appears that the combination or two-stage method of grain drying/storage is the most promising postharvest improvement and is being recommended for adoption. This involves fast drying and tempering in the first stage, followed by longer term in-store drying of bulk grain.

From the point of view of equity, the analysis has shown that net social benefit, which by definition is the sum of the changes in consumer and producer surplus adjusted for rates of adoption, probability of success, and cost of postharvest services, would accrue both to consumers and producers as a result of the introduction of improved postharvest services. It was observed, however, that the greater bulk of the benefits would accrue to consumers in the form of lower prices and better quality products. This does not imply little or no benefits would flow back to the producers. In a competitive situation, the introduction of postharvest improvements will, for two reasons, result in increased demand for paddy: (1) greater competition among traders for the paddy which will now be required in larger quantities; and (2) paddy will be bought during the wet season as the postharvest equipment will allow for drying and milling at this time of the year. The net result will be a higher price for the farmers. In the case where the postharvest facilities are in the hands of a farmer cooperative, the profit margins would flow back to the farmers directly. It is also observed that labourers, transport firms, and consumers will be beneficiaries to improvements in the postharvest system. Where there is concentration of ownership and hence a monopolistic and/or monopsonistic situation, there are fiscal measures that can be employed to transfer some of the benefits from millers and traders to farmers.

Acknowledgments

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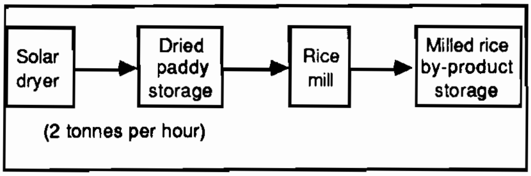
Appendix: Assumptions for the Cash Flow Analysis

The basic assumptions used in the construction of the cash flows are given in detail below.

I. Conventional System



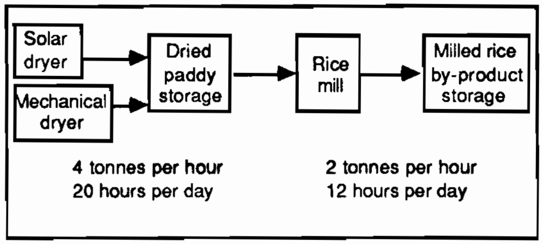
Assumptions

Procurement period	=	100 days
Drying period	=	100 days
Milling period	=	250 days @ 12 hours/day
Milling capacity	=	2 × 12 × 250 = 6000 tonnes
Milling recovery	=	65%
Bran recovery	=	8%
Storage loss	=	3%
Cost[1] of paddy	=	PHP2.80/kg
Cost of rice	=	6.00/kg
Cost of bran	=	2.00/kg
Cost of bags	=	4.00/cavan[2]
Cost of power	=	1.50/kWh
Cost of drying	=	1.50/bag
Salary of manager	=	PHP3000/month for 12 months
Salary of operator	=	PHP2000/month for 12 months
Salary of clerk	=	PHP1500/month for 12 months
Labour for milling	=	3 men @ PHP50.00/day for 250 days

[1] Costs are given in Philippine pesos (PHP). At the time of this study, the approximate exchange rate was 20PHP = US$1.

[2] 1 cavan = 50 kg.

II. Improved System with Dryer



Assumptions

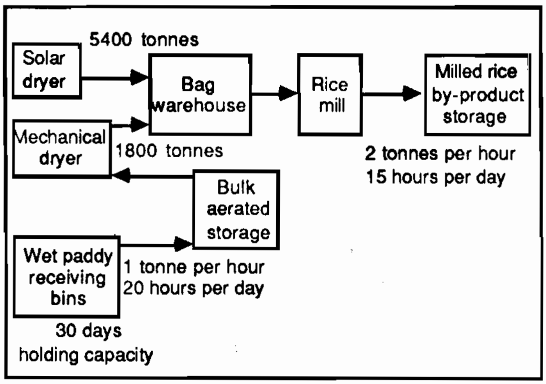
Procurement period	=	100 days
Sun dried paddy intake	=	4800 tonnes
Mechanically dried paddy intake	=	1200 tonnes

For single pass with 60 days drying at 20 hours per day requires 1 tonne per hour dryer. A three-pass strategy would reduce this to 400 tonnes of wet paddy.

Dryer h.p.	=	20 h.p.
Fuel rate	=	100 kg/hour rice hulls
Milling period	=	250 days, 12 hours/day
Mill crop	=	7200 tonnes
	=	2 × 12 × 300
Rice mill h.p.	=	60 h.p.
Total milling recovery	=	65% for sun dried
	=	67% for mechanically dried
Bran recovery	=	7% for mechanically dried
	=	8% for sun dried
Storage loss	=	2%
Cost of wet paddy	=	PHP2.80/kg
Price of milled rice	=	PHP6.00/kg for sun dried
	=	PHP6.12/kg for mechanically dried
Cost of energy (electricity)	=	PHP1.50/kWh
Cost of energy (rice hulls)	=	PHP0.20/kg
Cost of bags	=	PHP4.00/bag
Labour: sun drying	=	PHP1.50/bag
mechanical drying	=	3 men @ PHP50.00/day for 60 days

milling	=	4 men @ PHP50.00/day for 300 days
Salaries: 1 manager	=	PHP4000/month for 12 months
2 technicians	=	PHP2000/month for 12 months
1 clerk/typist	=	PHP1500/month for 12 months

III. Improved System with Dryer and Bulk Storage



Assumptions

During the 100 days procurement period it is assumed that the volume of paddy that can be mechanically dried would increase due to the availability of aerated receiving bins[3]. This in turn will increase the dryer and rice mill utilisation. Procurement could avail of reduced price of paddy at peak of supply on rainy days.

Procurement period	= 100 days
Drying period	= 90 days (60 + 30)
Milling period	= 250 days @ 12 hr/day
Total milling recovery	= 65% for sun dried
	= 68% for mechanically dried
Bran recovery	= 8% for sun dried
	= 7% for mechanically dried
Storage loss	= 1%
Cost of paddy	= PHP2.80 for sun dried
	= PHP2.70 for mechanically dried (can procure on rainy days)
Cost of rice	= PHP6.00 for sun dried
	= PHP6.24 for mechanically dried

Power requirement of bulk storage handling is 20 h.p. (All other assumptions are as in System II. Except for manager at PHP5000/month and three technicians instead of two.)

3 Previous study at CEAT UPLB indicates that wet paddy at 26% moisture content could be held in aerated storage bins for two weeks without appreciable decrease in grain quality (colour and head rice yield).

Some Engineering Considerations for Bulk Storage in the Humid Tropics

Amnaj Covanich*

Abstract

The effects of environment on grain as a living mass in a confined space are discussed. Graphical analysis is presented to pin-point the limiting zone in which grain can be safely stored in bulk form considering grain physical conditions, types of storages and their orientation, and climatic conditions.

THERE have always been doubts as to the suitability of bulk storage for grain in the humid tropics, especially under the climatic conditions prevailing in the ASEAN region. These doubts originated from incidences of grain damage experienced by the various ASEAN countries when grain was kept in large bulk storages. The countries in the region—Indonesia, Malaysia, the Philippines, and Thailand—have all reported many occurrences of deterioration in grain when it is stored in silos, although precise estimates of the damage caused have not been published in the scientific literature.

Despite these incidences, it might be premature to jump to the conclusion that the bulk storages themselves were the main causes of grain deterioration and to decide, without further thorough scientific investigation, that bulk storage systems are not suited to the ASEAN countries. When the incidences of grain damage were closely examined it was discovered that the damage normally followed a particular pattern. Caking of the grain was found at the bottom and around the inner walls of the silos. This grain caking, possibly caused by condensation of water, could have been prevented or at least minimised, had the suitability of the intended bulk storage system been assessed before installation. Although basic information on the physics of grain in bulk storage under humid tropical conditions is still being gathered, a method using known engineering principles can be suggested for determining the technical suitability of a system in a particular location. The method involves superimposition of the equilibrium grain moisture content onto the psychromatic chart, so that the interrelationships of environment, grain physical condition, and storage structure can be examined.

This paper discusses engineering considerations centred upon the bulk storage component of the postproduction system. It is important to mention that for bulk storage of grain to be effective and economical grain must also be handled in bulk throughout the entire postproduction chain. In the case of the ASEAN countries, since most postproduction practices still largely involve bagged grain, it is essential that all components of the chain receive attention should there be a move to greater adoption of bulk storage of grain in the region.

Physical Factors Influencing Grain Deterioration

Assume that grain has been carefully handled before storage and that it is loaded into steel

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silos at a moisture content low enough for safe storage, say 14% (wet basis). Paddy, for example, at 14% moisture content should be in equilibrium with surrounding air having a relative humidity of 75% and temperature 27°C (Karon and Maybelle 1949). However, during loading of the grain into the silo, ambient air will also be trapped in the grain mass, occupying intergranular spaces. The intergranular air, and the grain, will slowly exchange moisture until an equilibrium condition is reached. However, at the same time, the air also changes its physical/thermal properties at a faster rate as a result of the diurnal temperature cycle. For example, the monthly average maximum and minimum temperatures and relative humidities in Jakarta, Indonesia are 28°C and 24°C, and 95% and 73%, respectively (Esmay et al. 1984). If we examine the effects of these temperature changes on the intergranular air we find that condensation is likely to occur along the inner side of the silo wall. This condensation is caused mainly by the reduction of the temperature of the silo wall. We have not taken into account the additional moisture generated by the grain bulk through the process of respiration. It has been calculated (Teter 1979) that paddy at 14% moisture content and a temperature of 38°C will generate about 4.1 mL of water per tonne of grain per day. The increase in grain moisture content and humidity of the intergranular air will speed up the process of respiration and create an environment very favourable to mould growth on the grain.

Because of the temperature gradient in the grain bulk caused by the heating of the silo wall, internal convection of air in the grain mass will be triggered. This internal convection of air within the grain mass is caused by the difference in the densities of warmed and initially cooler air. Normally, the movement of air within the grain mass always causes moisture to transfer from a warmer part of the grain bulk to a cooler part. This phenomenon causes caking of the grain at the middle of the base of the silo (Burrel 1974).

Engineering Considerations for Bulk Storage

1. Proven preventive measures should be employed to prevent moisture condensation and moisture migration. However, at present the techniques of aeration which are effectively employed in temperate climates to prevent condensation and moisture transfer are still at an experimental stage as regards their use in the humid tropics.

2. Temperature gradients in the grain mass should be minimised by reducing the area of the silo wall which is directly exposed to sunlight.

3. Thermal characteristics, as well as structural properties, of the silo wall construction materials should also be taken into consideration; e.g. reinforced concrete has a lower thermal conductivity than steel.

4. If possible, grain to be stored in bulk should be dried to a moisture content lower than that considered safe for bag storage.

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Rice Industry Investment under Current Market Conditions, with Particular Reference to Malaysia

W.L. Cuddihy*

Abstract

Internal rates of return for investment in the rice sector when measured at current and projected international trade prices are generally close to or below the opportunity cost of capital. The success of domestic programs in raising output and productivity in Asia's rice and paddy sector, combined with aggressive export subsidy schemes and import substitution schemes in industrial countries, has driven real prices to an unprecedented low. In due course, some relief from a cyclical price upturn is expected, but the secular trend is downwards. On the cost side, the economic success of the ASEAN region will continue to drive up the opportunity cost of resources used in rice production. Reversing the cost-price squeeze is beyond the power of national intervention programs to sustain. The focus of investment programs will need to shift from output expansion and the retention of marginal resources to cost reduction and industry restructuring with important consequences for employment, incomes, food self-sufficiency, and other national goals. Even with present low prices, investment in postharvest activities offers satisfactory returns, but only if accompanied by sufficient market liberalisation and institutional adjustment.

INTERNAL rates of return for investment in the rice sector, when measured at current and projected international trade prices, are generally close to or below the opportunity cost of capital. This is particularly true for capital-intensive, large-scale irrigation schemes where the incremental production is to be exported or is to replace imports. The depressed state of the industry severely limits the amount of investment that can be absorbed in increasing output and enabling adjustment to changing conditions of production and marketing. Until recently, the expansion goal has gone unchallenged. However, the increased instability of world grain prices, especially since 1970, has brought into question the desirability of relentless expansion of production at ever-declining long-run prices unless it is matched by commensurate productivity gains and institutional change. This condition implies the phasing out of marginal lands and marginal producers and an emphasis on cost-reduction to maintain competitiveness.

While governments can and do intervene to change the relationship of domestic to trade prices to guard the welfare of their producers, they do so at considerable cost, not only in budgetary support of the program, but also in terms of producing a structure in the sector which is not sustainable without a continued infusion of an ever-increasing supply of public resources and greater institutional dependence. In addition, unintended but perverse effects usually follow. Guaranteed and minimum prices discourage investment in cost-reduction technology, inter-seasonal grain storage, and

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quality maintenance. Cost of production subsidies to growers eventually push up land costs, and larger producers benefit more from price support.

On the cost side of the equation, economic growth in the Asian region has pushed factor costs steadily upwards, requiring continued productivity grains. Where the two have not kept pace, factors are bid off elsewhere to where their returns are greater, as for example, occurred the well-known abandonment of marginal paddy lands and the out-migration of labour from paddy areas in Malaysia, despite incentive measures to the contrary. Investment in new technology that reduces unit costs, together with reforms in markets for factors and products, would seem to offer a better solution than administrative measures designed to prevent structural change. Worldwide experience has shown that adjustment to external markets has sooner or later to be made and that the longer the restructuring is postponed, the greater are the adjustment problems. The key issue, though, for private investors, state planners, and farmers alike is the future of world markets. In this paper, the particular problems of investment in the rice and paddy sector under prevailing and projected market conditions are discussed. The objective is to focus attention on the investment context into which the technical research results of the ASEAN grains projects must be placed.

Market Conditions

In mid-1987, the price of 5% broken Thai standard export rice, FOB Bangkok, was US$210/tonne, that is, less than one-half of the 1980 price of US$434/tonne, in current prices (Table 1). In constant dollar terms, the decline is even more precipitous. Measured in 1985 constant dollars, the real price has fallen from a peak of US$918/tonne in 1974 to US$175/tonne in 1987. Can we dismiss this as a cyclical phenomenon, or is it consistent with a secular trend? If we can expect price recovery, it makes sense to invest in output expansion. If we cannot expect recovery, then the pattern of investment changes significantly. This includes investment not only in irrigation and other infrastructure, but also in research and institutions.

Over the longer run, food and cereal prices have declined markedly. Since the late 1940s, the weighted index of real prices for food has declined about 40% and for cereals it has fallen about 60% (Table 2). It would be difficult to

TABLE 1. Export rice prices over the period 1970 to 1987. Prices are free on board per tonne for Thai 5% broken rice.

Year	Current US$	Constant 1985 US$[a]
1970	144	397
1971	129	336
1972	147	351
1973	330	681
1974	542	918
1975	363	553
1976	255	383
1977	272	372
1978	368	438
1979	331	347
1980	434	416
1981	483	460
1982	293	283
1983	277	275
1984	252	254
1985	216	216
1986	210	177
1987	210	175

[a]Deflated by MUV index (1985 = 100)
Source: World Bank, economic analyses and projections, various years

TABLE 2. Average weighted indexes (constant US$, 1979–81 = 100) of food and cereal prices, 1948/49 to 2000.

Period	Food	Cereals
1948/49	119	158
1950–54	144	163
1955–59	125	124
1960–64	106	120
1965–69	104	130
1970–74	111	136
1975–79	116	109
1980–84	92	92
1985–87	74	59
1990 projected	72	64
1995	75	65
2000	77	67

Source: World Bank, Economic Analysis and Projections, 17 January 1987.

disagree with the projections of little if any significant improvement over the foreseeable future. Over the very long run, Schuh (1985) shows that the secular decline can be traced back to the last century. In today's market environment for agricultural commodities, these observations seem quite reasonable. Yet, only 12 years ago, they would have been contested on the basis of a coming world food crisis, as relentlessly increasing populations shared relatively inelastic food supplies at ever-rising real prices.

The reasons for the changed perception are well known. Among them are the gains from the high-yielding varieties of rice and wheat, the heavy investment in large irrigation schemes allowing double cropping, and the provision of inputs from the nonagricultural sectors, such as machinery and fertiliser. Allied to these were institutional and policy changes, particularly the spread of new extension systems, improved accessibility of small farmers to formal credit, and increased public sector participation in storage and marketing. Special incentives were given through input and output price intervention mechanisms such as fertiliser subsidies and guaranteed product prices. Goals other than food supply were sought by the same policy measures, among which was producer income protection.

While international attention was focused on developing countries' supply response, total grain production in industrial market economies expanded rapidly in response to farm credit and other programs in the USA, and to high-threshold prices in the European Common Market. Increased export surpluses arrived on world markets at about the same time that major traditional importers—notably Indonesia and India—left the market or became occasional exporters. On the consumption side, measures to support rice prices changed the terms of trade between locally produced rice and imported wheat, thereby hastening the rate of substitution in consumption between the two.

Investment Implications

The global surplus is likely to come and go depending on short-run weather conditions and program support in major producing countries. Since only about 5% of world production enters international trade, major changes in either of these two factors in any of the United States, Thailand, China, and Burma, accounting for 70% of world exports, will continue to have a large impact on quantity available and its price. Aside from these short-run considerations, it seems fair to assume for planning purposes that long-run rates of return on investment in the sector will remain marginal, even for those producers with comparative advantage.

The difficulty is in determining comparative advantage. Standard methodology uses world trade prices as the reference, but recent prices are below cost of production. Protection policies in industrial countries and trade restrictions in developing countries, on balance, depress world prices (World Bank 1986). Whether or not world prices are 'fair' is not really relevant because these prices are those faced in the market and not some other set. What is most germane is the likelihood of their continuance. Attempts to isolate the domestic industry from the reality of the international trade environment bring high budgetary costs, distort the pattern of investment, and eventually penalise those it sets out to help by delaying eventual adjustment. For example, Japan's rice program costs its Treasury US$3 billion per year, with the main beneficiaries being part-time farmers. The cost to full-time farmers is unavailability of land, overcapitalisation, and lower labour productivity (Yagi 1987).

If the outlook of declining long-run prices and rising costs is accepted, it is particularly important that investment signals be set consistent with this view. It is also important to ensure that strategies for employment, incomes, and rural development be designed to cope with the consequences of change rather than to ignore them. Malaysia, in particular, has had a difficult time in defending its rice and paddy sector because of the view of a static set of sectoral conditions that were no longer valid. While rice import restrictions isolated the sector on the product side to save jobs, labour was being drawn into other sectors where returns were largely trade determined. The net result was the rapid mechanisation of harvesting in areas of comparative advantage and abandonment of land and underutilisation of investment in others, leading to a rapid loss of jobs. The financial benefits of free fertiliser, cheap water and credit, and a guaranteed subsidised paddy price certainly help explain the extraordinary spread of large-scale header harvesters among small-scale farmers in the Muda Agricultural Development Area, where it was supposed that growers had surplus labour and little cash.

While investment in irrigation infrastructure in Malaysia was particularly worthwhile in the 1960s and early 1970s in terms of increasing yields and enabling double cropping, experiences in later years were quite different for both large- and small-scale schemes. For example, an ambitious program of rehabilitation of small-scale irrigation schemes was implemented in the late 1970s covering 60 000 ha in about 200 schemes. After 6 years of investment totaling $M180 million[1], it became apparent that farmer interest in paddy production had waned. Cropping intensities for completed schemes actually fell from 109% in 1976 to 48% in 1983, ranging from 0% in Selangor to 107% in Perlis, out of a possible 200% (Table 3). Little interest was shown in off-season plantings because more remunerative work was available at that time. The ex-post evaluation calculated a rate of return on the investment of just 3%, and only 111 schemes were built.

What went wrong? Paddy yields had increased as expected, farmers used recommended varieties, free fertilisers and cheap water were available, and growers received a price bonus. Field surveys revealed that for Negri Sembilan (13 schemes), Perlis (2 schemes), and Malacca (4 schemes) only 7%, 14%, and 4%, respectively, of farmer income was derived from paddy growing with the balance coming from other activities, mostly non-agricultural or oil palm production. Even with the most supportive policy measures, these marginal areas could not be sustained.

Investment in high-productivity large-scale schemes has also been affected. Following the success of primary and secondary development in the Muda Agricultural Development Area, a program of tertiary investment in water control structures, roads, and services was undertaken to further increase yields. After 6 years and 12 seasons with tertiary development, there are no significant differences in yield between blocks with tertiary structures and those without them. The major reason for the lack of response is the use of labour-saving husbandry, consistent with the growth of absentee ownership and part-time farming. Devices for precise water control are not useful in raising yields where turn-out gates are left open to save on labour costs. The change from labour-intensive transplanting to direct seeding without attendant changes in the rest of the farming system and research focus has also restricted investment response.

Investment in postharvest operations has also suffered from unanticipated effects. For the private sector, the fixed processing margins have remained virtually unchanged since 1974 and are absorbed by operating expenses, leaving little surplus for investment and less incentive to do so. For the public sector, although the National Paddy and Rice Authority's (LPN) investment are paid for by government, the uncertainty over eventual market shares remains a major impediment to the satisfactory resolution of major difficulties in handling and storing increasing amounts of grain attracted by a pricing system not conducive to quality. Not surprisingly, underinvestment in the private milling sector can be ascribed to policy intervention in pricing, just as overinvestment in production can be ascribed to an unusual level of effective protection.

Although circumstances in other countries of the region are different from those in Malaysia, the view is emerging from experience in many countries with different economic systems that market signals are a better guide to investment planning and technology choice than administrative pricing and planning. For consumers as individuals or as importing countries, declining real prices and functioning markets result in increased welfare. For producers and exporters, welfare will decline to the extent that marginal producers are constrained from leaving by lack of opportunity or policy inducements to remain in the sector. Improvements in efficiency alone, without a reduction in the number of producers, will not permit farm income growth sufficient to keep up with incomes in other sectors. In the Malaysian

[1]$M = Malaysian ringgit: during October 1987, US$1 = $M2.50.

TABLE 3. Completed small-scale irrigation schemes in Malaysia: areas, yields, and cropping intensities, 1981–83.

State	No. of schemes	Area (ha)	Cropping intensity (%) 1981	1982	1983
Perlis	4	1 278	59	78	107
Perak	3	235	0	9	11
Kedah	23	6 879	40	57	72
Selangor	1	1 000	0	0	0
Negri Sembilan	26	2 776	39	60	68
Malacca	14	1 657	50	30	81
Johor	1	138	29	24	32
Pahang	7	2 559	17	11	9
Trengganu	9	4 322	1	2	2
Kelantan	9	4 489	42	73	69
Sarawak	5	5 863	9	18	24
Sabah	9	4 960	30	38	55
Total:	111	36 156	27	38	48

small-scale irrigation scheme example, the average paddy area per farmer was 0.9 ha, with fairly equal distribution. No feasible subsidy scheme tied to paddy production could have provided an income competitive with actual income opportunities in a fast-growing labour-short economy.

The need to support the income of poor paddy growers is not at issue but rather the means by which it is done. For example, Malaysia's Fifth Plan estimates that there are 114 000 paddy growers in the country. Even if all of them are poor, it is difficult to justify a transfer from consumers of about US$200 per tonne to about 230 000 beneficiaries registered with LPN and receiving the producer subsidy. What is required is an income support scheme for poor paddy farmers that is separate from measures aimed at production goals. Undue levels of protection, beyond those necessary to restore a second-best equilibrium, and justified on producer poverty grounds, reward technical inefficiency, help perpetuate obsolete patterns of land ownership, and misallocate investments in ongoing technical change. But perhaps the major cost is that they inflate perceptions of how much income and how many genuine jobs the industry can provide.

If the current and projected market conditions outlined here—declining long-run prices for products and rising prices for labour, resulting from economic growth—are correct, eventual attrition is inevitable[2]. It would seem appropriate to plan for the most suitable technical, economic, and institutional adjustment pathway, with due regard for the welfare of those who are in genuine need. In this context, bulk handling and storage is a technology package entirely consistent with the expected market conditions in that it will improve competitiveness in both quality and price at lower resource cost. But the gains will not be realised if policy results in bad grain in good silos.

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[2]Malaysian Ministry of Agriculture survey data show a reduction in man-days per ha for paddy production in the Muda Agricultural Development Area from 120 to 30 over the last decade. Yagi's (1987) study shows a reduction from 216 hours per ha to 78 between 1969 and 1981, with rising wages and labour productivity.

The Prospects for Bulk Handling in ASEAN Countries Session Summary

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Rapporteur: Anselmo Cabigan†

THE session presented socioeconomic, engineering, and investment approaches related to the adoption of bulk handling systems in the ASEAN countries. The presenters explored social benefit analyses for bulk handling and storage strategies in the Philippines, engineering considerations in drying and storage of grain, and a scenario of decreasing world prices and rising production costs as guideposts in investment decisions in the rice industry.

Bulk handling is a relatively new approach in the Philippines and has not been successful in the initial introduction. Even currently, it is not yet accepted by the commercial sector. The first paper in the session assessed the social profitability of improved bulk handling and postharvest operations, the firm level profitability of bulk handling and complementary equipment, and income distribution impact of bulk handling and storage using a modelling concept of producers and consumers surpluses.

The model used provided empirical estimates of net social benefits stemming from changes in postharvest technology; rates of technology adoption, profitabilities of successful improvements against those of the unimproved system. The increased returns were expected from increased milling resources, reduction of postharvest losses, and increased rice prices due to improved quality.

The results of the investigation indicated that mechanical drying (continuous flow with tempering bins) resulted in substantial net social benefits compared with sun drying. Bulk storage has overwhelmingly larger benefits compared with bag storage; and that integrated pest management has a high social desirability. There is considerable incentive for the private sector to invest in the drying, bulk handling, and integrated pest management technologies since the rates of returns are 2 to 3 times higher than the prevailing interest rate. The distribution of benefits appears to follow the concentration of ownership of equipment associated with improved technology, but a wider distribution of benefits is feasible.

The next paper discussed the relationship between certain physical properties of grain and that of the air it is stored in. It was also observed that the relative humidity of the air changes at a greater rate than that of the equilibrium moisture content of the grain at the same rate of change in air temperature.

When silos are filled with grain during the daytime when temperature is high, the grain equilibrium moisture content and the relative humidity of intergranular air space are more or less equal. However, night cooling results in much higher relative humidity in the air than the equilibrium moisture content of the grain.

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Condensation proceeds from the higher relative humidity of the intergranular air space.

Bulk storage requires preventive aeration, protection of silos from the sun, careful consideration of thermal properties of storage structure materials to reduce temperature gradients, and lower initial grain moisture content to allow for increase in moisture content during storage.

On the investment front, long run declines in real prices of grains and rising costs of labour and other production inputs, are expected to continue. These issues were discussed in the final paper of the session. The production capacity in areas of advantage needs to be maintained to capture the benefits of cyclical upturns in prices. Bulk handling and storage at the right time and place as part of ongoing technology changes appear to be an important aid to maintaining the competitiveness of major rice producers under these adverse price conditions, yet certain problems must first be solved before going into large scale bulk handling operations.

However, government intervention in pricing inputs and outputs often give the wrong investment signals to the private sector, resulting in premature technical change, over-capitalisation, wrong spatial distribution of facilities and undesirable social cases. Market liberalisation is suggested, with government using separate policy instruments for income distribution, employment generation, and other socio-political goals.

Concluding Session

Summary of Seminar

Abdul Kuddus Ahmad*

FOLLOWING the excellent presentations of the session chairmen and the ensuing discussion, my task seems almost superfluous. However, perhaps I could usefully recapitulate on what seem to me to be the main issues raised at this workshop.

There have clearly been two streams to the workshop, one technical and one socioeconomic, and a valiant, and I would dare to say successful, attempt has been made to bring these streams into a common flow. I think that this workshop *has* succeeded in exploring the critical linkages between technical, economic, and social factors in considering the introduction of new technology to the postharvest subsector in the ASEAN region. I think we all now know that we either have, or can develop, the technology to solve the major problems facing grain handling in the region. What is perhaps even more important is that we are coming to understand the impediments to the introduction of this technology and how these might be overcome.

This has been an extremely stimulating workshop because of the diversity of views expressed not only in the papers we have heard but also in the ensuing discussion. As Dr Champ has already said, it has been clear right from the beginning of proceedings that this has not been a workshop held to *promote* bulk handling and storage technologies in the region but rather to *assess* them in open and critical forum. The days of slavish adoption of new technology for technology's sake are gone, and I'm sure no one here has regretted their passing. We have had at this workshop all shades of opinion on bulk handling in the region, from those who are unequivocal supporters of the technology to those who see it as, for the most part, quite inappropriate to ASEAN. Perhaps the optimal solution, for the present at least, lies somewhere in between, as suggested by the proponents of 'semi-bulk' systems.

The papers arising from the joint Malaysian–Australian study of the paddy and rice industry in Malaysia have, of course, been of particular interest to us during this week and have indeed generated much broader community interest, as reflected in the broad press coverage of the workshop. This is not surprising given the basic importance of paddy and rice production and prices to a large proportion of our country's population. This interest is not, of course, generated by the fact that technical solutions have been found to particular grain handling and storage problems, but rather to the social and economic impact that these 'solutions' might have. What will the benefits of technological change be? Who will reap them? What will the costs be? Though the decisions we face are very difficult, daunting even, I think that it is very exciting to be able to come to a workshop such as this, which has tackled them head on. The fact that we can do this augurs well and it is heartening to see natural and social scientists and engineers, perhaps traditionally suspicious of one another, working together to common goals.

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While this workshop has made no specific recommendations, I think that one thing that is clear from many papers—particularly the case study papers from regional researchers—is that more research and development work is needed to refine the basic principles of the technologies that appear promising. Another issue raised more than once is the impact that falling world rice prices might have on investment in the industry in this region. Various speakers have pointed out that though falling prices may act as a disincentive for investment, this should be set against rising disposable incomes among consumers. This can reasonably be expected to lead to an increase in demand for higher quality grain, just the sort of grain for which better postharvest services are needed.

At a more general level, it is clear that governments in the region have to look at their rice production and pricing policies to ensure that they are economically efficient. If the industries are economically efficient, then prospects for the adoption of appropriate new technology will be enormously enhanced. Once new technology has been introduced, the final task of governments is to ensure that the resulting benefits are equitably distributed between the various sectors of society.

Thank you, ladies and gentlemen. I will now ask Professor McWilliam to provide us with his closing remarks on the workshop.

Closing Remarks

J.R. McWilliam*

THANK you, Mr Chairman, for the opportunity to have the last word at this workshop, which is indeed a privilege.

I have enjoyed the conference and I have learnt a lot. I believe it has provided a valuable forum on a topic of central importance to this region.

I would like to make a few brief comments as a lay participant at this meeting about the significance of what we have been discussing.

Rice, I would barely need to remind you, is by far the major food crop of Asia and by far the number one food crop of the developing world. At a recent review meeting, it was claimed following a rigorous study that the rice production of Asia will have to double in the next 20 to 25 years to meet the increase in population and the consequent rising demand for this staple food grain. To achieve this, there will have to be an increase in the productivity of rice growing land, and there will also have to be a major reduction in the losses of rice evident in the current system. Bulk handling and storage, and postharvest technology generally, will be a critical factor in achieving this doubling of rice yield in Asia, mainly through its impact on the reductions in losses which, as we have been told earlier in this workshop, can run as high as 20%. This saving from the adoption of appropriate or efficient postharvest technology will, of course, spillover to the other food crops of importance to the region.

Bulk handling and storage requires a systems approach, involving a series of processes from production right through to marketing. This is something we have heard at this workshop that is obvious to us, yet it bears repeating. We have to consider the whole process with a systems perspective. We cannot isolate a piece without reference to the other interacting factors.

A number of workshop participants have expressed the belief that bulk handling and storage is more likely to develop as a partial system, still within the systems context but not a complete system from its inception. I think that that is not an unreasonable prediction. Malaysia in many respects will act as a test bed for other countries in the region, and will, in a sense, try the water first, in the adoption of bulk handling and storage. The principles that we learn from Malaysia's movement into the field will obviously have relevance and importance in the other countries, despite the fact that their production and marketing systems are different.

My own view, and I believe the view of this meeting, is that bulk handling and storage is already in Southeast Asia. We have heard that many times, and of course it's true. The technology will continue to expand throughout the rice and the other food grain producing systems. I expect these will extend logically from the port side back to the farm, which is a logical way for the system to develop.

Evidence from a recent economic study in the Philippines, in which ACIAR was involved, suggests three important things. There is a good return for the

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investment in better postharvest and bulk handling systems. I don't think that comes as a surprise. There is a reasonable distribution of the social benefits, and though the major benefits will accrue to consumers, that's not all bad, because the consumers, and particularly the urban consumers, are becoming a dominant component of the population in much of Asia. These findings, like all products of economic surveys, have to be taken not so much with a degree of scepticism as with cognisance of the rubbery nature of the input data. But the message of the study is clear and important.

I think one should also remember that progress towards fully integrated systems of bulk handling and storage takes time. I'm not so old that I don't clearly remember bag handling of grain Australia: I've sewn and humped bags myself—and that isn't all that long ago. So we in Australia have reached a sophisticated level—if you could call it that—only fairly recently. I think we should not expect that Asia will move any faster than we have been able to in the west. So give it time. I've got no doubt that the process is in train and the development is on the way.

We've discussed many factors that influence the adoption of bulk handling and storage systems. Obviously technology, and the constraints associated with technology, are definable and are important. But perhaps the strongest push at this meeting has, I think, been for considerations of policy issues that influence incentives and other opportunities for the system to develop. We've heard a strong plea for price and institutional reforms in the rice and the paddy sector. We've had a strong call for a float in the prices in the major grades of rice and a gradual removal of all controls over subsidies and the retail price. We've had a plea, I think, to open up the system, to allow the private sector to compete more effectively with the public sector, particularly here in Malaysia. We've also seen a request for a support scheme as a safety net for small, poor producers, and I would endorse that last point.

Rice and wheat are often described as political crops. The price the producers receive for their rice, as well as the price consumers have to pay for it, are political issues. Hence, there is an enormous temptation, and sometimes a need, for governments to intervene in the whole system of rice production and marketing. That's a statement of fact. The workshop is suggesting that this intervention can be counter-productive at times, perhaps even all the time, I'm not sure which, and that there should be a greater reliance on the free market and involvement of the private sector in rice postharvest activities. This advice is not new. All I can say is that it's a matter for the governments concerned. The options have been put, the alternatives have been stated. Now it's a matter for governments to decide which way to go.

My final point is that one must remember that politics is the art of the possible. Meetings such as this bring issues out on the table, and this workshop certainly has done this in the last three days. As a result, they provide a valuable forum for ideas and viewpoints. I wholeheartedly support the continuation of this sort of meeting for this reason alone, that it provides an opportunity to, as it were, bring out the ideas, put them clearly on the table and let the chips fly. ACIAR has valued its participation in activities in the postharvest sector in Asia. I can assure you that, provided our partners want us, and provided our partners wish us to work alongside them, we're planning to continue, because we see it as a very high priority. Perhaps our role is to help bridge this technology around the region and, in a sense, act—as Dr Remenyi suggested—as a multiplier effect to help in the spillover of technology from one part of the region to the other.

It would not be right to conclude a meeting without reference to those who made it possible. I would like to acknowledge very sincerely the following people who have had a major role in making this very effective workshop possible. First, the Deputy Minister of Agriculture, Mr Kasim Ahmad, the ASEAN Food Handling Bureau together with MARDI and LPN and their respective directors, Mr Ray Gonzalez, Dr Yusof Hashim, and Dr Abdul Kuddus. We thank all of them very sincerely for their contribution and for their interest and preparedness to support the meeting. We've had also a strong support from the Ministry of Agriculture here in Malaysia, and from the Department of Veterinary Services. And last of all, we've had tremendous help and input from the Secretariat of this workshop which has made it all operate so smoothly.

I should also acknowledge those whose financial contributions oiled the wheels, as it were. A hidden contribution came from the Ministry and LPN—that's not recorded, but it's certainly acknowledged. ASEAN–EEC made a generous contribution to the conference as did the Kedah Perlis Ricemillers Association and Malaysian Container National. ACIAR was also pleased to be part of the conference, and I acknowledge all those who contributed through the Centre.

I'd also like to acknowledge and thank those who attended the meeting. It's your participation that of course makes the meeting. I'd also like to say to all here and all who will eventually read the published proceedings of this workshop, that if you want to mount a successful workshop, do so in Asia, and particularly do so in Southeast Asia. I have great respect for the excellent organisational capacity and the genuine ability and friendliness that we get from all of the meetings that are organised in this part of the world. It's a great pleasure to come to them.

Last but not least, I'd like to thank those who participated and those who contributed. firstly for attending, and secondly for the wisdom they've shared around the room over the last three or four days, for the valuable discussion, and for the viewpoints that have emerged and I think will be captured in the publication that emerges from this meeting. I would particularly thank you for your enthusiasm for the field and for your genuine support for what I think is one of the most important aspects of rice production. Thank you, Mr Chairman.

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