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Controversy About Agricultural Technology: Lessons From the Green Revolution

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Abstract

The development and introduction of transgenically modified organisms to enhance crop and animal production has generated considerable controversy about potential food safety and environmental impacts. The introduction in tropical Latin America and Asia of high yielding varieties of wheat, maize and rice beginning in the late 1960s was also controversial. Critics argued that the new technology was biased against the poor—would make the rich richer and the poor poorer. In this paper I review the equity and productivity impacts of the "green revolution" technology and draw several inferences about evaluation the effects of the new biotechnologies in agricultural production.

Key Words

Transgenically modified organisms; green revolution; income distribution; mechanical technology; biological technology; farm size, employment; allocation of scientific and technical resources.

Biographical Note

Vernon W. Ruttan is Regents' Professor Emeritus in the Department of Applied Economics and in the Department of Economics at the University of Minnesota. He attended Yale University (BA, 1948) and the University of Chicago (Ph.D. 1952). His research has been in the fields of agricultural development, resource economics, and science and technology policy. He is the author (with Yujiro Hayami) of *Agricultural Development: An International Perspective* (Johns Hopkins University Press, 1982) and *Technology, Growth and Development: An Induced Innovation Perspective* (Oxford University Press, 2002). Ruttan has been elected a fellow of the American Academy of Arts and Sciences (1976) and to membership in the National Academy of Sciences (1990).

Controversy About Agricultural Technology:
Lessons From the Green Revolution

1 Introduction

Concern about the unanticipated consequences of technical change is strongly rooted in public consciousness. Such concerns have emerged with particular force with respect to the potential adverse environmental effects of transgenically modified organisms and to the safety concerns about food products derived from transgenically modified crop or animal products [1]. These concerns have given rise to substantial tension in trade relations between the United States and the European Community [2, 3] and are viewed by some as a potential threat to food security in developing countries [4, 5].

The development and introduction in tropical Latin America and Asia in the 1960s and 70s of high yielding modern varieties (MVs) of wheat, maize and rice, characterized by the press as a "green revolution," was also controversial. Critics argued that the gains in production would be offset by losses in equity – that the new technology would make the rich richer and the poor poorer [6], pp. 51-52, [7], pp. 121-68, [8].

The view that modern agricultural technology is both subversive of traditional institutions and regressive in its impact on rural incomes has been supported by both Marxist ideology and populist sentiment. Much discussion on this issue is badly confused. There has often been a failure to distinguish between the different income distribution effects of mechanical-engineering and biological-chemical technology. There has also been a tendency to focus on single-factor explanations and to ignore the effects of such factors as the growing population pressure against land resources.

In this paper I draw on my earlier research on the introduction of modern varieties of wheat, rice and maize to explore whether there are lessons that are relevant to the current controversy about the new biotechnology revolution.

2 Technology and Agrarian Structure

The perspective was advanced by Karl Marx and elaborated by Karl Kautsky and Vladimir Lenin that an inevitable consequence of both modern technology and capitalism is to polarize the peasantry into commercial farmers and wage laborers [9, 10, 11]. In this perspective the institutions of pre-capitalist village society, such as communal landownership, mutual-help associations, and patron-client ties, were thought to assure the subsistence needs of the poorest members of the rural community. As those traditional institutions were replaced by modern market institutions, such as private property rights, village elites began to accumulate land for commercial production by encroaching on the commons, by evicting tenants, and by purchasing or appropriating the holdings of small peasants. The introduction of modern machine technology was viewed as further enhancing the efficiency of large-scale relative to small-scale operations, enabling large capitalist farms to displace the small peasants from their land and convert them into landless laborers. Those who were not able to find employment in agriculture owing to the labor-saving effect of modern agricultural technology were forced to migrate and join the urban Lumpenproletariat or the reserve army of industrial workers.

Why are Farms so Small

The 18^{th} and early 19^{th} century Enclosure movement in England and Scotland became the lens through which Marx viewed the effects of technical and institutional change in agriculture.

The Marxian predictions did not materialize in the other early industrializing countries of western Europe. In western Europe industrialization was accompanied by the persistence of small scale peasant production units. Even in the United States, where the development of labor-saving technology proceeded most rapidly, family farms continue to account for a high share of agricultural production. Unlike the industrial sector, large farm firms characterized by hired labor and management has not yet become the dominant mode of production in the modern capital-intensive system of agriculture practiced in the United States [12].

Why did the Marx-Lenin prediction fail to materialize in the course of capitalist development? The primary reason seems to be that intensive polyculture systems require high levels of husbandry skill. Only a few crops, such as sugarcane and cotton, have lent themselves to production by gangs of laborers working under the direction of hired overseers. Unlike the industrial sector in which the machine process makes work highly standardized and easy to monitor, the biological process of agricultural production is subject to infinite variations in response to ecological conditions. Very different crop or animal husbandry practice is often required in response to slight differences in temperature and soil moisture. It matters a great deal whether workers perform their work with care and judgment. The quality of such work is extremely difficult to monitor. The scattering of agricultural operations over a wide space adds to the difficulty of monitoring [13].

This difficulty multiplies as the farming system becomes more complex, involving more intensive crop and animal husbandry. “In areas more suitable for multiple enterprise farms, family operators have the advantage. Increasing the number of enterprises so multiplies the number of on-the-spot supervisory-management decisions per acre that the total acreage which a unit of management can oversee quickly approaches the acreage which an ordinary family can operate," [14], p. 331. Thus the development of biological technology geared to increase output per unit of land area by applying more labor, together with increased biological and chemical inputs for more intensive crop and animal husbandry, gives small family farms an advantage over large farms dependent on hired wage labor. Perhaps the strongest evidence of the relative inefficiency of the estate or plantation system, based on the use of large numbers of laborers carrying out standardized tasks under hired overseers, is its tendency to disappear whenever urban demand for labor has generated upward pressure on agricultural wage rates.

It is critical to recognize that modern technologies are not homogeneous in their effects on agrarian structure. Advances in mechanical technology are usually accompanied by scale economies, resulting in economy in management effort as well as in the use of labor in production. It is much easier to supervise one tractor driver than a large number of bullock teams. The development of mechanical technology has increased the relative efficiency of large farms as Marx and Lenin envisaged. Biological technology, in contrast, is generally embodied in divisible inputs such as improved seed and fertilizer and requires intensive on-the-spot supervisory management decisions. Its effect is to raise the relative efficiency of small family farms and promote a unimodal farm-size distribution.

Marx and Lenin failed to predict the course of agrarian change primarily because they failed to understand the complexity of the biological production process and the potential contribution of advances in biological technology to productivity growth. The Marxian model of agrarian change remained a source of bias in efforts to interpret the productivity and distribution effects of the green revolution in the work of scholars such as Cleaver [15], Griffin [6], Palmer [16], Pearse [8] and Oasa [17].

Technology and Population Pressure

The relation between new technology and income distribution is closely related to the characteristics of both the new technology and the structure of the economy into which it is introduced. The extent to which the income generated by a new technology, embodied in factors such as a new seed variety or a new machine, will augment the productivity and the income accruing to other factors will depend on the technical characteristics of the production function, the elasticity of supply of the several factors, and the institutional environment into which the new technology is introduced.

In rural communities in poor countries a major cause of inequality in income distribution has often been the inequitable distribution of land ownership. Land-saving and labor-using technological changes that raise the economic return to labor relative to land have the effect of equalizing the income distribution between the landless and the land owning classes. In contrast, labor-saving and land-using technological changes contribute to greater inequality.

Since biological technology saves land by applying labor and biological inputs more intensively, its diffusion might be expected to contribute to a more favorable income distribution in rural communities. Nevertheless, the new seed-fertilizer technology has often been blamed for benefiting landlords at the expense of tenants and laborers on the ground that land rents increased while wage rates stayed the same or even declined in many areas where MVs and related inputs were introduced. These arguments have often ignored a critical factor coinciding with the MV diffusion – the growing pressure of population on the land. If this had not been partially offset by the adoption of land-saving technology, incomes would have fallen further and a larger portion of agricultural income would have accrued to landlords.

3 Green Revolution Controversies

The discussions in the previous section should make it clear that the development of biological technology designed to increase agricultural output per unit of land area is a critical factor in offsetting tendencies toward a worsening of income distribution in the rural sector in response to growing population pressure on land. Yet since its introduction MV technology has frequently been viewed as a source of inequality in income distribution and of polarization in rural communities.

The critics of the green revolution have often argued that (a) the new technology tends to be monopolized by large farmers and landlords who have better access to new information and better financial capacity even though MVs and related inputs are divisible and, hence, applicable to small farms; (b) small farmers are unable to use MVs efficiently because financial constraints make it difficult for them to purchase cash inputs such as fertilizers and chemicals; (c) favorable access to the new technology by large farmers enables them to use their profits to enlarge their operational holdings by consolidating small farmers' holdings; and (d) as farm size increases it becomes profitable to purchase large-scale machinery and reduce the cost of labor management [6, 8, 15, 18, 19, 20, 21]. Tests of the several criticisms against experience suggest that the critics were wrong.

Was MV Technology Monopolized by Large Farmers?

The available evidence indicates that neither farm size nor tenure were a serious constraint to MV adoption. The data on adoption of modern wheat varieties in Pakistan, presented in Table 1, are fairly typical of those available for other areas where MVs are technically well adapted. Similar results have been reported for wheat in India, rice in India, Indonesia, Malaysia, and the Philippines, and maize in Kenya [22, 23, 24, 25, 26, 27, 28 - pp. 124-210, 29].

There are, of course, cases in which small farmers lagged significantly behind large farmers in MV adoption. One example was found in a rice village in Andra Pradesh, India, covered by an international project and coordinated by the International Rice Research Institute IRRI) to study the changes in rice farming in selected areas of Asia [30]. This village was characterized by extremely skewed farm-size distribution. Its experience supports the hypothesis that the introduction of MV technology into a community in which resources are very inequitably distributed tends to reinforce the existing inequality.

This village is an exception rather than a norm, however. Of the thirty-six villages studied by the project, it was the only one where a significant differential in the MV adoption among farm-size classes was observed. On the average, small farmers adopted the MV technology even more rapidly than large farmers (see the upper diagram of Figure 1). The pattern of MV diffusion contrasts sharply with the pattern for the diffusion of tractors in which large farmers achieved a distinctly faster and higher rate of adoption (lower diagram in Figure 1).

Did the MV Technology Make Large Farms Relatively More Efficient?

There is a large body of evidence that suggests that small farmers make more efficient use of available land than large farmers [30, 31]. They apply higher levels of labor input, particularly family labor, and they often have more livestock per unit of land than large farms. A carefully conducted study of the adoption of modern wheat varieties in the Indian Punjab by Sidhu [32, 33] showed that MV wheat represented a neutral technological change with respect to farm scale-both small and large farms achieved approximately equal gains in efficiency.

A study in Pakistan by Azam interpreted the data from the Pakistan Punjab to indicate that, although "the smaller farmers do face relatively more severe constraints of irrigation water and credit, the difference in the severity of these constraints is not serious enough to have caused any significant differences in the yields obtained by the small farmers as compared with large farmers," [34, p.18]. Similar results have been reported for rice from the Philippines by Mangahas [24, 25] and from Indonesia by Soejono [26]. Among the thirty-two villages throughout Asia covered by the IRRI-coordinated project, significant differences in rice yields per hectare between large and small farmers were recorded in only eight villages [35].

A major puzzle is why, in view of the evidence, political leaders and planners in developing countries and officials in national and international development assistance agencies remain skeptical about the efficiency of small farms. One reason may be that as a country develops and the opportunity cost of labor rises, the efficiency advantage of small farms tends to disappear. It thus becomes natural to associate large farms with a highly developed national economy. But this inference is irrelevant in most developing economies in which the absolute size of the agricultural labor force is continuing to increase.

Did the MV Technology Promote Mechanization?

The popular perception that MV technology stimulates the introduction of labor-displacing machinery has not been borne out by careful analysis. The data in Figure 1 indicate that throughout Asia large farmers began to adopt tractors before the introduction of MVs. Nor was there any indication that adoption of tractors was accelerated by the dramatic diffusion of MVs from the late 1960s to the early 1970s.

Much of the early adoption of tractors in South and Southeast Asia can be attributed to distortions in the price of capital by such means as overvalued exchange rates and subsidized credits from national governments and international lending agencies. Also, the ease of supervising the operation of one tractor with an operator relative to that of supervising a large number of laborers and bullock teams seems to have worked as a strong inducement to tractorization on already large farms [36, 37, 38]. This factor should have been especially serious where regulation of land rent and tenure arrangements depressed the incentive of large landowners to rent out their holdings in small operational units.

Did the MV Technology Reduce Labor Employment and Earnings?

An extensive review of the literature by Bartsch [39] indicates that the introduction of MVs into traditional wheat and rice production systems has typically resulted in substantial increases in annual labor use per unit of cropped area and, in some cases, in higher cropping intensity. Similarly, data assembled by Barker and Cordova [40] from various areas in Asia show that labor input per hectare of area in rice was higher for MVs than for traditional varieties by 10 to 50 percent. The econometric investigation by Sidhu [32, 33] indicates a very substantial shift to the right of the labor demand function on wheat farms in Indian Punjab as a result of the introduction of MVs. Similar results were obtained by both Rao [41] and Staub [42].

Increases in labor use associated with MVs were often realized despite the concurrent progress in mechanization. The data on labor use in rice production from the Laguna province in the Philippines, as presented in Table 2, are typical. This province experienced rapid diffusion of both modern rice varieties and tractors. Tractorization reduced the amount of labor needed for land preparation, but the reduction was more than compensated for by increases in labor use for weeding and in other areas of crop husbandry. The econometric test by Sidhu [32, 33] for Punjab wheat production shows that the new technology was neutral with respect to factor use, implying that labor's income rises proportionally with the incomes accruing to land and capital. A similar study by Ranade and Herdt [43] on rice in the Philippines suggests that the MV technology is biased in the land-saving direction.

Several studies do indicate, however, that the labor share of income declined and the land share increased in some areas during the period of MV diffusion. Jhai [44] indicates that the factor share to land rose in India between 1960-61 and 1970-71. Data assembled by Mellor and Lele [45] indicate that a disproportionately small percentage of the increased output attributable to MV adoption was allocated to labor. The data on relative shifts in factor shares cannot be interpreted without further analysis to indicate that landowners have gained relative to tenants and laborers from the adoption of MVs. Considerable confusion has resulted from neglect of the fact that while the income share of land increased, as Jha's data clearly show, not only did technology change but labor supply increased. If the labor supply increases faster than demand for labor, it is possible for the factor share of land to rise even if the technological change is biased in the land-saving and labor-using direction [45, pp. 334-336].

Much of the data that indicated a rise in the factor share to land, such as that presented by Mellor and Lele, was obtained during the initial stages of MV adoption. At that time MVs accounted for only a small percentage of area cultivated and of output. There was, therefore, only a modest shift in aggregate wheat or rice production or in aggregate factor demand. Early adopters were able to capture excess profits from the use of more efficient technology without forcing down product prices or bidding up factor prices appreciably. As the technology is diffused more widely, innovators' excess profit tends to be lost as product and factor prices move toward a new equilibrium. In the long run, the relative share of labor will return to the same level as before the introduction of MVs represents a neutral technological change. It will become larger if the technology is biased in the land-saving and labor-using direction. This sequence is supported by a number of studies. For example, Bardhan [47] found that in North India MV diffusion initially had no significant effect on the demand for rural labor. An analysis by Lal [48] in the same region for a later period, however, shows clearly that as MV use diffused more widely the net effect of the resulting increase in demand for labor was a significant rise in the real wage rates in Punjab and other parts of North India at a time when real wage rates were constant or declining in other parts of India where MV diffusion was limited.

4 Perspective

How do we interpret the critical assessments of the effects of the green revolution on income distribution in view of the findings reported in this paper? First, it is apparent that many of the assessments that were made during the initial years of the green revolution were based on casual observation and on limited data [49 p. 1-7]. The initial concerns were largely resolved in the professional literature by more careful observation and analysis of the mid-1970s. But the less securely grounded early impressions of green revolution impacts have remained pervasive in the popular literature and in public consciousness, even though the private and social rates of return to the investment in research and development that led to the green revolution have been high by any standard [50, 51].

Second, there was a general failure to understand that the impact of technical change on income distribution is a function both of the character of the technology and of the economic and institutional environment into which it is introduced. When the green revolution technology was introduced into economies with relatively equitable income distribution it reinforced that equity; when it was introduced into countries with inequitable income distribution in rural areas it reinforced that inequity. There is no substantial evidence that the MV technology was heavily biased against labor. There is substantial evidence that in most areas where it has been adopted it has increased the demand for labor. And there is a growing body of evidence that the impact on production and on demand for labor has had a positive effect on the quality of life in rural villages. In his study of a Punjab village, for example, Leaf notes that farmers now "grow more per hectare . . . and more per capita overall. As measured by food, medical care, educational facilities, and housing, there have been substantial improvements in general welfare . . . .The gains have gone at least as much to the poorer villagers as to the wealthier" [52, p. 268].

The critics of the biotechnology revolution in agriculture draw their inspiration from substantially different sources than those cited by the critics of the green revolution. European consumers, who were scarcely aware of the green revolution, have been a major source of opposition to food products derived from commodities produced using TGMO technology. Non-governmental organizations (NGOs) have played a major role in focusing attention on potential adverse environmental and health effects associated with their production and consumption. And the environmental and health concerns—although unsupported by research and experience over many years-- have served as a mask for implementation of protectionist trade policies advocated by developed country agricultural producers.

There have been, however, important similarities in the dynamics of popular perception of the impacts of the green revolution and of the new biotechnology revolution. In both cases the substantial critical literature, both prior to and following introduction of the new biological technologies in crop and animal production, succeeded in creating considerable confusion about the potential economic benefits that farmers and consumers in developing countries could realize from the development introduction and diffusion of the new technologies. One effect has been to delay the realization by agricultural producers and consumers in developing countries of the benefits, first of the MVs, and more recently of the TMGOs. A second effect was to draw very large scientific and technical resources into the assessment of MV and TGMO impacts. It is not yet clear whether, in retrospect, we will judge that the resources devoted to TGMO assessment and regulation were productively employed or whether they will be viewed as a diversion of technical and scientific resources from more productive employment.

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1 The language used to describe the agricultural products produced by genetic engineering has been indelibly compromised. The health and environmental concerns with the products of genetic engineering are most appropriately focused on transgenically modified organisms (TGMOs)—that is on organisms in which genetic material from an unrelated species has been inserted. All domestic crops and animals have been genically modified since first being domesticated and are appropriately referred to as GMOs.

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Table 1. Mexican-type wheat acreage as percentage of all wheat acreage, by size and tenure of holdings: 1969-70 post –monsoon season in Lyallpur, Sahiwal, and Sheikhupura districts, Pakistan

Number of acres in holding	Owner holdings	Owner-cum-tenants	Tenant holdings	All holdings
Less than 12.5	71.0	80.4	66.7	72.5
12.5 to 25	63.3	71.7	69.2	68.0
25 to 50	71.9	92.7	81.9	82.0
50	73.2	87.3	57.3	78.6
All sizes	69.4	80.5	70.0	73.4

Source: K. M. Azam, "The Future of the Green Revolution in West Pakistan: A Choice of Strategy," *International Journal of Agrarian Affairs* 5 (March 1973): 408. Original source: Government of the Punjab, Planning and Development Department, Statistical Survey Unit, *Fertilizer and Mexican Wheat Survey Report* (Lahore, 1970), p. 38.

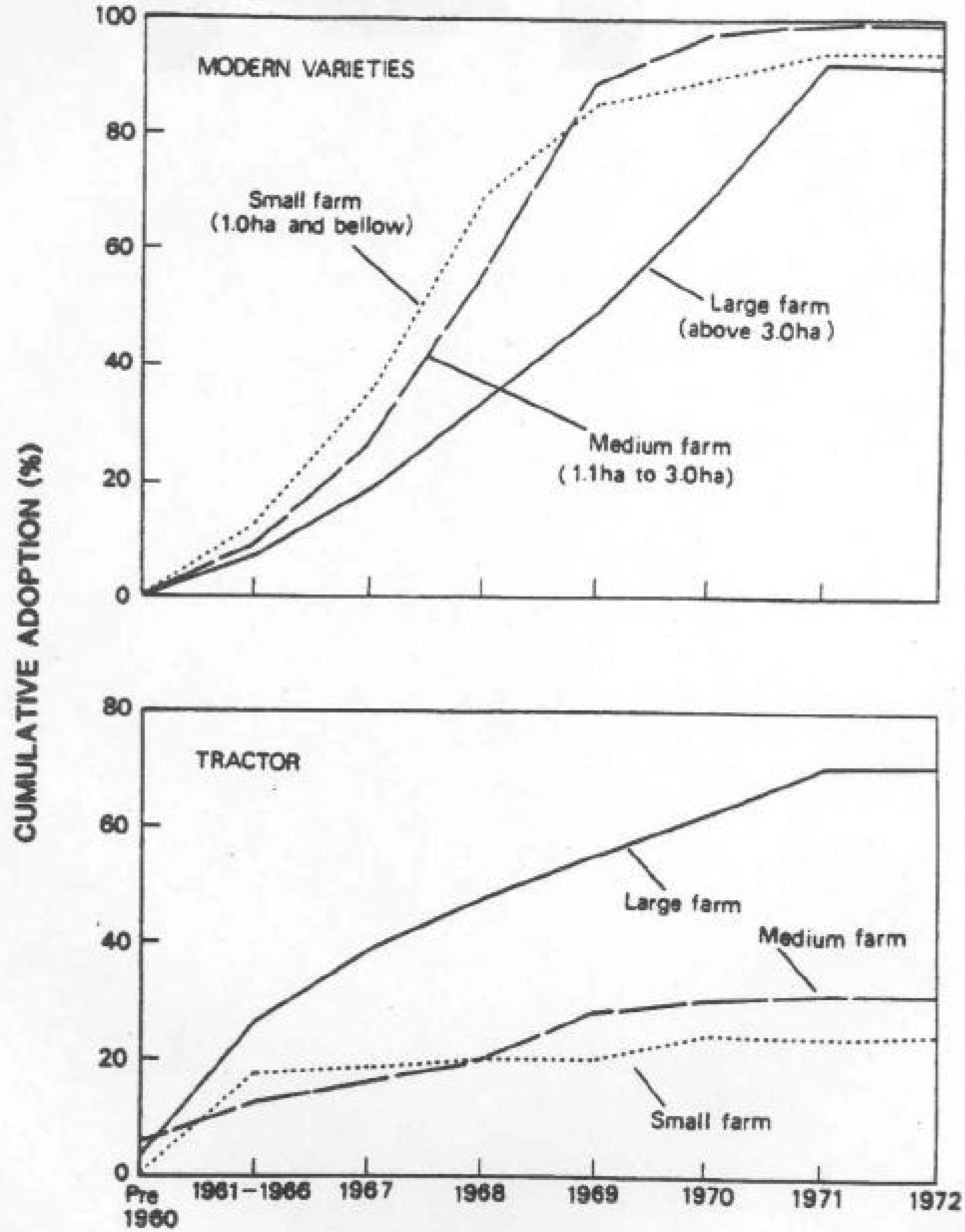
Table 2. Percentages of farms adopting MVs and tractors and use of labor man-days per hectare for rice production in Laguna, Philippines, 1966-75, wet seasons

	1966	1970	1975
MV adopters (percent of farms)[a]	0	76	94
Tractor adopters (percent of farms)[a]	26	71	90
Average paddy yield (metric tons/ha)	2.5	3.4	3.5
Labor input (man-days/ha)			
Land preparation	18.7	11.1	9.0
Transplanting	10.2	10.2	10.9
Weeding	13.8	17.8	31.3
Other preharvest operations	9.4	14.8	20.2
Harvesting and threshing	31.6	33.6	31.6
Postharvest operations	4.4	5.4	3.4
Total	88.1	92.9	106.4

Source: Randolph Barker and Violeta G. Cordova, "Labor Utilization in Rice Production," *Economic Consequences of the New Rice Technology in Asia*, ed. Randolph Barker and Yujiro Hayami (Los Banos, Philippines: International Rice Research Institute, 1978), pp. 120 and 127.

[a] Averages for wet and dry seasons.

Figure 1. Cumulative percentage of farms in three size classes adopting modern varieties and tractors in thirty villages in Asia.



Source: International Rice Research Institute, *Interpretive Analysis of Selected Papers from Changes in Rice Farming in Selected Areas of Asia* (Los Baños, Philippines, 1978), p. 91.