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Maintaining the Momentum in Post-Green Revolution Agriculture: A Micro-Level Perspective from Asia

by

Derek Byerlee

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EXECUTIVE SUMMARY

This paper reviews from a micro-level perspective, the opportunities for increasing agricultural productivity in the large areas of Asia in a "post-green revolution stage of development," where modern rice and wheat varieties and moderate to high doses of fertilizer have already been widely adopted. Productivity increases in these areas from the spread of new varieties and increasing fertilizer use have now slowed. Continued rapid growth in productivity to exploit the genetic potential of modern varieties depends on more efficient use of available technology. Farmers increasingly use a wide range of "second generation inputs" such as secondary and micro-nutrients, pesticides, and improved cultural practices. Complexity of crop management in these areas has increased dramatically due to interactions between a wider array of technological components and increased location specificity of the technology. The new technology is also more management intensive since it requires more information and skills for efficient use. In addition, increased multiple cropping, complex crop rotation effects and a rapidly changing technical and economic environment add further complexity to farmer management.

In this situation, the potential for inefficiencies in resource use is much greater if farmers lack ready access to a continual flow of up to date technical information or have inadequate technical and managerial skills. Evidence is presented that technical knowledge of farmers regarding new technological components is often very poor. In addition, in post-green revolution agriculture, technical inefficiency - the difference between farmers' production levels and the potential given existing input and resource use - generally ranges from 20 to 50 percent. Technical knowledge, extension contacts and education are shown to be the major factors explaining differences in technical efficiency between farmers in a given area. The Schultzian characterization of farmers as "poor but efficient" is no longer applicable to post-green revolution agriculture in Asia.

Deficiencies in technical knowledge and skills can be traced to the performance of rural institutions, especially adaptive research, extension, and rural schooling. Adaptive research generally lacks a farmer and problem orientation and is often the weakest and

most neglected part of the agricultural research system. The low quality of extension advice and rural schooling in many areas compound this problem, especially for small farmers. Recent innovations in adaptive research (the use of a farming systems perspective) and in extension (the Training and Visit System) are reviewed. These institutional innovations should help to improve the capacity of the research and extension system to increase the flow of relevant and useful information to farmers. However, in both of these approaches there is too much emphasis on prescriptive information or recipes for crop production at the expense of providing farmers a better understanding of new technology and improving technical and managerial skills. Moreover, both innovations have been instituted from the "top down" and provide little opportunity for farmers themselves to influence the direction and performance of research and extension.

The evidence presented strongly supports the need for increased efforts to increase the quantity and quality of information and skill acquisition by farmers in post-green revolution agriculture. Critical issues for investment allocation between adaptive research, extension, and rural schooling are discussed. It is concluded that there are limited opportunities to substitute between these three components of the formal information and skill system and that in general they are strong complements. In some post-green revolution areas, particularly in South Asia, the low level of formal schooling may be a major constraint on increasing the pay-offs to the investment in adaptive research and extension that is needed to sustain rapid increases in productivity in the future. The private sector can also play a greater role in adaptive research and information dissemination, especially for chemical inputs, but the public sector must provide leadership in the foreseeable future. Finally, applied research activities, such as plant breeding, can to some extent substitute for weaknesses in adaptive research, extension and education by developing technologies that require less information and managerial skills in order to be efficiently used by farmers.

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I. INTRODUCTION

For large areas of Asia, the rapid growth of agricultural productivity associated with the introduction of semi-dwarf wheat and rice varieties of the so-called green revolution has entered a new phase. Most farmers in these areas now use modern varieties and moderate to high doses of fertilizer, and productivity increases from these two sources have slowed. Improvements in other crop management practices and in cropping intensity play an increasing role in maintaining productivity growth and exploiting the genetic potential of existing varieties. While much of the literature on agricultural development continues to focus on the green revolution and its impact, this new post-green revolution phase is already well established in many areas but has been largely ignored by analyses of Third World agricultural development. Rather, attention seems to have turned to more macro-level concerns, especially pricing policy and food security.

While agricultural development thought is notably "faddish," one of the enduring themes over the past two decades has been Schultz's (1964) seminal contribution on the efficiency of small farmers in traditional agriculture in allocating their resources and responding to price incentives - the so-called "poor-but-efficient" hypothesis. This laid the theoretical justification for the high pay-off input, or science-based model of agricultural development exemplified by the green revolution. A further implication of the poor-but-efficient hypothesis was that there were low pay-offs in traditional agriculture to extension and farm management efforts to encourage farmers to use their existing technology more efficiently (Staatz and Eicher, 1984). Hence, most increases in productivity would have to come about through introduction of new high pay-off inputs into traditional agricultural systems.

In the two decades since Schultz's book was published, the rapid uptake of improved varieties and fertilizer technology has transformed the agricultural landscape in many developing regions, especially in Asia. The image of a traditional subsistence agriculture no longer holds as small farmers use an increasing number of purchased inputs and strive to keep pace with a dynamic technical and economic environment. The green revolution has highlighted the role of agricultural research and especially plant breeding research in stimulating technological change in agriculture. But the very success of the green revolution with its emphasis on technical change may have drawn attention away from the importance of the human element in agricultural development (Jones, 1978). In particular, Schultz's poor-but-efficient hypothesis still widely prevails today although it is by no means universally accepted.[1] A central thesis of this paper is that general acceptance of this hypothesis has led to a relative neglect of efforts by research, extension and farm management to increase economic efficiency in farmers' resource use, and insufficient emphasis on upgrading farmers' technical skills and managerial ability.[2] The very assumptions underlying the hypothesis - that farmers in traditional agriculture have evolved over a long period an efficient system through accumulation of experiences and an intimate knowledge of their environment - have become outmoded by the rapid process of change introduced by the green revolution. Indeed, Schultz himself has persuasively argued (largely in the context of the U.S.) that, in a dynamic agriculture, farmers are continually in a state of disequilibrium and that there are high returns to better information and skills to improve farmers' economic efficiency (Schultz, 1975).

This paper argues that two of the major sources of agricultural growth in the past two decades in Asia - the spread of modern varieties and rapid increases in fertilizer use - have already been substantially exploited. A new and more complex second generation of inputs and management practices plays an increasing role in productivity growth, and investments in better information and skills of farmers to improve economic efficiency in using this wider array of inputs are needed to maintain the momentum in post-green revolution agriculture. Furthermore, in many of these countries, increasing food self-sufficiency, reductions in subsidies on agricultural inputs, and declining world prices for food grains in the 1980s have led to less favorable price incentives and more

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[1] See, for example, Shapiro (1983), Nair (1979) and for a particularly stinging attack, Adams (1986). The publication of Schultz's book also generated considerable controversy at the time (e.g. Lipton, 1968).

[2] Economic efficiency in this paper refers to both technical efficiency - the productivity of farmers' existing input mix - and allocative efficiency - the combination of inputs that leads to profit maximization.

pressure to increase economic efficiency.[3] However, the development of the capacity of rural institutions to meet the needs of this changed environment has lagged the process of technical change (Ruttan, 1978; Bonnen, 1986), although recent innovations in research and extension are beginning to close the gap.

The paper is organized as follows. First, the increasing complexity of crop management issues facing small farmers in post-green revolution Asia is described. Second, evidence of economic inefficiencies in resource use in these regions and the importance of farmers' information and skills in reducing these inefficiencies is presented. This leads to a discussion of institutional changes in research, extension and rural education aimed at improving information and skills of farmers and their implications for development strategy in the post-green revolution era. The paper focuses on those post-green revolution areas where almost all farmers use modern varieties of rice or wheat and moderate to high levels of fertilizer of 75 kg/ha of nutrients or more.[4] A conscious effort is made throughout the paper to analyze these issues from the vantage point of an accumulating body of farm-level research and experiences.

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[3]Price discrimination against food grain production is probably not as large or as widespread as commonly suggested (see Byerlee and Sain, 1986) and with declining world prices and increased self-sufficiency, many countries have producer prices above the world price equivalent. Herdt (1987) also documents declining economic incentives to Philippine rice farmers in recent years.

[4]The issues discussed here are not exclusive to post-green revolution irrigated areas of Asia. In many rainfed areas, improved varieties and moderate doses of fertilizer have also been widely adopted, especially in maize in Latin America and Eastern and Southern Africa.

II. INCREASING COMPLEXITY OF CROP MANAGEMENT IN POST-GREEN REVOLUTION AGRICULTURE

The green revolution in Asia involved widespread and rapid adoption of semi-dwarf wheat and rice varieties, especially in the decade 1967-77, that, in turn, stimulated adoption of two other key inputs - nitrogenous fertilizer and improved supplies of irrigation water. By the mid to late 1970s, modern varieties had been fully adopted in many environments, although there were important exceptions for large rice growing tracts of eastern India, Bangladesh and Thailand (See Figure 1 and Table 1).[5] Genetic gains in yield potential in successive generations of modern varieties have slowed and an increasing proportion of plant breeding research in wheat and rice is now devoted to "maintenance research" to protect yield gains against breakdown of pest resistance (Plucknett and Smith, 1986) and to adapt semi-dwarf varieties to less favorable environments.[6]

A similar situation also holds for the two other major inputs - nitrogenous fertilizer and water. Fertilizer levels increased rapidly for several years after adoption of modern wheat and rice varieties (see Figure 1) and explained much of the agricultural growth in the 1970s in Asia (Scandizzo, 1984). Fertilizer levels have now reached fairly high levels in many areas, are increasing much more slowly and provide lower gains at the margin than in earlier years. For example, fertilizer use on wheat averages about 120 kg/ha of nutrients in well irrigated areas of the Punjab, Pakistan and 160 kg/ha in the Indian

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[5]In the past decade, modern wheat varieties have also been extensively adopted in less favorable environments (Dalrymple, 1986a). For example, in rainfed areas of Pakistan's Punjab, the proportion of area sown to modern varieties increased from 20 percent in 1975 to over 60 percent in 1985.

[6]Semi-dwarf wheat varieties released in the 1960's generally yielded 30-50 percent more than earlier taller varieties under irrigated conditions with moderate doses of fertilizer (Nagy, 1984). Releases since then have increased yield potential by an average of one percent per year or a total of about 20 percent. Most of this increase was due to the crossing of spring by winter wheats. Similarly, Dalrymple (1986b) notes that no new rice variety has out-yielded the potential in favorable environments of the variety IR8 released nearly 20 years ago, although major progress has been made in incorporating pest resistance, stress tolerance, quality characteristics and earliness (probably at the expenses of gains in yield potential). Recent advances in biotechnology are not expected to change yield potential for cereals before the turn of the century.

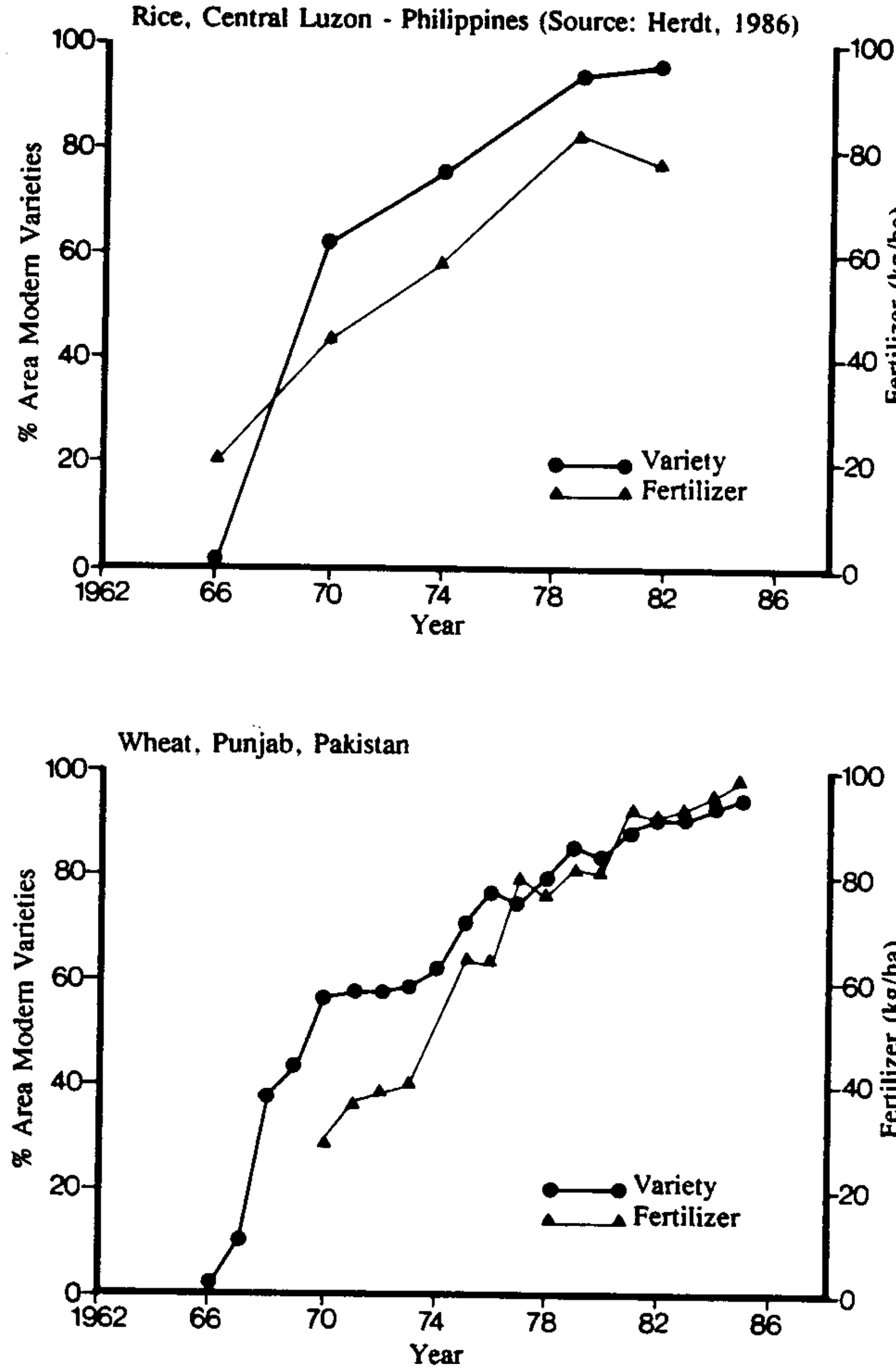

Figure 1. Changes in area under modern varieties and fertilizer applied to wheat in Pakistan's Punjab and rice in Central Luzon, Philippines.

Table 1. Percent of Area Planted to Modern Varieties of Wheat and Rice in Selected Asian Countries, Early 1980s.

	Rice	Wheat
Bangladesh	25	96
Indonesia	82	b
India	54[a]	76
Nepal	36	92
Pakistan	46[a]	86
Philippines	85	b
Sri Lanka	87	b
Thailand	13	b

[a] Some important rice producing regions of India and Pakistan (e.g. Punjab and Tamil Nadu in India and Sind in Pakistan) had adoption rates over 80%.

[b] Wheat is not a commercial crop.

Source: Dalrymple, 1986a, 1986b.

Punjab. Similar levels are recorded for rice in the Philippines (e.g. Lingard et al., 1983). Likewise, introduction of semi-dwarf varieties was accompanied by rapid expansion of irrigation facilities and improved water control. However, investment in irrigation is also slowing in many post-green revolution areas as only the more difficult, and hence more expensive investments remain.

Hence, the major sources of rapid growth during the green revolution era have to a large extent been utilized, especially in better endowed irrigated areas (Vyas, 1983; Huke et al., 1982), although steady gains will continue to be achieved through release of newer varieties and rising fertilizer doses. Yet most observers agree that there are substantial opportunities to increase productivity in these areas through increased yields, reduced costs, and improved cropping systems. Most of these opportunities depend on non-genetic gains in productivity through use of new inputs and more efficient use of existing inputs to exploit the genetic potential of existing varieties.

Farmers now face a wide array of "second generation inputs" that offer the opportunity to substantially increase productivity but at the same time greatly increase the complexity of crop management. For example, for irrigated wheat in Pakistan, farmers now commonly purchase five inputs - tubewell water, nitrogenous fertilizer, phosphatic fertilizer, tractor power and thresher services - none of which were in wide use two decades ago. In addition, an increasing number of farmers, especially in the Indian Punjab use potash fertilizer and micro-nutrients (e.g. zinc), soil amendments, seed treatment for disease control, improved on-farm water management methods including precision land leveling, and more precise planting methods and spacing. Higher yields and increased cropping intensity also lead to increased crop losses from pests (in absolute terms) and pesticide use has become widespread, especially in rice.[7] At the same time, improved water supplies, earlier maturing wheat and rice varieties, and in some cases, selective mechanization, have greatly expanded the opportunities for multiple cropping which require management of complex double and triple cropping patterns that sometimes include new and unfamiliar crops.

In these evolving production systems, crop management is generally complex. Changes in practices required to sustain increases in productivity, while still quite profitable, do not provide the spectacular economic returns characteristic of the first round of inputs adopted during the green revolution. Hence, their successful adoption is more sensitive to the efficiency with which they are used by farmers. The wider array of technological options available and the interactions between them, requires farmers to identify a logical stepwise sequence for adoption that fits their agro-climatic and socio-economic circumstances. Interactions between technological components may also require adjustment in traditional inputs. For example, irrigated wheat yields in much of South Asia appear to be limited by low plant populations. Farmers use seed rates and planting methods that were appropriate for low yielding conditions but which now no longer appear to be adequate.

In multiple cropping sequences with two or three crops per year, management complexity is also increased by the need to sometimes make simultaneous decisions on management of each crop in the sequence. For example, in the cotton-wheat rotation of Pakistan, the potentially positive effect of introducing earlier cotton varieties on planting dates for wheat following cotton was largely cancelled by farmers' rapid increase in pesticide use for cotton which increased cotton yields and delayed the cotton harvest (Byerlee, Akhter and Hobbs, 1987). With earlier maturing varieties grown in

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[7] Crop losses due to pests are often proportional to yield levels (Zadoks, 1985) and pest control measures which were uneconomic at low yield levels become economic at higher yield levels.

multiple cropping systems timeliness of operations is often a critical determinant of system productivity and places additional burdens on management. In addition, crop rotation in more intensive cropping systems often plays a key role in managing pest populations.

In addition, neither the technical nor economic environment in which these management decisions are made remains static. Increased yields and cropping intensity tend to deplete soil potasium and micro-nutrient reserves and lead to responses to application of these inputs. Application of phosphatic fertilizers has substantial carryover effects that eventually allow the application of lower maintenance doses. Control of broadleaf weeds in wheat reduces the competition for grassy weeds whose increasing population demands control measures. Increased supplies of tubewell water and higher cropping intensities complicate water and salinity control management in irrigated areas of South Asia.[8] Evolving insect and disease biotypes require the rapid adoption of new varieties. Indeed, there is evidence that, unless farmers keep abreast of these changes in the technical environment, productivity may decline over time due to depletion of soil nutrients or pest build-up in intensive cropping systems.[9] Along with these changes in the technical environment, the economic environment has also been subject to sharp adjustments in price relationships in some countries in the 1980s due to so-called "policy reforms", especially the reduction in input subsidies. (For evidence on the Philippines, see Herdt, 1987).

The second generation inputs are also more "management intensive" - that is, they often require more information and skills for successful adoption than the earlier introduction of new varieties and nitrogenous fertilizer (Kahlon, 1984). While the semi-dwarf varieties, especially for wheat, are well known for their adaptability over a wide range of environments, the use of more complex fertilizers and pesticides often interacts strongly with variation in soil type and with year-to-year variation in climate and pest incidence. Hence, individual farmers need to adapt the technology to their own requirements and frequently there are substantial returns to managing inputs for individual fields and seasonal conditions within a farm.[10]

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[8]Even the switch from bullocks to tractor power appears to have led to increased soil compaction in some areas that requires modifications of tillage methods.

[9]See Winkelmann (1987) for a discussion of sustainability in intensive production systems of the tropics.

[10]The highest returns to input management by fields and seasons are obtained from deciding whether to use or not use a particular input in a specific circumstance and how

Technical skills required to efficiently use the new inputs are also much greater than for a simple varietal change. An extreme example is use of integrated pest management (IPM) in rice in Asia. While the practice has potentially high returns to farmers and to society, it requires skills in identification of pest insects and beneficial insects, quantification of pest populations and damages, knowledge of threshold levels of pest damage, and skills in selecting the appropriate chemical, calculating the dosage and applying the product (Goodell, 1984b). Management complexity is further increased by the wide variety of inputs available. For example, one survey of 150 rice farmers in the Philippines recorded 38 different insecticides being used by farmers, many of them similar products under different names (Litsinger et al., 1980). Even the number of new wheat varieties available to farmers has tended to increase in order to provide different maturities to fit multiple cropping systems, and to reduce the risk of disease epidemics.

Hence, effective crop management in this post-green revolution era places heavy demands on the information and skills of farmers. In traditional agriculture, information is primarily generated internally by farmers through a process of learning-by-doing and informal experimentation (Johnson, 1972; Biggs and Clay, 1981). Although management in traditional agriculture is also often quite complex, gradual changes in the resource base and in the external environment, especially through population growth, allowed an evolution of farmer management to incorporate these changes based on farmers' experiences and knowledge of their environment accumulated over generations of farming. In the new science-based agriculture, however, the value of traditional knowledge rapidly depreciates as new inputs and cropping patterns are introduced. Even outside sources of information will have a built-in obsolescence (Welch, 1978).

If there is a one-shot disturbance to the equilibrium due, for example, to a new input becoming available or a change in price ratios, farmers will eventually adjust to a new equilibrium by their own trial and error. Yet the green revolution was not a one-shot disturbance (as implied by Welch, 1978) but a series of increasingly complex changes as new inputs and cropping patterns were introduced. Whereas the spread of semi-dwarf varieties was very rapid as new seeds and information passed from farmer to farmer, information flows from farmer to farmer for the second generation inputs are expected to be much slower and less effective, since a much greater range and complexity of information and skills are needed.

Management skills developed in traditional agriculture through experience in

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that input is used (e.g. timing and method of application). The level of an input may often be adjusted in a fairly wide range around its "true" optimal level without having a large effect on productivity (Anderson, 1975).

learning-by-doing are also no longer adequate to keep pace with these changes. The movement toward "optimal" levels and technically efficient use of a new input is a process of continual improvement and adjustment as farmers' experience and information grows. However, the optimum level of an input is itself continuously changing in a technically and economically dynamic environment so that farmers can be expected to remain in a constant state of disequilibrium as they strive to hit a "moving target."

It is now widely recognized that formalized schooling helps to develop technical and managerial skills for a science-based agriculture.[11] Schultz (1975), Welch (1978) and others have convincingly argued that education increases the ability to acquire and evaluate information. Or, in economic terms, education reduces the cost of obtaining a given amount of information (e.g., through literacy skills) and increases the benefits of this information in decision making (Ram, 1981). Education may increase farmers' technical skills (e.g., computing dosages) as well as improve farmers' allocative ability in adapting new technology to their own needs and adjusting to changes in the environment. Understanding of basic scientific principles may be necessary to adopt innovations which are sometimes counter-intuitive, or whose benefits are not immediately obvious (e.g., use of a new wheat variety to guard against breakdown in rust resistance).

In many post-green revolution areas, decision making complexity in small-holder agriculture is now closer to the situation of farmers in industrialized countries (the levels of bio-chemical technologies are similar) than the image of traditional agriculture commonly held for farmers in developing countries. Just as farmers in industrialized countries have moved from a science-based to an information-based agriculture (Sonka, 1985), small farmers in the post-green revolution era are also entering this "information age." However, unlike farmers in industrialized countries who have had a relatively long period to adjust to a science-based agriculture, the increased demands on knowledge, technical skills, and managerial capacity of post-green revolution farmers, most of whom used practically no purchased inputs two decades ago, has been collapsed into a very short period of less than two decades.

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[11]Evidence on the importance of education in Asian agriculture will be discussed in Chapter 3.

III. INFORMATION, EDUCATION AND ECONOMIC EFFICIENCY

The green revolution in the 1960s and 1970s spawned a large number of studies of the adoption of the new varieties and fertilizer and their equity implications [12] Until recently, however, there were few studies on the efficiency with which the new technology was used once adopted.

In this chapter, empirical studies of farmers' technical information and how it affects economic efficiency are reviewed. Two types of micro-level studies are reviewed; a) those that describe and analyze farmers' technical knowledge and its effect on input use, and b) production function studies that estimate economic inefficiencies and try to identify factors responsible for these inefficiencies.

A. Farmers' Technical Knowledge and Input Use

The positive effects of farmers' technical knowledge, education and extension contacts on the adoption of a new input are well known (see reviews by Feder, Just and Zilbermann, 1985; Herdt and Capule, 1983; Rogers, 1983). However, few studies have examined the evolution of farmers' technical knowledge in the post-adoption stage that characterizes post-green revolution Asia. In the mid-1970s, Bernsten (1977) surveyed farmer's technical knowledge of 50 management practices judged by rice scientists to be "critical for the farmer to achieve maximum input efficiency" (Bernsten, p. 191). These included age for transplanting modern varieties, appropriate depth of standing water for herbicide use and appropriate insecticides for given insect pests. Out of a maximum score of 12, farmers averaged 5.7, suggesting substantial scope to increase farmers' technical knowledge.

Recent surveys in Pakistan (Heisey et al., 1987) show that most farmers, even after nearly two decades of experience with modern wheat varieties and fertilizers, were not able to compute nutrient doses, especially for phosphatic and compound fertilizers. They had inadequate knowledge of newer varieties and their characteristics, and most were unaware of the potential breakdown in rust resistance of wheat varieties. In northwest India, where more effective extension has been in place, farmers' knowledge appears to be much better, but away from these areas, farmers' information scores for modern

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[12] For reviews, see Lipton and Longhurst, 1985; Herdt and Capule, 1983; and Ruttan and Binswanger, 1978).

inputs are generally poor (Feder, Slade and Sundaram, 1986; Srivastava, 1976). Deficiencies in farmers' technical knowledge generally increases with increasing complexity of the practice (Mayani and Kumar, 1980). In particular, information on plant protection is generally poor. Even the relatively literate farmers in the highly commercialized agriculture of northwest Mexico have poor knowledge of plant protection measures that they often employ, especially the appropriate product and time of application of herbicides for grassy weeds in wheat, a major problem in the area.[13]

Within an area, too, there are often quite large differences between farmers in technical knowledge (Heisey, et al., 1987; Feder and Slade, 1984). Feder and Slade(1984) were able to relate these differences to information supply (extension contact), the cost of information acquisition per unit area (farm size) and human capital variables (numeracy and education).

Farm level surveys also indicate the substantial variation in use of modern inputs even where farmers have had many years of experience with a given input. Table 2 compares the Coefficient of Variation (CV) in per hectare use of fertilizer - a modern input - to the CV of traditional input usage for a number of surveys in relatively homogeneous areas in which most farmers had adopted fertilizers. The CV is always higher for the modern input than for the traditional input. Even after nearly 20 years of experience of using fertilizer, farmers in Pakistan's irrigated areas still exhibit wide variation in fertilizer doses in a given area. Taking cross-sectional data the CV has fallen from over 100% in an area where fertilizer was only recently introduced, to 50-60% in the irrigated Punjab. By contrast the CVs for fertilizer use on wheat in three counties of Michigan were 30-40% in 1959-61, less than 10 years after widespread adoption. (Calculated from Hoffnar and Johnson, 1966). Much of this variation can be explained by differences in access to capital and irrigation water, soil variation, and crop rotation (Byerlee et al., 1986) (which are likely to interact more strongly with modern inputs than traditional inputs), but in part, it is due to differences in information, skills and experiences of farmers (Heisey et al., 1987).

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[13] Grassy weeds in wheat such as wild oats are taxonomically related to wheat and in the early growth stages are difficult to distinguish from wheat plants. Many farmers have difficulty comprehending that herbicides can selectively kill these weeds in a wheat crop.

Table 2: Coefficient of Variation of Traditional and Modern Inputs for Farmers 5 to 10 and 15 to 20 Years After Introduction of Modern Varieties.

	Kenya (Vihiga)	Pakistan (Gilgit)	India (Palanpur)	Pakistan (Gujranwala)	Pakistan (Multan)
Number of years since initial adoption of variety and fertilizer	5-10	5-10	5-10	15-20	15-20
			Coefficient of Variation (%)		
Traditional inputs					
- seed/ha		29	11	14	12
- number of ploughings		28	33	43	34
- organic manure/ha		70			
- labor/ha	35		46		
Modern inputs					
- nitrogen/ha	98	100	61[b]	52	53
- phosphorus/ha	85	131		60	66

[a]All inputs were used by over 80 percent of farmers in the year of the survey, except phosphorus in Gilgit (47 percent).

[b]Total fertilizer applied.

Source: Vihiga - Moock (1981): Gilgit - Hussain (1986); Palanpur - Bliss and Stern(1982); Gujranwala and Multan - original survey data.

B. Technical and Allocative Efficiency in Asian Agriculture

There is a growing body of literature that attempts to measure economic inefficiencies within a production function framework and relate these inefficiencies to socio-economic characteristics of farmers. These studies are not without conceptual and methodological difficulties and some discussion of these problems is necessary before presenting empirical results.

1. Measuring Economic Inefficiency

Economists widely distinguish between technical inefficiency and allocative or price inefficiency, following pioneering work of Farrell (1957). Technical inefficiency refers to failure to operate on the production frontier and is generally assumed to reflect inefficiencies due to the timing and method of application of production inputs. Allocative inefficiencies refer to the failure of farmers to meet the marginal conditions for profit maximization - that is, to equate the Marginal Value of Products (MVPs) of inputs to their market prices.[14] It is often useful for policy purposes to further divide allocative errors between a) the constrained case where allocative gains are measured by reallocating inputs within the existing expenditure level - i.e. movement along the isoquant to the expansion path, and b) the unconstrained case where allocative gains also accrue due to movement along the expansion path until the marginal return on expenditures is equal to the cost of capital.[15] Allocative errors in the constrained case, like technical inefficiencies, are most likely to reflect deficiencies in information and skills and be easier to correct in the short run. Allocative errors in the unconstrained case (i.e. scale errors) may also reflect inadequate information and skills, but they are also likely to arise from the effects of market imperfections and risk aversion and non-monetary goals of farmers that imply different and longer run interventions than in the case of imperfect information. These various inefficiencies and policy interventions are summarized in Table 3.

It is important to note at the outset that economic efficiency is only a standard for society to judge resource productivity against its potential and is not intended to suggest irrational decisions on the part of farmers because they do not maximize profits. The failure of farmers to use the most efficient techniques of production because of inadequate information suggests that the cost to the individual farmer of acquiring better information is greater than the benefits.[16] The question arises as to whether policy interventions can improve the "market" for information and reduce its costs to farmers.

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[14] In multi-product firms, allocative efficiency also implies that the Marginal Rate of Transformation between products be equal to the ratio of product prices.

[15] Empirical studies have used both specifications. The unconstrained case with all factors variable implies diminishing returns to scale. An additional restriction in the constrained case is to constrain expenditures for only variable or cash inputs.

[16] Other possible reasons for inefficiencies include fixed assets and vintage effects, property rights (e.g. tenancy) as well as farmers' non-monetary values (see, for example, Carter, 1982).

B-4

Table 3. Classification of Economic Inefficiencies and Their Policy Relevance

Type of Inefficiency	Likely Cause of Inefficiency
1. Technical Inefficiency	
Failure to operate on the production frontier due to errors in the timing or method of application of inputs	1. Inadequate information 2. Insufficient technical skills
2. Constrained Allocative Errors	
Errors in allocating input within existing expenditure levels - movement to expansion path.	1. Inadequate information 2. Market failure in input supply 3. Differential risk effects of inputs
3. Scale Errors	
Increased levels of input use through higher expenditure levels - movement along the expansion path	1. Capital constraint 2. Risk aversion 3. Inadequate information

The distinction between technical and allocative efficiency also depends on the level of aggregation and specification of the production function. Stigler (1976), for example, argues that if the production process is completely specified (including timing and method of using inputs) there would be no technical inefficiency, only allocative inefficiency. This point is particularly important given that most production functions are specified with very aggregate categories of inputs such as land, labour, fixed capital and variable cash inputs. If cash inputs are an aggregate of say, herbicides and nitrogen and phosphatic fertilizers, measured "technical" efficiency will include both allocative errors among these three inputs as well inefficiencies due to timing and method of application of these inputs.

2. Empirical Estimates

Technical efficiency has typically been measured by estimating a frontier production function.[17] The frontier production function attributes variation from the most efficient farm to technical inefficiency. In fact, if specified in aggregate terms of land, labor and capital, it also captures micro-level variation in soil and land type, crop rotation, etc., as well as sampling and measurement errors, and hence tends to overestimate technical inefficiency. More recently, stochastic formulations of the frontier production function have been applied to sort out the effects due to random errors from those due to technical inefficiency (e.g. Huang and Bagi, 1984; and Kalirajan and Flinn, 1983). However, methodological debate still arises in interpretation of the results (Taylor and Shonikwiler, 1986; Pasour, 1981; Russell and Young, 1983).

Table 4 summarizes empirical measures of technical inefficiency for farmers in post-green revolution Asia and within the caveats of the previous discussion, suggest that on average, farmers could increase output by 20-50%, given existing resource use. Comparable estimates of technical inefficiency in traditional agriculture are scarce but suggest that the average level of inefficiency is less than 20 percent (e.g., Belbase and Grabowski, 1985 in the Nepal hills and Mijindadi and Norman, 1984 in northern Nigeria.)

Several of these studies from post-green revolution Asia have tried to explain the individual farmer-specific technical inefficiency in terms of farmer characteristics. In some cases, these are related to external constraints, such as access to credit (Lingard, et al., 1983) or irrigation water (Flinn and Ali, 1986) (see Table 4). However, a particularly important finding is that in all studies where farmer-specific technical efficiency was analyzed, the major factors explaining differences in efficiency were variables measuring farmers' information and skills such as education, age, experience, contacts with extension agents, and technical knowledge (Table 4).[18] Hence, even if the absolute level of technical inefficiency is overestimated due to inadequate specification of the production function (e.g., failure to include micro-soil variation), there is

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[17]For an excellent overview of methodological issues in frontier production functions, see Forsund, Lovell and Schmidt (1980).

[18]The lack of significance of some of these information and skill variables in some cases may be due to their relative uniformity in the sample population. For example, the study of Kalirajan (1981) found no effect of education on technical efficiency, probably because the sample included only persons with primary school education and above (Kalirajan and Shand, 1985).

Table 4. Estimates of Technical Efficiency in Modernizing Agriculture In Asia

	Author(s)	Region	Year	Crop	N	Method	Average Efficiency (%)	Farmer-specific Factors Determining Efficiency
1.	Huang & Bagi (1984)	Northwest, India	1969/70	Irrigated Wheat	151	Stochastic production frontier	89	Not analyzed
2.	Kalirajan (1981)	Tamil Nadu, India	1978	Irrigated Rice	70	Stochastic production frontier	47	Extension* Knowledge score* Experience*
3.	Kalirajan & Flinn (1983)	Bicol, Philippines	1980/81	Rainfed Rice	79	Stochastic production frontier	50	Planting method* Extension Experience* Education
4.	Lingard, et. al. (1983)	Central Luzon, Philippines	1970-79	Irrigated Rice	32 x 10 yrs.	Farm-specific dummy	50	Soil type* Credit access* Education* Tenancy Age
5.	Kalirajan (1984)	Laguna, Philippines	1979/80	Irrigated Rice	81	Stochastic production frontier	63	Extension* Experience* Education
6.	Peng and Chen (1985)	Taiwan	1979	Maize	na	Frontier production function	72	Education* Farm size Extension
7.	Flinn and Ali (1986)	Punjab, Pakistan	1982	Irrigated Rice	120	Stochastic production frontier	80	Education* Timing of Inputs* Water constraints*

*Significant at 5% level or less

na = not available

convincing evidence that information and skills play an important role in the relative degree of inefficiency among farmers.

A number of methods have also been used to measure allocative inefficiencies. Many studies have compared the overall sample Marginal Value of Product of each input to the average price of the input and tended to be highly conservative in rejecting the null-hypothesis that farmers were efficient in allocating their resources. Even though most authors concluded that farmers were acting in a profit maximizing manner, the estimated marginal productivity and price relationships often suggested quite substantial allocative inefficiencies. For example, Barnum and Squire (1978) for irrigated wheat in India conclude that farmers were allocatively efficient even though the ratio, K = (Marginal Value Product/Marginal Factor Cost), for "other variable inputs" (presumably fertilizer) was 2.7. Other studies also typically find a high value for K for modern inputs in post-green revolution settings (Bliss and Stern, 1982 (wheat); Khan and Young, 1979 (all crops); Armenia, 1983 (rice)).[19] These studies also measured average allocative errors for the total sample. Even if, on average, farmers are efficiently allocating resources, individual farmers may exhibit substantial variation from the optimum.

The use of the profit function approach has been proposed as a means of measuring both technical and allocative efficiency (Yotopolous and Lau, 1979), although its application requires cross-sectional variability in prices of variable inputs. Application of the profit function in modernizing agriculture gives somewhat conflicting results. Junankar (1980a,1980b) rejects the hypothesis that Indian farmers in two separate samples (wheat and rice areas, respectively) are economically efficient while Yotopolous and Lau (1979) and Jamison and Lau (1982) accept the hypothesis for other Asian settings.

In a combination of the above approaches, Ali and Flinn (1986) estimated a frontier profit function for rice in Pakistan using a stochastic specification. Average economic inefficiency was estimated at 28% with over half of farmers showing at least a 25% loss in efficiency. Education was the dominant factor explaining differences in efficiency in this sample of farmers.

Another approach is to include farmers' knowledge and education as variables in the production function to measure relative economic efficiency. Jamison and Lau (1982) review 36 such studies of the effect of education on agricultural productivity and find that education has a statistically significant or important impact on technical efficiency

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[19]For reviews of earlier studies, see Dillon and Anderson, 1971 and Shapiro, 1979.

in all but four of the studies. More importantly, the average increase in productivity due to completion of basic education (4-6 years) was 9.5% in a modernizing environment versus 1.3% in a traditional environment, thus supporting Schultz's (1975) hypothesis. The studies from Asia showed a particularly strong and consistent effect of education (see Phillip's (1987) comments on Jamison and Lau) and more recent evidence from Asia further confirm these findings (Antle, 1984; Pudasaini, 1983; Butt, 1984; Jamison and Moock, 1984). There is thus strong evidence of the importance of education in farmer efficiency in post-green revolution settings.

There is little evidence from these studies on <u>how</u> schooling affects agricultural productivity. Recently, Jamison and Moock (1984) have attempted to establish the intermediate outputs of formal education in Nepal that have a bearing on efficiency. These can be classified into the development of basic competencies (e.g., literacy, numeracy and cognitive skills) and the transmission of technical information. They found that numeracy had a large and significant effect on efficiency in wheat production, although their results were inconclusive for other educational outputs and other crops. Fuller (1983) concluded that literacy (in this case from adult education) increased economic efficiency of Bangladesh rice farmers. A better understanding of the pay-offs to the different products of schooling has an important bearing on policy interventions to improve efficiency since some of these products can provided by alternatives to formal schooling (e.g., extension or mass literacy programs).

Schultz (1975) and Welch (1978) have hypothesized that the main benefit of education in a dynamic agriculture is to increase the allocative ability of farmers. The evidence from Asia in this respect is less conclusive. Pudasaini (1983) in Nepal concluded that the allocative effect of education was more important than the effect on technical efficiency but Jamison and Lau (1982) in Thailand and Wu (1977) in Taiwan found no effect of education on allocative ability.[20] As yet there are no studies from developing countries relating education to efficiency in specific management decisions (e.g. the study of pesticide use and integrated pest management in the U.S. by Pingali and Carlson, 1985) or in adjusting specific inputs to a rapidly changing environment (e.g. Huffman, 1977 again for the U.S.).

Two studies (Bernsten, 1977 and Bhati, 1973) have included a measure of farmers' technical knowledge in the production function and in both cases (for rice in the Philippines and Malaysia, respectively) the effect on productivity was highly significant

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[20] These results are subject to the problem of input aggregation discussed above which leads to over-estimation of technical efficiency relative to allocative efficiency.

and strongly positive.[21] Bernsten (1977) further showed that farmers' technical knowledge was related to socio-economic characteristics of the farmer, such as age, experience and extension contacts, although educational level did not emerge as a significant factor.

The production function approach reviewed here is a blunt instrument for analyzing complex farming systems and crop management issues, characterized by substantial heterogeneity in resources within farms and variability in crop response over seasons. These studies generally employ quite aggregate specifications and show little appreciation for the complexity of technical relationships in agriculture.[22] These problems are most pronounced for farm-level as opposed to crop-specific production functions. As Upton concludes, "the farm is a highly complex and dynamic system and any attempt to represent such a system by a single equation is unlikely to be operationally meaningful" (Upton, 1979). In addition, the successful application of production function analysis with cross-sectional data depends on the existence in the sample of substantial variability between farmers in technical and/or allocative efficiency (Doll, 1974).

In recent years, a number of multi-disciplinary farm-level studies have been initiated that combine the insights of agronomists and economists and integrate on-farm survey and experimental data. These studies not only estimate the productivity "gap" but also help identify the specific sources of inefficiencies.

Table 5 summarizes results of integrated survey-experimental research at the farm level for irrigated wheat in Pakistan (Byerlee, et al., 1986) and rice in the Philippines (Herdt and Mandac, 1981). A complex of factors is shown to explain variation in yields between farmers as well as the difference between farmers' yields and what is potentially attainable and profitable given available technology. These factors include exogenous variables related to soil type, availability of irrigation water, agronomic variables such as pest incidence and plant density, and production practices such as crop

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[21] A similar approach by Jamison and Moock (1984) showed no effect of farmers' technical knowledge on productivity. Both Bhati (1973) and Jamison and Moock (1984) measured technical knowledge in terms of farmers' knowledge of research recommendations. This assumes that research recommendations are in fact relevant to farmers (see Chapter 4).

[22] The major exceptions to this generalization is the series of studies on rice sponsored by the International Rice Research Institute (e.g. Kalirajan and Flinn, 1983; Lingard et al., 1983; Flinn and Ali, 1986).

Table 5: **Summary of Two Integrated Surveys - Experimental Studies of Farm Level Productivity of Wheat and Rice.**

	Irrigated Wheat	Rice
Location	Rice/wheat area, Pakistan	Philippines
Years	1983-86	1974-77
Number of farmers surveyed	300	50
Number of on-farm experiments	100	76
Factors influencing yields		
1. Exogenous	Soil texture Irrigation system	Soil texture Solar radiation
2. Agronomic problems	Grassy weeds Plant density	Moisture stress Diseases
3. Production practices	Crop rotation Planting date Nitrogen Variety Tillage	Fertilizer Weed control Insect control Age of nursery
4. Interactions	Several	Many
Opportunities to increase productivity		
1. With existing technology	1. Nutrient balance 2. Weed control	Fertilizer application method and timing
2. With emerging technology	Direct drilling with zero tillage	na
Yield gap[a]	40%	33%
Major constraints	1. Farmers' technical knowledge & skills 2. Input distribution	Farmers' technical knowledge & skills

[a] [(Potential yield/farmers' yield)-1]*100
na = not available

Source: Wheat - Byerlee et al. (1986); and Heisey et al. (1987). Rice - Herdt and Mandac (1981).

rotation, planting date, and nutrient balance (see Table 5). The average yield gap between potential yields that were considered profitable and feasible from on-farm experiments and surveys, and farmers' current yields is 30-40 percent in each case. Much of this gain can be achieved within existing expenditure levels by a better mix and timing and method of application of inputs. Deficiencies in technical knowledge and skills of farmers were identified in both cases as important factors determining productivity levels.

In both of the above studies the productivity gap was expressed through a yield gap between farmers' actual yields and economically feasible yields. In several post-green revolution areas (e.g. parts of the Indian Punjab, Northwest Mexico, Central Luzon of the Philippines) farmers' yields are now close to this potential and the productivity gap is expressed in high costs of production relative to the potential (Kahlon, 1984; Byerlee and Longmire, 1986). Here better information may substitute for high input use, for example, in the form of lower doses of fertilizer for crops grown in multiple cropping patterns with substantial nutrient carryover, or in integrated pest management strategies to reduce pesticide use. For example, Kenmore (1986) estimates that 50 percent of insecticide applications in rice in Southeast Asia are unnecessary, and that better farmer information and skills in identifying the threshold pest population for economic application of pesticide would help reduce this inefficiency.

In sum, the evidence from Asian farm-level research points toward substantial opportunities to increase productivity through improved economic efficiency. The evidence seems to indicate that technical inefficiencies occur more consistently and on a large scale than allocative inefficiencies. However, this finding must be qualified by the difficulties discussed above of separating the two types of inefficiencies in empirical studies due to the problems in specifying the production function (i.e. level of aggregation of inputs). But whatever the type of inefficiency, differences in information and skills of farmers are usually identified as the major factor explaining the variation in efficiency between farmers.

This does not negate the Schultzian position of small farmers of the Third World as rational decision makers responsive to economic incentives. Rather, it suggests that constraints in development of appropriate rural institutions to service farmers' increased information and skill requirements, limit farmers' ability to exploit these opportunities to improve economic efficiency and make rapid adjustments in a technically and economically dynamic environment. This is not to say that other factors such as market failure in input markets, capital constraints and risk aversion are not important, but even these factors may interact closely with decisions on acquisition of information (Feder and Slade, 1984).[23] Moreover, these constraints due to capital and risk aversion have received relatively greater attention from researchers and policy makers than constraints due to information and skills.

[23]Evidence, however, suggest that risk aversion plays a relatively minor role in input allocation decisions (Roumasset, et. al., 1987).

IV. THE FORMAL INFORMATION SYSTEM - INSTITUTIONAL PERFORMANCE AND INDUCED INSTITUTIONAL INNOVATIONS

The constraints on improving productivity analyzed above reflect inadequacies in rural institutions - agricultural research, extension and education - that participate in the development and dissemination of information and skills to farmers. This set of institutions is often referred to as the formal information system to differentiate it from farmers' informal learning-by-doing and experimentation.[24] Institutional changes often lag in adapting to technical change; however, these institutional changes are needed to realize the full potential provided by new technology (Ruttan, 1978). This chapter examines some of the problems of these rural institutions in serving a dynamic post-green revolution agriculture and also analyzes recent institutional innovations aimed at correcting some of these deficiencies.

A. Adaptive Research[25]

In most countries, the agricultural research system is a major source of improved technical information for farmer decision making. For simplicity, agricultural research can be categorized into science-oriented research to improve the understanding of physical and biological processes, applied research to generate new inputs or component technologies, and adaptive research to provide better information on crop management at the local level, to extension and to farmers. Adaptive research should then play the primary role in generating useful information for farmers to stimulate changes in management and input use to increase economic efficiency. Yet according to a recent World Bank review, adaptive research is generally "the weakest, most neglected and most confused aspect of national research systems" (World Bank, 1985, p. 54). This situation is in contrast to the relative strength of applied research, particularly plant breeding research. In part stimulated by the successes of semi-dwarf varieties in the green revolution, most Asian countries now have reasonably well-established plant breeding

[24]The private sector, such as input suppliers, can also be regarded as part of the information system and will be examined later.

[25] Much of the information in this section is based on the author's personal involvement in adaptive research in several Asian countries.

programs for major food crops capable of sustaining a continuing flow of improved varieties.

The "poverty" of adaptive research efforts reflects the common approach of conducting a series of well-controlled experiments (usually on the experiment station) and then issuing technical information in the form of recommended "packages" of practices for large heterogeneous groups of farmers. Typically, each discipline - agronomy, soil fertility, weed science, entomology, water management, etc. - develops recommendations for practices related to that discipline and these are then "packaged" without considering interactions between technological components or between commodities in the farming system. Social scientists who might contribute to the identification of farmer problems and relevant solutions to these problems have typically not been included in this research process.

This approach to adaptive research has a number of problems:

1) The information is often not appropriate to farmers because: a) uniform recommendations are made for large heterogenous groups of farmers, b) recommendations are generated on the experiment station often under conditions very different from farmers' fields or c) the socio-economic circumstances of farmers are not adequately considered , especially those due to complex interactions in the farming system.
2) The recommendations promote a package of several technological components even though there is considerable evidence that farmers adopt these components in a stepwise manner (e.g., Byerlee and Hesse de Polanco, 1986; Crouch, 1981; Herdt, 1987).
3) The information is condensed to simple "recipes" even though farmers require a much broader range of information and skills to efficiently use complex technologies and to adapt them to their own economic circumstances, fields and seasonal conditions.

These problems reflect less the quantity of adaptive research (although expenditures on applied research have probably expanded more rapidly than expenditures on adaptive research) than the quality of adaptive research.[26] For example, thousands of fertilizer experiments are conducted annually on irrigated wheat and maize in Asia, yet

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[26] For example, classifying research on maize and wheat into technology generating (applied research) and information generating (adaptive research) indicates that about half of all research expenditures in Pakistan are allocated to adaptive research.

many fertilizer recommendations still lack relevance to farmers' circumstances (Eklund, 1983). Hence, in many areas, a critical weakness in the farm information system is the inadequacy of the research system in generating a stream of relevant and useful information for farmers.

B. Agricultural Extension

The poor quality of technical information provided by adaptive research is often compounded by weaknesses in the quantity and quality of extension advice. Extension has often assumed a very secondary role in the post-green revolution era. The rapid spread of the new seeds and fertilizer from farmer to farmer with only minimal input by extension (Lowdermilk, 1972) seemed to bear out the image of the small farmer as poor-but-efficient and to down-play the role of extension. A good technology will "sell itself" might be the logical conclusion from the green revolution experience. The widespread involvement of extension agents in input delivery, credit programs, and petty rural administration also allowed little time for their primary role - information dissemination to farmers.[27] And in any event, much of the technical information to be disseminated on cultural practices was not appropriate to the circumstances of farmers, leading to a credibility problem for those extension agents who did become seriously involved in information dissemination.

The research system has also encouraged extension methods based on a "recipe" approach to crop production whereby farmers are exhorted to use a rigid technical package which assumes that fixed technical coefficients apply to all farmers, fields, and seasons.[28] Yet, as shown above, crop management is far too complex for a formula approach to be used. Typically this formula or recipe has also stressed information on types and quantities of inputs aimed at increasing yields through use of higher levels of inputs. Opportunities to increase allocative efficiency within existing resource levels and to improve technical efficiency have largely been neglected. Emphasis on communicating recipes has also been at the expense of broader extension education to improve farmers' understanding of new technology, and enhance farmers' technical and

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[27]See Benor, Harrison, and Baxter (1984), Mohammad (1984) and Roling (1981) for brief reviews of problems in extension systems.

[28]For example, in much of South Asia, an annual workshop is held to formulate a "package of practices" for the coming crop season.

managerial skills. This understanding and these skills are needed if farmers are to adapt prescriptive information to their own needs and improve their technical efficiency and allocative ability. Moreover these skills should have a much lower rate of obsolescence in a dynamic world than prescriptive-type information (Welch, 1978).

Many factors including inadequate training, inappropriate organization and lack of incentives underlie the poor performance of many extension programs. However, it is also widely observed that village level extension agents often lack even the basic skills needed by farmers for effective management of modern inputs. Training courses run by IRRI (Matheson, 1984) and CIMMYT (in Pakistan) have both observed that most extension entrants to these courses are not able to calculate dosages correctly for even basic inputs such as fertilizer, nor are they knowledgeable of the appropriate pesticide for a given pest. Job incentives have not promoted a problem-solving approach to providing farmer advice, and wide dispersal of extension agents in the villages complicates management and supervision. In addition, the lack of linkages between research and extension systems has often been a serious constraint on the effectiveness of both systems.

These weaknesses in the extension system account for the rather variable findings on the returns to extension in developing country agriculture (Perraton et al, 1983; Huffman, 1978; and Lockheed et al., 1980) and even the suggestion that there may be over-investment in extension (Evenson, 1986). For example, Jamison and Lau (1982) in their review of 16 studies that analyzed the effect of extension contact on productivity, found only eight studies with a positive extension impact. Perhaps reflecting this variable performance, there has been a general decline in extension expenditures relative to research. In countries of South and Southeast Asia where the green revolution had its greatest impact, real research expenditures almost tripled from 1970 to 1980 while expenditures on extension stagnated or even declined in some cases (Table 6). This change in emphasis also represents a backlash against the heavy emphasis on extension in the community development strategy of the 1950s and early 1960s. In this period, with few viable technological improvements (due to neglect of research) for "poor-but-efficient" farmers operating in a traditional setting, results of this strategy were generally disappointing (Holdcroft, 1984).

Table 6: Growth Rates of Real Expenditures on Research and Extension, South and Southeast Asia, 1959-80.

	Research	Extension
	[%/year]	
South Asia		
- 1959 - 1970	7.4	4.0
- 1970 - 1980	9.7	-.6
Southeast Asia		
- 1959 - 1970	13.1	9.3
- 1970 - 1980	10.2	1.4

Source: Calculated from Evenson (1986)

C. Recent Institutional Innovations in Research and Extension Systems

Without an effective "formal" information system represented by adaptive research and extension, a large part of the burden of technology adaptation has fallen on farmers' own informal learning-by-doing. Indeed, deficiencies in the formal information system have sometimes led to a credibility problem among farmers and probably discouraged them from seeking information through the formal system. Not uncommonly, farmers are ahead of the research and extension system in technology adaptation (Biggs and Clay, 1981) although this "informal" system is not adequate to keep pace with the complexity and dynamics of post-green revolution agriculture. However, the emergence of a continuing stream of new technology and the opportunities to improve productivity through increasing the technical information and skills of farmers, have led to institutional reforms in adaptive research and extension. Two of these - a) the farming systems perspective in adaptive research and b) the Training and Visit System of extension - are briefly reviewed below.

1. The Farming Systems Perspective in Adaptive Research

A major innovation in recent years has been the farming systems approach to adaptive research that emphasizes a strong farmer focus and problem-solving orientation to research (Simmonds, 1986; Byerlee, et. al., 1982).[29] In a farming systems approach, explicit efforts are made to understand the complexity of interactions characteristic of small farmer systems as a basis for planning research. Adaptive research is largely carried out in farmers' fields with farmers' participation, using survey and experimental methods to identify and solve constraints limiting productivity at the local level. The research objectives call for a multi-disciplinary problem-solving approach involving both technical scientists (e.g., agronomists) and social scientists (e.g., economists).

Adaptive research programs based on a farming systems perspective are being tested or have been adopted in most Asian countries and promise to increase both the quality and quantity of technical information for farmers. Onfarm experiments and a farmer-orientation in design and analysis of experiments improves the relevance of production recommendations to farmers. Decentralization of research by focusing on relatively homogeneous farming systems or recommendation domains ensures that information is tailored more specifically to farmers' needs. At the same time, there is a move away from the package approach to providing recommendations to an approach emphasizing a few priority stepwise changes from farmers' current practices.

The farming systems perspective in adaptive research can be viewed as a way of combining the contributions of farmers' informal learning-by-doing and the scientific knowledge and experimental methods of researchers. The approach calls for researchers to integrate the knowledge and experience that farmers gain in adapting new technologies into the design of experiments and the formulation of recommendations.

Returns to adaptive research conducted with a farming systems perspective are potentially high although to date, there are few quantitative estimates of the pay-offs to this approach to research.[30] Returns are expected to be especially high in the irrigated post-green revolution areas, where a substantial amount of technology is available to be "adopted" and "adapted". Moreover, the relative uniformity of irrigated areas ensures that information generated will be relevant to a large number of farmers. To meet the complexity of crop management decisions, adaptive research programs increasingly

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[29] The farming systems perspective has emphasized adaptive research although the approach is also very relevant to setting priorities for applied research programs, such as plant breeding (e.g. Byerlee, Akhtar and Hobbs, 1987).

[30] Martinez and Sain (1983) estimate high pay-offs to a pilot project in Panama.

provide recommendations conditional on specific field characteristics (e.g. land type, crop rotation) and seasonal pest and weather conditions.[31]

Successful adoption of this institutional innovation in adaptive research requires appropriate incentives for location-specific problem-solving research. This goes against traditional centralized research planning, fragmentation of research by disciplines and commodities, and promotion based on publications rather than solutions to farmers' problem. The weakness of the farming systems approach is that to-date, it has often been implemented, usually with donor support, as a project outside of the mainstream institutional structure of agricultural research and has not really addressed the fundamental weaknesses of research incentives (i.e. a lack of a problem-solving and client orientation and the need for a systems perspective) that have resulted in poor quality technical information for crop production (Hienemann and Biggs, 1985). As yet institutional arrangements have not evolved where the major client of agricultural research systems, the small farmer, can formally or informally pressure these systems to address their priorities.

2. The Training and Visit Extension System

The most important recent innovation in extension systems is the Training and Visit (T & V) System now adopted in many Asian countries usually with World Bank funding (Benor, Harrison, and Baxter, 1984). The T & V system addresses a number of the basic weaknesses in traditional extension systems through the following measures:

1) Non-extension duties (e.g. credit supervision, input distribution, statistical data collection) are removed from the workload of extension agents to allow them to focus on information dissemination.
2) Extension agents are unified under a strong management system and well defined duties and routines are assigned to each level of the hierarchy.
3) Regular training programs are established to upgrade the skills of extension workers.
4) The ratio of village extension agents to farmers is increased and extension agents are required to regularly visit "contact" farmers in each village. Improved mobility (e.g. bicycles) is often provided for this purpose.
5) Efforts are made to bridge the gap between adaptive research and extension.

[31] See Byerlee (1987) for a more comprehensive discussion of these issues.

Early experiences with the T & V system indicate mixed successes. Feder, Lau and Slade (1985) estimated a 6-7% increase in wheat productivity in Haryana State of India due to improved technical efficiency attributed to introduction of the T & V system. This implies high returns to the investment in this institutional innovation.[32] Preliminary data from some other states of India (Shingi et al., 1982; and Benor, Baxter and Harrison, 1984) as well as from Nepal (Jamison and Moock, 1984) support these findings. However, other observers in India (Moore, 1984; Howell, 1982) note that extension advice is still not relevant to many farmers and quantitative targets for farmer contacts are emphasized over the quality of information disseminated. Elsewhere, the results are less encouraging. Khan et al. (1984) found no effect of the T & V system in Pakistan's Punjab on either productivity or knowledge of farmers. The lack of a strong adaptive research program may partly explain the failure of the T & V system in Pakistan.[33] Overall, the experience with T & V extension is still too short to draw definite conclusions. Institutions are notably slow to evolve and especially when an innovation emphasizes improvements in human capital and management it may take a decade or more before the reforms become effective.

A major shortcoming of the T & V system for farmers in post-green revolution agriculture in Asia is its emphasis on the communication role of extension - that is, transferring specific "messages" as prescriptive information to farmers. It has yet to meet the need for farmers to have a better understanding of new technology and improved technical and managerial skills. In post-green revolution areas these principles and skills include diagnostic skills on factors reducing yields, technical knowledge of chemical inputs such as residual effects or downside risks from untimely application, as well as specific technical skills such as calibration of knapsack sprayers or computation of nutrient doses for compound fertilizers. Eventually, as farmers' technical skills improve, extension efforts might shift to enhancing farmers' managerial skills, including the ability to recognize problems and seek out additional information. This change in

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[32] Feder, Lau, and Slade (1985) estimated that returns on investment were at least 15% annually within a 90% confidence interval. This is probably a conservative estimate since they did not attempt to measure improvements in allocative efficiency.

[33] In Pakistan, separate adaptive research programs were introduced with the T & V system and these programs have yet to produce useful recommendations for farmers. In addition, there appear to be significant lapses in extension management. In the survey by Khan et al. (1984) only half of farmers designated by extension as "contact" farmers were aware that they were in fact contact farmers with special obligations to disseminate extension messages to other farmers.

emphasis from communication of crop production "recipes" to education in crop production principles and skills recognizes the growing complexity of crop management and the need for farmers operating different land types and crop rotations in an uncertain and dynamic environment, to adjust technical information to their own specific situation.

The shift in extension emphasis from a communication role to more of an educational role requires continual upgrading of the quality of extension staff.[34] One successful example, has been training in the complex principles of integrated pest management for rice in several countries in southeast Asia. This program has generated a payoff of 440 percent (undiscounted) due to a reduction in pesticide use (Kenmore, 1986). It is significant that a large part of this program was devoted to field-oriented training of both extension agents and farmers in broad principles of pest management as well as specific skills in pest identification, subjective scoring of pest densities and pesticide use.

Institutional innovations in extension also suffer similar problems to adaptive research in being imposed from the "topdown", usually with donor support. The problem is how to maintain a client orientation to extension in the longer run. Farmer and village level associations which can exert pressure on the performance of local extension agents have had some success in performing this role (Lionberger and Chang, 1970; Stavis, 1979) but are not a part of the T & V system.

D. Rural Schooling

Beyond adaptive research and extension systems, the other major source of increasing knowledge and skills for a scientific agriculture is rural schooling. Expenditures on rural education have been one of the fastest growing sectors in the developing world and primary school enrollments have increased steadily. In the period 1960 to 1982 the proportion of children enrolled in primary schools increased from 55% to 75% in South Asia and from 83% to 101% in Southeast Asia.[35] Studies of economic

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[34]This change in roles also implies changes in extension methods. Mass media which may be appropriate for communicating messages is probably less effective for teaching principles and skills than informal and formal training programs for individual farmers and groups of farmers.

[35] Calculated from World Bank, World Development Report, 1984, Table 25.

returns to education also show attractive pay-offs to investments in basic education, generally (Colclough, 1982) and in agriculture, specifically (Jamison and Lau, 1982). To the extent that these national figures reflect expenditures and returns in rural areas where the majority of the population resides, it would be easy to conclude that institutional changes are already underway in the educational sector to meet the growing need to increase the general educational level of farmers. However, these data are misleading for a number of reasons.

First, there are still large numbers of farmers in post-green revolution areas, especially in South Asia, who lack basic numeracy and literacy skills (Table 7). Adult literacy rates in rural areas of Pakistan, Bangladesh and Nepal average 25% or less and in northwest India are less than 50%. Even if most of the children of these farmers attend school and complete a basic education it will require at least another generation to achieve a minimally educated population of farmers. Added to this is the problem that drop-out rates even for primary schooling, are often close to 50% in rural areas.

Table 7: Percent Adult Population (25+ years) Who Have Attended School in Selected Asian Countries.

	Year	Percent Attended School
South Asia		
Bangladesh	1974	18
India	1971	21[b]
Nepal	1971	4
Pakistan	1981	18
Sri Lanka	1971	68[b]
Southeast and East Asia		
China	1982	55
Indonesia	1980	55[b]
Korea	1980	80
Philippines	1975	86
Thailand	1980	79

[a]Figures are averages of male and female adults. Especially in South Asia, female education is much lower than for males.

[b]Rural population only.

Source: United Nations, Demographic Year Book, New York, 1983.

Second, there is now growing concern that the quality rather than the quantity of education may be a major limitation (Behrman and Birdsall, 1983; Heyneman, 1983). Educational quality is difficult to measure and even more difficult to relate to agricultural productivity. Even evidence on returns to higher levels of education (presumably a proxy for quality, at least for basic numeracy and literacy skills) is scanty and conflicting for agricultural settings. Butt (1984) found a significantly higher productivity of farmers with secondary schooling relative to primary school education in Pakistan while Kalirajan and Shand (1985) in India found no impact of educational level on agricultural productivity from primary school to university level. We would expect that increasing complexity of crop management in post-green revolution agriculture would lead to increased returns to quality and level of education. Heyneman (1983) has expressed educational requirements for different levels of agricultural technology that suggest a minimum of lower secondary school education for much of irrigated Asia.[36] These standards are probably too rigid since extension in its educational role can partly substitute for formal schooling, a theme to be addressed in Chapter 5.

Finally, related to the issue of educational quality is the fact that both private and public demand for education has largely been driven by the urban employment market, rather than agricultural employment (Todaro, 1985), presumably because returns to education in urban employment are perceived to be higher than in farming. Given the evidence that both social and private returns to education in a modernizing agriculture are quite high (Jamison and Lau, 1982), this suggests a lag in adjustment of rural household investment decisions to the new situation in the agricultural sector. It also increases the rate of out-migration of educated youth, especially those with secondary schooling, beyond what might be socially desirable (Todaro, 1985) and depletes the stock of human capital needed for sustaining agricultural productivity increases.

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[36]For irrigated post-green revolution areas, Heyneman (1983) (citing A. Harma) gives the minimal requirements as: mathematics, independent written communications, high reading comprehension, ability to research key words and concepts; elementary chemistry, biology and physics. Leaf (1984) suggest somewhat similar needs for farmers in the Indian Punjab.

V. FARM INFORMATION AND SKILLS: IMPLICATIONS FOR DEVELOPMENT STRATEGY

The critical importance of farmer information and skills in maintaining productivity increases in post-green revolution agriculture has far-reaching implications for the design of agricultural development strategies. The total information and skill system consists of public sector institutions, the private sector and farmers, as well as policies which affect the technical and economic environment in which these institutions and agents operate (Figure 2). The development of an appropriate strategy to create an effective information and skill system depends on four key inter-related issues discussed in this section.

1) Within the formal information system of the public sector, what is the appropriate mix of adaptive research, extension and education to exploit the complementary and substitution relationships between these different types of investments? What institutional mechanisms are available to promote complementarity?
2) What is the potential role of the private sector (input suppliers or specialized information markets) in complementing and eventually substituting for public sector information services?
3) To what extent can other policies substitute for the formal information and skill system either through reducing the cost of farmers' own informal learning and experimentation, or through applied research efforts to develop less management-intensive technologies?
4) What are the equity implications of increasing returns to information and skills in post-green revolution agriculture?

A. Integrating Research, Extension, and Rural Schooling

Farmers in post-green revolution agriculture require a farm information and skill system that a) generates and communicates useful technical information on a continuing basis, b) develops farmers' understanding of new technologies, c) provides basic literacy, numeracy, and cognitive skills, and d) develops farmers' technical and managerial skills. Table 8 summarizes the role of each institution in providing these products.

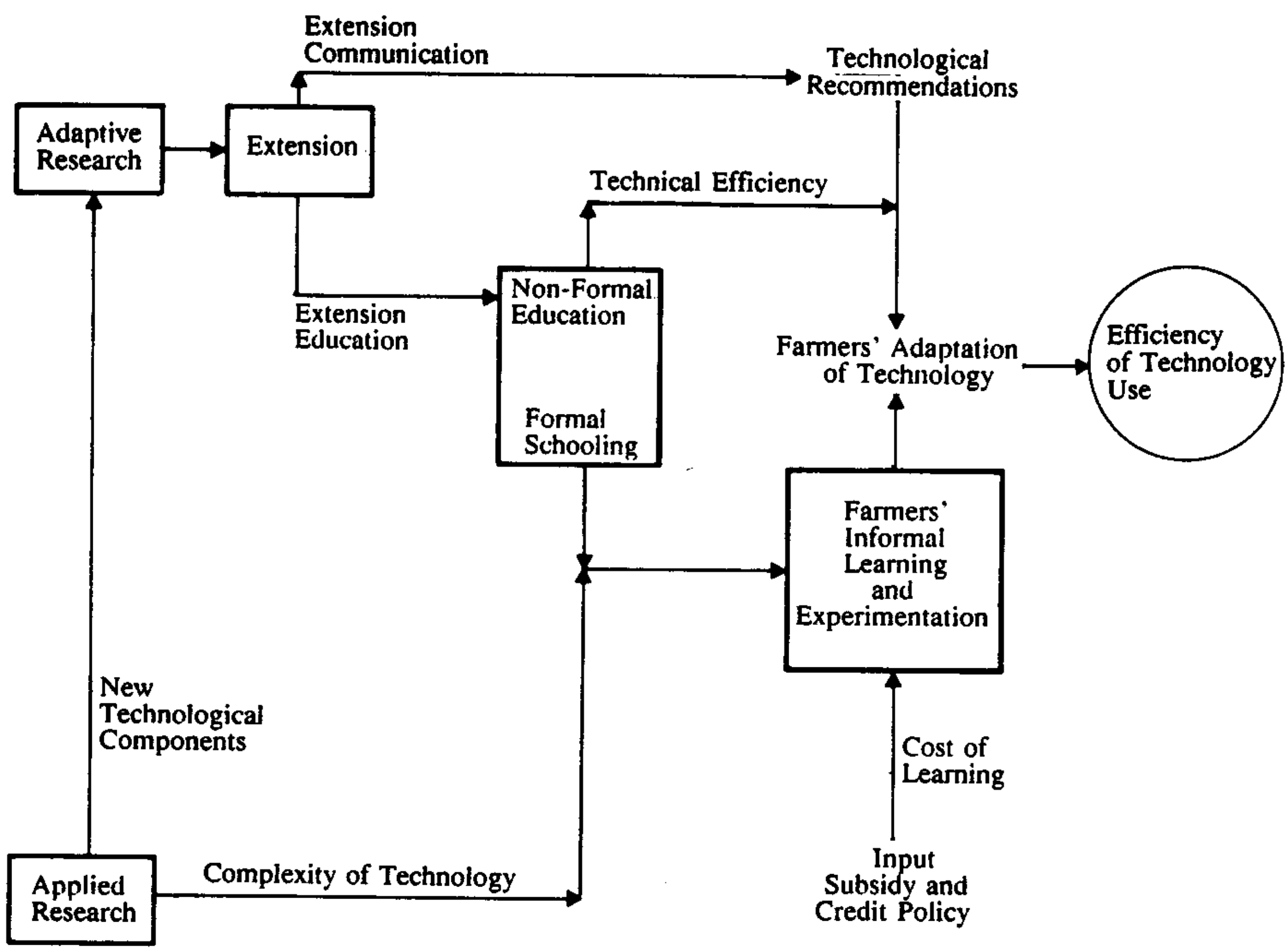

Figure 2. Components of farmers' information and skill system.

Table 8: **Institutions and Functions Servicing the Information and Skill Needs of Farmers.**

	Institutions		
	Adaptive Research	Extension	Schools
Functions	(** Main Role)	(* Secondary Role)	
Generating technical information	**	*[b]	
Communicating technical information	*[a]	**	*
Developing agriculture-specific skills (technical & managerial)	*[a]	**	*
Developing general skills (literacy, numeracy, etc.)			**

[a]Through involvement of farmers in adaptive research

[b]Through farmer testing, feedback and comparisons across farmers.

A strategic policy question is the relative priority that needs to be given to each institution and function at different stages of development, and in particular in the post-green revolution era. Much depends on the extent to which the various elements are regarded as substitutes or complements.

Given the management intensity of many second generation technologies, adaptive research and extension are expected to be highly complementary. Increasing amounts of information generated by adaptive research programs will be wasted or will diffuse too slowly (and possibly become outdated) without a strong extension input. Likewise, extension programs will have little impact and may lose credibility if they do not have useful and relevant information to extend. To a limited extent, extension might operate independently of research by utilizing experiences of successful or innovative farmers in formulating extension advice. The relatively high degree of variation in production techniques between farmers (as seen earlier in Table 2) suggests that this avenue could be useful.[37] However, this is a short term solution that gives rapidly diminishing returns unless new information is continuously supplied by research.

To exploit their complementarity, adaptive research and extension must be closely linked. One of the major problems in most countries is the lack of effective linkages between research and extension (e.g. World Bank, 1985; Howell, 1982). Often they are institutionally separated, with extension in the Ministry of Agriculture and research in a parastatal organization. Differences in incentives and prestige also undermine working relationships. Many research systems, believing that there is a wide "technological gap" that is not being effectively addressed by existing extension systems, have established their own technology transfer and extension activities, such as the "Lab-to-land" program in India and "crop maximization" programs in Pakistan (Mohammad, 1984).

It is a feature of both the farming systems perspective in adaptive research and the T & V extension system that they emphasize close research-extension linkages, especially in verification of technology at the farm level. Researchers are also expected to play a leading role in upgrading the knowledge and skills of extension workers through training programs. Despite this emphasis, poor linkages between research and extension remain a major weakness of most farm information systems (Cernea et. al., 1983; Howell, 1982). This weakness is most apparent in feeding back information from farmers via extension to research. A client-oriented extension system with farmers able to influence extension performance (e.g., through farmer associations) and extension able to influence research priorities is probably one of the most effective models for farmers to exert pressure on research (e.g., Lionberger and Chang (1970) for Taiwan).

Whether extension and formal schooling are complements or substitutes is also a critical policy question. The relationship between them is likely to be quite complex. To the extent that extension emphasizes its communication function, farmers receiving the information may use it more effectively if schooling helps them to understand the rationale behind the recommendation. Where extension emphasizes its educational role, it could also partly substitute for formal schooling. However, in either its communication or educational role, the cost of extension should be significantly reduced by competencies in literacy, numeracy and cognitive skills imparted through schooling.

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[37] This is only true to the extent that variation in production technique reflects differences in information and managerial skills and not micro-environmental variation (e.g., land type, soils). Recent experiences in Pakistan indicate that variation in yields between fields can generate hypotheses on the response to different management practices (Hussain et al., 1986; Byerlee et al., 1986).

Hence, extension might be able to substitute for education in the early stages of development, but diminishing returns will soon be reached unless there are advances in basic education. In a dynamic agriculture where extension advice is subject to rapid depreciation, the viable skills will be those of "learning to learn" imparted by formal schooling (Welch, 1978). Sims (1985) suggests that one of the reasons for the higher productivity of farmers in the Indian Punjab compared to the Pakistan Punjab is that Indian farmers have better technical information, not because of better extension (which she rates as poor in both cases), but because the higher level of education of the Indian farmers acts as a substitute for extension. Better educated farmers can exploit a wider range of information sources. At the extreme, the role of extension may decrease for highly educated farmers who have access to a wide range of alternative sources of information.[38]

Empirical studies of the interaction effects of education and extension on agricultural productivity reflect these conflicting trade-offs. Some studies show that education and extension are substitutes (e.g., Moock, 1981) while others find little effect (e.g., Pudasaini, 1983). More research is needed to determine the extent to which extension programs might substitute for education at different levels of agricultural development.

Where educational levels are very low, especially in South Asia, there is a danger that even if recent institutional innovations in research and extension are successful, the low level of education of most farmers will be a binding constraint on rapid increases in productivity in the medium term. Formal schooling is a long term investment that will only affect the productivity of the next generation of farmers. In post-green revolution areas, dramatic changes in managerial requirements have taken place within one generation of farmers as shown by the wide array of purchased inputs already adopted or in the process of adoption. The question then arises on the role of adult education programs as a means for effecting short run improvements in general educational levels. Some limited evidence exists that adult literacy classes have positive effects on agricultural productivity (Fuller, 1983; Jamison and Lau, 1982) but as yet too little is known about the specific products of formal schooling that increase agricultural productivity, and the extent that these products can be transmitted through adult education programs.

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[38]This may represent the situation of farmers in industrialized countries that own micro-computers and can use a wide array of information (Sonka, 1985).

Overall, the evidence suggests strong complementarities between each of the institutions and functions bearing on information and skills in agriculture (Table 8). Hence it will be important to identify the weak points in the system. To date, those involved in research and extension have often ignored the role of formal schooling while many of the studies of education and agricultural productivity have lacked an adequate base in technical agriculture.

B. The Private Sector and Information Generation and Dissemination

In industrialized countries the private sector plays a major and increasing role in the generation and transfer of better technical information to farmers (e.g. Ruttan, 1982; Bonnen, 1986; Turpin and Maxwell, 1976). It does this through its own adaptive research programs, advertising, promotion and demonstration programs, dissemination of information through input suppliers and by providing specialized information services (e.g., magazines, consultants, soil testing services etc.).

In post-green revolution areas, the private sector has often been slow to adopt these roles, despite the rapidly increasing use of purchased inputs and the associated demand for better information. The most obvious opportunity for the private sector is the dissemination of information in association with input sales, especially chemical inputs. Some studies do note the importance of input dealers as a source of information (e.g. Rogers and Meynen, 1975; Pontius, 1983) but they are often regarded by farmers as a secondary source of information (Heisey et al., 1987; Feder and Slade, 1985; Litsinger et al., 1980; Gill, 1982). A number of factors explain this anomaly. In the early stages of the green revolution, the public sector often played a major role in the delivery of inputs to farmers, often through the extension service. With demand for inputs and credit established and the need to move extension back to their basic task of information dissemination, the private sector has assumed a larger role in input dissemination. Hence, the private sector is often a relatively recent entrant in input distribution at the farm level, and needs to develop its own capacity and knowledge in the local use of the inputs. This is especially the case for input dealers in direct contact with farmers who are often local shop keepers whose major business is consumer goods.

Private firms must also establish credibility as a source of reliable information.[39] Private sector promotion of inappropriate chemicals and pressure (and even bribing) of

[39] Claims of adulteration of chemicals are widespread by farmers in many countries, and tests of inputs often confirm these claims (Goodell, 1984a; Hussain et al., 1985.)

public agencies to distribute a particular product through official credit programs are not uncommon. Even deliberate misinformation is reported, such as the distribution of a fungicide as a "growth enhancer" (Kenmore, 1986). There is also a natural tendency for chemical companies to recommend above-optimum doses and to prefer prophylactic treatments to treatments conditional on the specific farmer, field and seasonal circumstances (Zadoks, 1985; Kenmore, 1986).[40]

Despite these problems, the role of the private sector in distributing information in association with inputs is likely to increase, especially as specialized input dealers assumed a greater role in input sales. Hence efforts to train local input dealers in use of modern inputs offers a cost effective opportunity to improve information flows to farmers. For example, in Bangladesh, the government has arranged training programs for fertilizer distributors, while chemical companies are participating in training of pesticide dealers (C. Pray, personal communication). The increasing trend toward private sector involvement in applied research, especially in development of hybrids, should also provide more incentive for private sector extension initiatives. For example, a privately owned hybrid maize program in Pakistan's Punjab has been notably successful in raising productivity of maize in one area through employment of its own extension agronomists to advise farmers.

The combination of deficient public sector extension efforts and farmers' increasing need for technical information should also provide the environment for developing specialized information services by the private sector where farmers pay for information services. Such institutional arrangements are relatively rare for food crop production in developing countries. In commercial areas of northwest Mexico, Uruguay and Argentina, private consulting services play an increasing role in advising medium and large scale farmers. Likewise, there are examples of small farmers forming cooperative extension services paid for by members of the cooperative (e.g., the farm extension service for collective farmers in northwest Mexico, pest surveillance services in the Philippines and farmer association extension services in Taiwan.) Not surprisingly, these private extension and consulting services have a sound reputation for effectiveness. These institutional arrangements are likely to expand in other areas where there is a high payoff to better information and public extension services are not responding to this demand. However, the high relative cost of information for small farmers (Feder and

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[40]For example, farmers in the central plateau of Mexico have evolved an effective dosage of 2-4, D herbicide for wheat and barley which is less than one-half the dose recommended by the manufacturer.

Slade, 1984) limits the development of specialized markets for information for small farmer agriculture. Finally, where specialized technical skills are needed, such as in pesticide application, the private sector by offering contractual services for input application can also play a role in increasing technical efficiency. Specialized contractors with more information and experience, as well as more specialized equipment, should be able to substitute for farmers' lack of technical skills.

C. Substituting for Farmer Information and Skills

While it seems inevitable that increasing complexity and commercialization of agriculture will place greater demands on farmers' information and skills, there may be ways to partly alleviate these demands. Applied research and particularly plant breeding research can, and often is, aimed at the limited managerial capacity of small farmers.[41] For example, plant breeding programs for small farmers generally give much higher weight to pest resistance in varietal selection than similar programs aimed at commercial agriculture. This is partly to reduce expenditures on pesticides but it also substitutes for extension resources and the managerial capacity of small farmers.[42]

However, genetic resistance to many pests erodes over time (due to genetic adaptation by the pest population) so that a continual stream of new varieties is required to maintain pest protection. This wider selection of varieties tends to increase farmers' management complexity.[43] More importantly, for farmers who do not understand this breakdown in pest resistances, the challenge to plant breeders is even greater, since succeeding generations of varieties must have other superior traits, especially higher yields, to encourage rapid farmer adoption.[44]

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[41] Conversely in developed agriculture, plant breeding might aim at relatively high managerial capacity. For example, maize hybrids appear to be superior to open-pollinated varieties under high input and management but this difference is reduced at lower levels of management.

[42] For example, both CIMMYT and IRRI devote a large share of their crop improvement programs to genetic resistance to insects and diseases.

[43] In irrigated wheat, the expected effective life of a variety is about five years.

[44] Severe rust attacks in wheat occur only sporadically so that breakdown in rust resistance may not be obvious for some years. In Pakistan only 25% of farmers in one recent survey understood the potential breakdown of disease resistance and the need to continually update varieties (Heisey et al., 1987).

Broad adaptability of varieties is another trait which can partly substitute for extension and managerial capacity of small farmers. A broadly adapted variety that does well over a range of conditions reduces the complexity to extension and to farmers of recommending a number of individual varieties for specific conditions. For example, farmers often plant wheat in irrigated areas over a range of planting dates depending on the crop rotation in specific fields. Wheat breeders have traditionally developed separate varieties for normal and late planting. However, recognizing the managerial complexity of this strategy, breeders are now screening for single varieties that do well over a range of planting dates. Incorporating these breeding objectives to accommodate limited managerial capacity of farmers will, of course, be at the expense of more rapid growth in yield potential. However, where there is a wide gap between farmers' yields and potential yields of existing varieties this does not seem a high price to pay in the medium term.

Similar principles can be applied to chemical inputs. Pesticides which have a broad spectrum of application to several pests are easier for farmers with limited information to apply than narrow-spectrum pesticides that require accurate identification of the major pests and sometimes the mixing of two or more pesticides.[45] Likewise, "management neutral" pesticides that are effective over a range of dosages and times of application will require less technical skills for successful use.[46] Research on herbicides that can be applied in granulated form in irrigation water, and on slow-release nitrogen fertilizers are other examples of attempts to increase technical efficiency of input use, through reducing "management sensitivity". In general, these types of applied research activities aimed at reducing demands on extension services and farmers' management have, with the exception of genetic resistance to pests, received less emphasis than they deserve.[47]

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[45]This is particularly true for weedicides. Broad-spectrum insecticides are likely to have the disadvantage of killing predator insects as well.

[46]The sensitivity to dosage is important not only to allow for errors in calculating dosage and mixing the product, but also in ensuring a uniform response within the field. The latter is often a major constraint on technical efficiency in fertilizer and pesticide use. Simple methods of application, such as hand spreaders for broadcasting chemicals also have much potential for reducing technical inefficiencies by helping to provide a more uniform application of the product in the field.

[47]In many cases, this may reflect the fact that most research and development in agricultural chemicals is undertaken by the private sector for farmers in industrialized countries with quite different levels of technical skills and better access to technical information.

Another alternative to complement the formal information system is to reduce the cost of farmers' own learning-by-doing through subsidized input prices and credit programs. Subsidies on chemical inputs have been a widespread policy response. For example, fertilizer subsidies in Pakistan are strongly biased toward phosphatic fertilizers in the belief (debatable) that this is the limiting nutrient for most crops and regions. While these subsidies can help reduce subjective risk and speed early adoption, they are politically difficult to reduce and often account for a high proportion of total government expenditures for the agricultural sector. They may also eventually lead to input use above the social optimum (Stoneman and David, 1986) as has occurred in irrigated wheat in northwest Mexico (Byerlee and Longmire, 1986) and with pesticide use on rice in Indonesia. Hence, the high cost of these subsidies must also be evaluated against investments in adaptive research and extension to provide better information to farmers.

In addition to subsidies, governments frequently try to "force" the use of a technological package through "tied credit". In these programs farmers are required to use the recommended package as a condition for loans from official credit banks, usually at low or negative real interest rates. This system if enforced, allows little opportunity for farmers to adapt technology to their own circumstances and frequently leads to inefficient input use due to the inappropriateness of the recommended package to individual farmers. More importantly, by fixing the technological coefficients, farmers are discouraged from developing their own knowledge of the technology through informal experimentation on different levels and combinations of inputs under their own conditions (Scobie and Franklin, 1977).

D. Information, Skills, and Equity

The green revolution provoked major controversies on the equity effects of technological change. The accumulated body of evidence now indicates that small farmers quickly followed large farmers in using the seed and fertilizer technology, and that the technology was essentially scale neutral (Ruttan and Binswanger, 1978; Anderson et al., 1986; Lipton and Longhurst, 1985). There is substantial evidence that input and water supply systems and credit were initially biased toward large farmers, but in most cases this bias has been reduced over time, allowing small farmers to benefit equally (on a relative basis) from green revolution technologies. However, differential access to information and education is a continuing problem in post-green agriculture and increases the potential for growing inequities in the future. This is especially so in South Asia where large differences in farm size persist in many areas. Adaptive research that conducts most experiments on research stations is more likely to produce information of greater relevance (or less irrelevance) to large farmers. Likewise, extension programs in many countries have long been criticized for their emphasis on large farms (e.g., Roling et al., 1981). The diffusion model of innovations by identifying the "progressive" farmer as the innovator, has led to a deliberate bias of extension systems toward large farmers (Roling et al., 1981).[48]

There is also considerable evidence that access to education in rural areas is closely related to income, wealth and social status of rural households (Psacharopoulos and Woodall, 1985).[49] As the value of education in agricultural production increases with technological change, inequalities in schooling have potentially long run implications for rural equity.

Recent evidence from Pakistan demonstrates these biases (Table 9). Although education and literacy levels are generally low and extension services deficient, there is a marked bias in these services towards large farmers, most of whom had received some basic education and had some contact with extension.[50] But even most large farmers had not completed lower secondary schooling, which is hypothesized to be the minimal requirement for efficiently adapting post-green revolution technologies.

The payoff to better information and skills is also hypothesized to increase with farm size. Larger farmers have greater incentives to seek additional information, and this in part explains the earlier adoption of green-revolution technology (Feder and Slade, 1984). Farm size will also increase the returns to allocative ability and hence education (Welch, 1978).

Recent institutional innovations in adaptive research and extension can potentially reduce inequities in access to information and skills. The farming systems perspective in adaptive research emphasizes an understanding of small farmer circumstances as a basis for designing technologies. Hence the probability that research recommendations are

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[48]Most studies of recipients of extension advice provide empirical support for this bias (Garforth, 1982).

[49]For example, the school enrollment ratio for boys in Gujrat and Maharastra States in India for the wealthiest 10% of rural households (55%) is double that for the poorest 10% of households (23%). The differences is even larger for girls (Psacharopoulos and Woodall, 1985).

[50]These differences in access to information and education are rarely considered in the voluminous literature for South Asia on the efficiency of small versus large farms.

Table 9: Relationship Between Extension Contacts, Education, and Farm Size, Punjab, Pakistan, 1986.

	Farm Size		
	Less than 5 ha	5 to 10 ha	More than 10 ha
Percent farmers with extension contact in past year	13	24	61
Percent farmers literate	32	50	71
Percent farmers some secondary schooling	14	25	32

Source: Original data from survey of 300 farmers in 1986.

appropriate to small farmers is enhanced. The T & V extension system by increasing the mobility of extension workers and the number of field visits should allow greater access by small farmers to extension services. A key element in the T & V system, however, is the selection of "contact farmers" who receive the extension messages with the understanding that they will pass them along to other farmers. Some controversy exists as to whether contact farmers are representative and, if not, the extent to which extension advice is monopolized by large farmers (see Moore, 1984 and Feder, Slade and Sundaram, 1986). In a stratified rural society, differences in social and economic circumstances between farmers are likely to be major barriers to the transfer of information from large to small farmers.

VI. CONCLUDING COMMENTS

The changes initiated by the green revolution have revolutionized the technology of rice and wheat production in much of Asia and has had a profound effect on the managerial complexity of small farmer agriculture. A major premise of this paper is that in many of these post-green revolution areas, knowledge and skills of farmers have become critically limiting factors in maintaining increases in productivity. Investments to increase the quantity of technical information and develop the technical and managerial skills of farmers have not kept pace with investments in developing new technology. More importantly, institutional changes in research, extension and rural schooling needed to improve the quality of information and skill development have limited the opportunity to exploit the potential of the new technology, resulting in substantial technical and allocative inefficiencies in post-green revolution agriculture.

The endurance of Schultzs' "poor but efficient" hypothesis in development thought, aid agencies and national policy makers has maintained emphasis on the "high pay-off input" strategy to development and slowed the shift in priorities toward investment in information generation and transfer, and skill development for farmers.[51] Indeed, the pendulum seems to have swung from viewing small farmers as ignorant and tradition bound to a situation where they are looked to as an example of rational decision making and a store of knowledge from which scientists should learn. The challenge is to combine the knowledge and insights of farmers of their environment with the information and skills generated by research, extension and formal schooling that are needed for effective management of science-based agricultural technology.

The increased emphasis on farmer-oriented adaptive research (the farming systems perspective) and extension reform in the 1980s represents the beginnings of a process to alter the balance. Appropriate institutional arrangements to accommodate these changes are still evolving. Moreover, investment in adaptive research, extension and rural education is still inadequate in many areas. Unless these imbalances are corrected there is a danger of further increasing inequalities in the agricultural sector between small and large farmers due to differential access to knowledge and skills.

Agricultural economics and other social science research is needed to guide critical decision making in investment and institutional change. These research needs include the

[51] This is particularly ironic given Schultz's championship of the role of human capital in agricultural change (e.g., Schultz, 1975).

relatively neglected topics of managerial processes of small farmers, appropriate institutional arrangements for inducing a problem-oriented research and extension system and the more general but critical questions relating to the complementarity and substitutability between applied research, adaptive research, extension communication, extension education, rural schooling and adult education.

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