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AGRICULTURAL RESEARCH STRATEGIES FOR FAVOURED AND MARGINAL AREAS: THE EXPERIENCE OF FARMING SYSTEMS RESEARCH IN PAKISTAN

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SUMMARY

This paper draws on the results of farming systems research (FSR) conducted over five years at eight sites distributed throughout Pakistan. The main research findings with respect to the irrigated plains, or favoured areas (four sites), and the marginal mountainous and rainfed areas (four sites) are summarized, with emphasis on the role of system interactions in technology development. In favoured areas, most system interactions occur between crops grown in multiple cropping patterns, whereas in marginal areas, crop–livestock interactions dominate. Appropriate research strategies for each kind of environment are discussed. It is concluded that although there is a need for quite different research strategies for favoured and marginal areas, the methods and perspective of FSR are equally appropriate and even critical for achieving future gains in agricultural productivity in each type of environment.

Estrategias de investigación agrícola en zonas favorecidas y marginales: Experiencias recogidas durante la investigación de sistemas agrícolas en Pakistán

RESUMEN

Este trabajo examina los resultados de la investigación de sistemas agrícolas (ISA) llevados a cabo a lo largo de cinco años en ocho emplazamientos ubicados en distintas zonas de Pakistán. Se resumen los principales hallazgos de la investigación en lo que se refiere a llanuras irrigadas, o zonas favorecidas (cuatro emplazamientos), y zonas marginales montañosas y con riego por precipitaciones (cuatro emplazamientos). En las zonas favorecidas la mayor parte de la interacción entre sistemas se produjo entre cosechas producidas con diversos patrones de cultivo, mientras que en las zonas marginales dominó la interacción entre cosechas y ganado. Se discuten las estrategias de investigación que resultan apropiadas para cada uno de estos medios. Se llega a la conclusión de que, si bien existe la necesidad de utilizar estrategias de investigación diferentes para las zonas favorecidas y las zonas marginales, los métodos y el enfoque de la ISA cuentan con el mismo peso e importancia para lograr el futuro incremento en la productividad agrícola de cada uno de estos medios.

INTRODUCTION

Following the spectacular success of the Green Revolution in increasing productivity in favoured, usually well-watered areas, agricultural research and development efforts have in recent years given more attention to the marginal areas, many of which have benefited little from the new technology. One strategy widely promoted for marginal areas has been the farming systems approach to research (FSR) (Simmonds, 1985; Maxwell, 1984; Gilbert *et al.*, 1980). This approach has a number of features which are especially appropriate for research directed at

Table 1. *Classification of farming system interactions*

Type of interaction	Examples
1 Direct interaction between crops	
(a) Interactions in space	(i) Interactions caused by intercropping
(b) Interactions over time	(i) Conflicts in planting crop in relation to harvest of previous crop
	(ii) Carry-over of soil structure and crop residues from preceding crop
	(iii) Carry-over of fertility from previous crops
	(iv) Carry-over and build-up of weed seeds and other pest populations from previous crops
2 Interactions between crops and livestock	(i) Use of crops and crop residues for fodder
	(ii) Use of farmyard manure as crop nutrient source
	(iii) Use of animals for draught power
3 Resource competition and complementarity	(i) Conflicts in labour use and cash needs between enterprises, including non-farm enterprises
	(ii) Competition for irrigation water between enterprises
4 Meeting multiple objectives of farm households	(i) Choice of multiple crops, livestock, and production practices to manage risk
	(ii) Planting and storage of food crops to balance seasonal food needs, and off-farm work to provide seasonal cash needs

Source: Byerlee & Tripp (1988).

small farmers in marginal areas. In particular, FSR explicitly recognises that small farmers operate complex systems characterized by important interactions between enterprises (Table 1). Crop enterprises may interact directly with each other *in space*—through intercropping—and *over time*—through crop rotations and carry-over effects—and may also interact with livestock through fodder supplies, draught power and farmyard manure. Farm enterprises may also interact indirectly through competition for resources or through household strategies aimed at maintaining subsistence food supplies and reducing risk. The importance of each of these interactions depends critically on the type of farming system—a point we will develop in some detail.

Experience with FSR is now sufficient across both favoured and marginal areas to enable some lessons to be drawn on the relevance of the approach for different environments or systems. This paper summarizes experiences in applying the FSR approach across a range of farming systems in Pakistan. These systems can be broadly classified into the irrigated farming systems of the Indus plains, the farming systems of the rainfed plains, and mountain farming systems, both rainfed and irrigated (Table 2). The first of these represents the favoured environment that, with rapid and widespread adoption of semi-dwarf wheat varieties and fertilizer beginning in 1966, became an early beneficiary of the

Table 2. *Summary of major cropping systems and technological level for FSR projects in Pakistan*

Site†	Main crops: *Kharif* season	Main crops: *Rabi* season	Current status of technological adoption: Biological and chemical	Current status of technological adoption: Mechanical
		Irrigated plains		
1 Punjab rice–wheat	Rice	Wheat	Improved varieties of rice and wheat; fertilizer	Land preparation; threshing
2 Punjab cotton–wheat	Cotton	Wheat	Improved varieties of cotton and wheat; fertilizer and insecticide (cotton)	Land preparation; threshing
3 Sindh rice–wheat	Rice	Wheat	Improved varieties of rice and wheat; fertilizer	Land preparation; threshing
4 NWFP, Mardan District	Sugarcane Maize Tobacco	Wheat	Improved varieties of wheat and sugarcane; fertilizer	Land preparation; threshing
		Rainfed plains		
5 Northern Punjab	Sorghum Maize Pulses Fallow	Wheat	Improved wheat varieties (since 1976); fertilizer	Land preparation; threshing (since early 1980s)
		Mountains		
6 NWFP Swat Valley	Maize Rice	Wheat Fodder	Improved wheat varieties; fertilizer	Land preparation; threshing (since early 1980s)
7 NWFP Swat Mountains	Maize	Wheat Fallow	Improved wheat varieties (since 1976); fertilizer	Limited
8 Gilgit	Maize	Wheat Fodder	Some improved wheat varieties; fertilizer	Limited

†Numbers correspond to sites identified in the map (Fig. 1).

Green Revolution. The remaining two environments represent the less favoured or 'marginal' environments of Pakistan, where the seed–fertilizer revolution began much later and has had less widespread impacts.

Beginning in the early 1980s, several projects experimented with FSR in these different environments of Pakistan. By far the largest effort, and one in which the authors were intimately involved, was a collaborative programme between the Pakistan Agricultural Research Council (PARC), the international agricultural research centres (especially the International Maize and Wheat Improvement Center, CIMMYT) and various provincial government and non-government organizations (NGOs). This programme included research at four sites in the irrigated plains and four sites in the rainfed plains and mountain systems (Fig. 1). In total these projects covered most of the major farming systems of Pakistan. More detailed information on these systems is provided in Byerlee and Husain (1992).

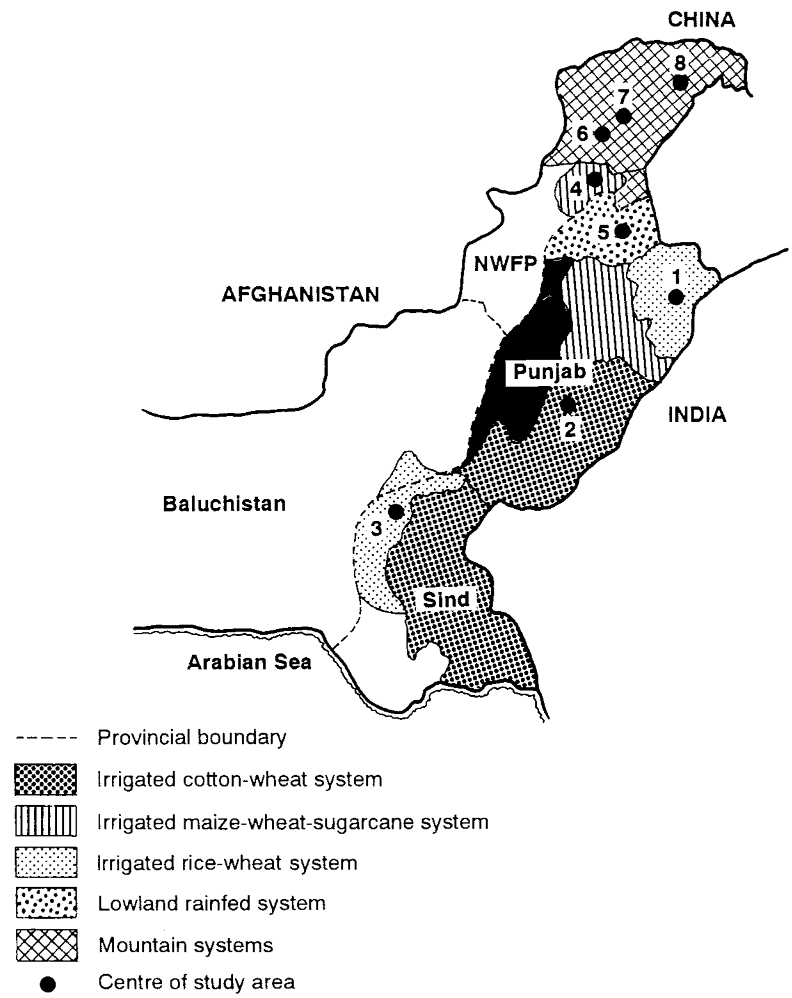

Fig. 1. Major cropping systems of Pakistan analysed in this paper.

The FSR programme aimed to broaden the narrow, single commodity-oriented research approach implemented in Pakistan after the Green Revolution, in order to meet the needs of the increasingly complex and intensive farming systems of both the favoured and marginal areas. The programme emphasized a high degree of farmer contact and participation through diagnostic surveys and on-farm experimentation.

One of the key activities in each research area was an informal diagnostic survey, in which a multidisciplinary team of researchers spent about seven days in the field talking with farmers, observing their fields, and meeting daily to synthesize findings. Next, formal surveys using a short questionnaire focused on key practices and issues identified in the informal surveys. In addition, several other surveys were conducted to follow up issues relevant to a particular system.

These surveys were followed by an extensive programme of experimentation conducted on farmers' fields that were selected to represent the dominant crop rotations in each research area. The experiments concentrated on a few priority research themes that had been identified in the diagnostic stage in each system.

This paper summarizes the major differences between systems in the favoured areas and marginal areas, with particular emphasis on the interactions within different types of farming system. From this summary, we show that although the FSR approach is equally relevant in each type of environment, quite different strategies may emerge for the development and diffusion of improved technology. Throughout we give special attention to identifying the important interactions in each type of system and their implications for designing technologies to improve system productivity.

OVERVIEW OF MAJOR SYSTEMS

The eight major systems studied are grouped by environment in Table 2 and differences in the farming systems and practices in each environment are summarized in Table 3.

Irrigated systems of the Indus Basin

The irrigated plains of Pakistan constitute the largest irrigated system in the world, covering 16 million ha or 80% of the cultivated area of Pakistan. They provide the bulk of the national food supply and export earnings from the agricultural sector. Wheat is the major *rabi* (winter) crop almost everywhere, often constituting over 80% of the cropped area in the *rabi* season and providing the bulk of subsistence food supply. As a result of widespread adoption of shorter-duration semi-dwarf wheat varieties and increased supplies of irrigation water, cropping intensity has increased significantly in all the three systems studied. Wheat is now commonly double-cropped with a *kharif* (summer) crop, which varies depending on climate, soils, and access to markets but is often an important source of cash income.

The most extensive cropping system in the irrigated plains is the cotton–wheat system, which extends from southern Punjab through Sindh Province. The second major system, where rice is the major *kharif* crop, can be further subdivided into the rice–wheat system of Sindh, in which high-yielding coarse-grained rice is grown, and the rice–wheat system of northern Punjab, where the fine-grained and higher value, but later maturing, Basmati rice predominates. The third major system is found in central Punjab and the Peshawar Valley of North West Frontier Province (NWFP), where sugarcane and maize are the most important *kharif* crops, although rice, cotton and potatoes and other vegetables are also grown. In all the irrigated systems analysed, livestock are important, but crop–livestock interactions have less impact than in the rainfed and mountain systems.

Table 3. *Some differences between farming systems in the irrigated lowlands and rainfed and mountain areas in Pakistan, as shown by on-farm research surveys, 1984–87*

Characteristic	Irrigated lowlands, Punjab and NWFP	Rainfed lowlands, Punjab	Mountain areas, NWFP
Average farm size (ha)	8 (NWFP 3.6)	3	1.0–1.5
Farms less than 5 ha (%)	57	85	100
Main source of draught power	Hired tractor (60–80%)	Hired tractor (88%)	Draught animal
Farm households with a deficit in food grains(%)	21	33	63
Main source of cash	Cash crops	Off-farm work; livestock	Off-farm work
Main cropping patterns	Rice–wheat; cotton–wheat; maize–sugarcane–wheat	Fallow–fallow–wheat–fodder; maize–wheat	Maize–fallow; maize–wheat; maize–fodder
Cropping intensity (%)	135–160	118	Rainfed–120 Irrigated–160
Coefficient of variation of maize/wheat yields between fields (%)	25–45	50–65	40–55
Number of livestock (in cow equivalents)	3.6 (Mardan only)	5.6	6–10
Value of crop by-products and intercrops in relation to value of grain (%)	10–20	40	40–50
Farmers with no access to rural road (%)	19	32	36

Rainfed systems of the northern plains and plateaus

The rainfed plains considered here—generally referred to as the *barani* areas—cover an area below 1000 m altitude stretching across northern Punjab into southern NWFP. An important aspect of these farming systems is that crop production is based solely on rainfall, which varies from an annual average of about 300 mm to over 1000 mm. The empirical results presented here are based on research in areas in the middle of these rainfall extremes, encompassing a variation in annual rainfall from about 450 to 800 mm.

Wheat is the basic crop in these rainfed systems; in the drier areas *rabi* pulses, especially chickpeas, are also important. *Kharif* crops are secondary to wheat, and become unimportant in the drier areas. Livestock are integral to the rainfed systems. Their importance relative to crop production increases in the drier areas.

Many elements combine to increase the difficulty of farming in these rainfed areas and the complexity of introducing agricultural innovations. These include the considerable year-to-year variability in rainfall, which substantially adds to the risk of farming operations, the small size and fragmentation of farm operations, which increases the importance of off-farm work and out-migration, and an infrastructure and marketing opportunities that are generally less well-developed than in the irrigated areas.

Farming systems of the mountain areas

Pakistan's mountain areas form an inverted crescent around the north and west of the country that spans widely varying topography, rainfall, vegetation and farming systems. Extreme variation in micro-environment over relatively short distances makes it expensive to generate locally adapted agricultural technology. These varied farming systems, however, share some characteristics that pose unique challenges for agricultural research and development: physical isolation from major markets and high transport costs; small farm size, generally with very uneven topography; and significant emigration to work in off-farm activities, often outside the region. As a result, adoption of improved technology is more recent and less widespread than in the irrigated and rainfed plains.

The mountain sites discussed here lie at an altitude of 1000–2000 m and receive from 125 to over 1000 mm rainfall each year. (In the low rainfall areas, agriculture depends entirely on irrigation from snow and glacial melt.) A maize–wheat rotation can generally be found up to 1850 m, above which there is a transitional zone to single cropping. Given the small cultivated area and the availability of rangelands, livestock are important in most mountain areas.

Major differences between farming systems

Major differences between each category of farming system are shown in Table 3. In rainfed and mountain areas, single cropping of a food crop is the norm, while in the irrigated plains, double cropping of food and cash crops is common. In the rainfed and mountain areas, farmers depend on livestock and off-farm work for cash. In addition, most farmers in the irrigated areas, even small farmers, are self-sufficient in grains, while in the rainfed and mountain environments most farm households are net food purchasers.

In the marginal areas, the relatively large numbers of livestock have important implications for crop production. For example, in the irrigated plains wheat straw accounts for about 10% of the gross value of the wheat crop, and the price of straw has declined in real terms by half since 1970 (Byerlee and Iqbal, 1987). In contrast, in the mountain areas the value of crop by-products (wheat straw or maize stover and green maize thinnings) approaches half the total value of the major cereal crop. This reflects the high price of fodder in these areas due to the large number of livestock relative to farm size, and a closed fodder market because of high transport costs relative to its value. Most farm households in these areas aim to be self-sufficient in fodder; nonetheless, limited fodder supply in certain seasons is often the most important constraint on greater livestock productivity.

Finally, a major difference between the systems is the greater variability across space and time in the marginal areas. The coefficient of variation in cereal yields measured by taking cuts in over 100 fields was about 25% (up to 40% at one site) in irrigated lowland sites, compared with coefficients of 40–65% in the marginal areas (Table 3). This is despite the fact that the research sites in irrigated areas covered up to 500 000 ha, compared with only 10 000–20 000 ha in many sites in the marginal areas. Although variability over time could not be quantified, farmers in most of the marginal sites were also clearly concerned about year-to-year variation in yields caused by rainfall variability and, in the mountains, by the incidence of frosts.

MAJOR FARMING SYSTEM INTERACTIONS IN FAVOURED AND MARGINAL AREAS

In the irrigated lowlands, the dominant farming system interaction in all cases occurs between crops over time. Increasing adoption of double cropping (made possible by increased irrigation water supplies, adoption of chemical fertilizer, and the use of earlier-maturing varieties) provokes conflicts because of the short turn-around from one crop to another. Land preparation and timely planting of wheat (the dominant food crop) are compromised by the late harvest of the preceding cash crop—rice, cotton or sugarcane. This has led to late planting of wheat in all the irrigated systems analysed, as more wheat is planted after the *kharif* crop rather than after the traditional fallow. Survey data over time reveal an increasing tendency towards late planting (Table 4).

Wheat yields in Pakistan are very sensitive to date of planting because of the risk of exposure to high temperatures at flowering and grain filling. Each day's delay in planting after mid-November decreases yields on average by 1% (Hobbs, 1985; Aslam *et al.*, 1989). However, the returns to *kharif* cropping are generally high relative to wheat, so farmers are behaving quite rationally in extending the *kharif* season and planting wheat late (Byerlee *et al.*, 1987).

The carry-over of crop residues, fertility and weed and pest populations also has a considerable influence on the management of succeeding crops in the more intensively cropped irrigated areas. In particular, carry-over of pests is important in a number of systems, the most common effect being the crucial role played by crop rotation in determining the population of grassy weeds, especially *Avena fatua* (wild oats) and *Phalaris minor* in the wheat crop (Table 5). In some cases these

Table 4. *Wheat fields planted late (after 1 December) in different irrigated cropping systems (%)*

	1970†	1977†	1985‡	1988†
Punjab rice–wheat	6	26	60	47
Punjab cotton–wheat	28	38	70	84
NWFP maize–wheat	na	na	34	na

†Data from various sources, as reported in Byerlee and Siddiq (1990); ‡data from FSR surveys reported in this paper; na, not available.

Table 5. *Effect of crop rotation on incidence of grassy weeds in wheat fields*†

	Punjab rice–wheat system	NWFP maize-wheat system
Fields infested with grassy weeds (%)		
One or two years' continuous wheat in the *rabi* season	12	6
Three or more years' continuous wheat	34	41
Fields with three or more years' continuous wheat in the *rabi* season (%)	72	27

†Based on surveys of about 150 fields in each system.

carry-over effects can be quite complex; zero-tillage in wheat, for example, leaves the rice stubble intact and may encourage a build-up of the rice stemborer population in the following rice crop.

Since the wheat crop typically accounts for nearly 80% of the cultivated area in the season in which it is cropped, competition for resources between crops grown in the same season is relatively unimportant in most irrigated systems (the exception is the diversified cropping system of Mardan, NWFP). Also, since farmers in the irrigated lowlands usually plant a separate fodder plot for animals and have largely substituted tractor power for animal power and chemical fertilizer for farmyard manure, crop–livestock interactions have become less important in recent years.

In contrast, in the rainfed and mountain areas livestock are closely integrated into the farming system and crop–livestock interactions have a major influence on crop management. The most important crop–livestock interaction is the supply of fodder for domestic animals obtained by intercropping green fodder in food crops and from crop residues. Farmers in the rainfed plains commonly intercrop mustard in wheat and remove it over the winter months when green fodder is scarce. In all the marginal areas, farmers typically plant maize at three to five times the optimal density for grain production and then thin throughout the season to provide green fodder for animals. Although researchers and extension workers have for many years discouraged these practices (because of an adverse effect on grain yields), the FSR programmes established that total productivity is increased in economic terms so that farmers are quite rational in rejecting the recommended practices (Table 6; Byerlee *et al.*, 1989; Hobbs *et al.*, 1985). In addition, in a variable environment these systems provide substantial management flexibility. For example, in dry areas, farmers in rainfed areas remove the intercropped mustard early and reduce the competition with wheat for moisture.

A second major crop–livestock interaction relates to the use of organic manure for maintaining soil fertility and improving soil structure and moisture retention capacity, especially in rainfed areas. In the larger farms of the irrigated plains,

Table 6. *Comparison of the profitability of farmers' technology with the recommended package of technology*

	Farmers' technology	Recommended package of technology
Grain yield (t ha^{-1})	4.0	5.5
Total variable costs (Rs × 10^{-3} ha^{-1})†	1.0	2.4
Gross revenue (Rs × 10^{-3} ha^{-1})		
Grain	5.3	7.3
Fodder	5.0‡	3.0
Gross margin (Rs × 10^{-3} ha^{-1})	9.3	7.9

†Exchange rate at the time, Rs 17 = $US1.0; ‡includes the value of green fodder removed. Source: Byerlee *et al.* (1989).

organic manure now plays a minor role, apparently because of the replacement of draught animals by tractors, the increased demand for manure for cooking fuel, and the increased labour cost of application. For example, in the cotton–wheat system, 75% of farmers are reported to have applied organic manure in the early 1970s, compared with only 13% in 1985. A similar decline has been observed in the Indian Punjab (Byerlee and Siddiq, 1990; Sidhu and Byerlee, 1991).

In contrast, farmers in marginal areas carefully conserve and use organic manure in crop production. In the rainfed plains, farmers commonly apply organic manure mainly to fields close to the village, known as *lepara* fields. This increases the moisture-holding capacity of these fields and enables them to produce higher yields and to be cropped much more intensively than fields away from the village which receive little manure. Hence, although *lepara* fields account for only about one-quarter of the farm area, they provide over half of the value of farm production (Sheikh *et al.*, 1988). Clearly this distinction has important implications for research—for example, in recommending the appropriate dosage of fertilizer for different field types.

TECHNOLOGICAL CHANGE IN FAVOURED AND MARGINAL AREAS

All the systems studied have undergone rapid technological change over the past two decades. In the irrigated areas over the past decade, the Green Revolution in wheat has been followed by rapid technological change in *kharif* crops, especially in Basmati rice (brought about by the release of new high-yielding and earlier-maturing varieties) and cotton (brought about by improved varieties and pest control).

In the more marginal areas, technological change has occurred more recently but in some cases has been equally rapid. The adoption of improved varieties, fertilizer and some mechanical innovations in the rainfed plains resulted in an average increase in wheat yields of over 8% annually between 1976 and 1986, a rate comparable to that resulting from the adoption of these same technologies in the irrigated area a decade earlier. In the mountain environments, steady improvements in infrastructure have enabled chemical fertilizer to be widely adopted in recent years; under certain conditions (discussed below), improved varieties have also been widely adopted. The rapid pace of change in these more marginal areas indicates their potential for improved productivity.

In addition to the later and incomplete diffusion of the seed–fertilizer technology in marginal areas, the sequence of adoption has been somewhat different. In irrigated areas, most farmers adopted semi-dwarf varieties and fertilizer at the same time or even adopted improved varieties *before* fertilizer. In the marginal areas, there was a clear tendency to adopt improved varieties *after* the adoption of chemical fertilizers, partly because of the high value of straw as a livestock feed in these areas. Semi-dwarf varieties yield more grain but less straw than traditional varieties when grown with limited fertilizer. Hence, with sufficiently high straw prices relative to grain prices, it may not be economic for farmers to adopt semi-dwarf varieties until fertilizer use increases above a threshold level (Traxler and Byerlee, 1992).

Finally, because of agro-climatic and socio-economic circumstances, farmers in marginal areas seek greater diversification. For example, traditional varieties are preferred in dry years because they emerge better from deep planting into residual moisture; hence many farmers plant both old and new varieties. In mountain areas, the planting of varieties with different maturities enables wheat to be planted over a range of dates to accommodate farmers' needs to accumulate sufficient organic manure before planting, or to work away from the farm in the winter season.

Emerging challenges in the irrigated environments

The widespread diffusion of seed and fertilizer technology in the irrigated areas poses a challenge to agricultural researchers to identify future sources of increased productivity and to find ways to sustain current productivity levels. To a large extent the principal sources of growth over the past two decades have already been exploited. Semi-dwarf wheat varieties are now sown on almost all the irrigated wheat area, fertilizer doses on irrigated wheat now average 150 kg ha^{-1}, and the availability of irrigation water per hectare of cultivated land has levelled off or is falling.

Plant breeders face a challenge in serving farmers' diverse and evolving needs for new varieties in irrigated areas. The conflict between harvesting and planting dates in double-cropping systems can be partially resolved by using earlier-maturing varieties of either or both crops in the double cropping pattern. During the 1980s some progress was achieved in resolving these conflicts. In the cotton–wheat area an early maturing high-yielding cotton variety, NIAB-78, was planted on more than 50% of the cotton area in the space of four years (Byerlee *et al.*, 1987). Likewise in the rice–wheat area of the Punjab, an early maturing, high yielding variety of Basmati rice was adopted by 70% of farmers in just three yeaı~ This variety not only significantly increased yields but enabled wheat to be planted about one week earlier (Sharif *et al.*, 1992). Finally, Pak-81, a wheat variety recommended for the optimal wheat planting date, was found by the FSR programme to perform well over a range of planting dates, and especially with late planting. By 1990, Pak-81 had become the dominant wheat variety in the Punjab.

The FSR programme highlighted the need for close communication between breeders of crops grown in rotation in double cropping patterns. For example, changes in maturity of cotton or rice varieties, or even changes in the management or the price of these crops, can have important implications for wheat breeders (Byerlee *et al.*, 1987). In some cases these conflicts may best be resolved by replacing late planted wheat with other crops, such as oilseeds, provided appropriate varieties of these crops can be made available (Tetlay *et al.*, 1990). Despite recent successes, mechanisms for close coordination and communication across crop breeding programmes for crops grown in the same cropping system still need to be strengthened.

While plant breeding will continue to play an important role, a large share of future increases in productivity in the irrigated systems will have to come through improved crop and resource management. This will require a change in emphasis, from increased use of inputs to reducing costs through increased input efficiency, and greater attention to system sustainability. This emphasis on crop and resource management is needed because of diminishing marginal returns from higher levels of input use, and because of changes in the economic environment, in part induced by policy changes. For example, most input subsidies have recently been removed.

Increasing input efficiency and sustainability require more emphasis on practices such as crop rotation, tillage methods, weed and pest control, timing and method of fertilizer application, fertilizer nutrient balances, and efficient use of irrigation water at the farm level. Recommendations will also have to be tailored more closely to the specific agro-climatic and socio-economic conditions of farmers. For example, in the past a single recommendation on fertilizer levels has been provided for all irrigated wheat areas in Pakistan. But on-farm experimentation carried out as part of the FSR programme has emphasized differential responses to fertilizer by crop rotation and land type. This research has shown, for example, that the optimal level of phosphorus varies markedly between systems. In the long run, however, more efficient fertilizer use will depend as much on complementary improvements in irrigation practices, weed control, and stand establishment, as on fertilizer management *per se*.

In some cases, researchers must seek new inputs to complement traditional practices. For example, hand weeding is practised in only a few wheat fields, and very few farmers use chemical weed control. Rotation, particularly with the fodder crop berseem (*Trifolium alexandrinum* or Egyptian clover), is a common way of controlling grassy weeds but is only profitable for farmers who have enough animals or who are close enough to city markets to justify the fodder production.

Hence the FSR programme tested chemical weed control, which is now being adopted as an important complement to traditional methods of control.

Another major opportunity for reducing costs as well as allowing more timely planting of wheat is through the adoption of reduced tillage. This is particularly crucial in the rice–wheat area, where the seedbed for wheat has to be prepared on the puddled, compacted soils left from the previous rice crop. Even though farmers prepare land more intensively in this area, the resulting seedbed is often inadequate to achieve a good stand of wheat and planting of wheat is delayed. Experiments using a specially designed drill showed that direct drilling of wheat with zero-tillage reduced turn-around time with no loss in wheat yields (Aslam *et al.*, 1989).

Finally, the FSR programmes raised concerns about the longer-term sustainability of intensive cropping systems in irrigated areas. Evidence from farm surveys suggests that continuous planting of wheat in the same field without rotation leads to a serious decline in yields. In addition, wheat yields of semi-dwarf varieties in irrigated areas have remained static over the past decade although the amount of fertilizer applied has more than doubled. This yield stagnation may relate to micro-nutrient deficiencies, poor quality tubewell water and soil disease problems (Byerlee and Siddiq, 1990).

A major sustainability issue for all irrigated systems is the management of crop residues and organic manures to stabilize or increase soil organic matter and improve soil structure. This kind of research will often require strong interdisciplinary cooperation. For example, in the rice–wheat system, after zero-tillage had been demonstrated to be feasible and cost effective for wheat, concern was expressed that leaving rice stubble in the field would increase the problem of rice stemborer damage in the following rice crop. Accordingly, the rice entomologist organized field surveys of the population of rice stemborers in zero-tilled and conventionally tilled wheat fields and devised a strategy for rice stemborer control which allowed zero-tillage (Inayatullah *et al.*, 1989).

The development of effective crop and resource management research for irrigated areas to meet the challenges of the next stage of development will depend on good collaboration between different commodity programmes and research institutes, and better integration of the various disciplines related to crop and resource management. These disciplines—soil science, irrigation water management, soil fertility, tillage, weed science and especially social science—have traditionally worked in isolation from each other, usually in separate disciplinary research institutes and often at different locations.

Research for marginal environments

In rainfed and mountain areas, the nature of system interactions and the level of variability require a somewhat different research and extension strategy. In these areas, it is difficult to identify homogeneous strata comparable to those in the irrigated plains, because of the extreme variability across space and time. Even if such strata can be identified, they are often too small to justify a specific adaptive research programme. Hence, the best strategy is to look for system interventions that are appropriate for a wide range of conditions, such as tillage methods to conserve moisture (in drier areas), a new fodder crop to relieve fodder constraints, a new cash crop suited to local conditions, or a new early maturing variety to promote increased cropping intensity. For example, in the rainfed plains on-farm experimental work at many locations over five years showed that the use of a mouldboard plough for deep tillage to facilitate moisture conservation produced a consistent and profitable yield response averaging about 25%.

Although high-yielding varieties have had less spectacular success in marginal areas, plant breeding has a potential role in overcoming key system constraints. In higher altitude mountain systems, cropping intensity is limited by lack of early maturing wheat or maize varieties tolerant of the disease complexes found in these environments. In the rainfed plains, a wheat variety with good heat tolerance in the seedling stage could be planted earlier to make better use of the moisture from the receding monsoon.

Researchers in marginal areas must give particular attention to crop–livestock interactions. Crop varieties need to be tailored to systems in which grain and fodder are produced jointly, for example, maize varieties that perform well at high densities or wheat varieties that compete well with intercropped mustard (Byerlee *et al.*, 1989; Hobbs *et al.*, 1992).

Fodder has generally been neglected by Pakistan's research institutes. Until recently crop and livestock scientists have had very little contact but the establishment by PARC of a coordinated farming systems programme has helped initiate better communication.

Finally, given the importance of farmyard manure in the system, more research is needed to analyse the allocation of manures to various uses and to document long-term trends in farmers' use of manure and their implications for system productivity.

STRATEGIES FOR TECHNOLOGY DEVELOPMENT AND DIFFUSION IN FAVOURED AND MARGINAL AREAS

This review has clearly shown four major differences of farming systems in marginal areas relative to those in favoured areas. First, the resource base of farmers in marginal areas is poorer so that farmers find it difficult to meet subsistence requirements and therefore depend on livestock or off-farm work to provide cash. Hence research on food grains for marginal areas must give greater weight to subsistence needs and preferences for home consumption. Second, marginal areas are agroclimatically heterogeneous, often over short distances. Indeed, fields within individual farms may be quite diverse with respect to soil type and topography, and in some cases farmers' management increases this diversity, for example, by the concentration of the use of organic manure on particular fields. Because of this heterogeneity, the 'package approach' to technology development is inappropriate. Farmers need a range of technologies from which to select those that are appropriate to specific fields and seasonal conditions. Third, crop–livestock interactions are critical in system management in marginal areas, and commodity research that does not consider issues such as the value of crop residues and fodder intercropping will not be successful. Finally, farmers in marginal areas use relatively low levels of purchased inputs so there is still scope for increasing productivity through input intensification as infrastructure improves.

These factors suggest a somewhat different strategy for research for marginal areas. Occasionally it may be possible to find technological interventions that can have a widespread impact, such as deep tillage for rainfed wheat. However, in contrast to the irrigated areas, such discoveries are likely to be exceptional. The micro-climatic variability in marginal areas suggests that research should be decentralized, with more involvement of farmers in selecting among technological options. In most cases, it will not be cost effective to try to define specific recommendations for each microclimatic niche. Furthermore, plant breeding research may be relatively less important in overcoming the major system constraints (which in irrigated areas can often be resolved by earlier maturing varieties). Rather research may need to be directed towards crop management, fodder production and livestock management.

Even in the favoured areas the successful research strategy based on high-yielding varieties and intensification of cropping and input use will have to be adjusted in future. Diffusion of high-yielding varieties is now complete, and the breeding of newer varieties must be targeted at resolving conflicts in planting and harvesting dates as a result of increased cropping intensity. This will require close coordination among breeders of crops (or potential crops) grown in a double cropping pattern, especially wheat, rice, cotton and oilseeds, in order to develop varieties with maturity characteristics that maximize the productivity of the entire cropping pattern. Similarly, input use has now reached levels at which there are diminishing returns to further input intensification. Research and extension systems must now emphasize ways of enhancing input efficiency through improved timing and method of application, improvements in cultural practices, and better management of input support systems (especially irrigation).

Differences between favoured and marginal areas also have implications for the way technology can be transferred. In the irrigated plains, the private sector has increasingly taken over the role of input distribution and marketing, and in some cases, for example, in the case of hybrid maize, is increasing its role in agricultural research. As the public sector withdraws from input distribution, it must focus its efforts on improving the information and skills of farmers so that they can use the available technology more efficiently. This implies an enhanced role for extension, which at present is relatively weak. Less than 20% of farmers have any contact with extension agents, and even those who have contact often lack basic information about the technology they are using or are expected to use, such as information on the nutrient composition of fertilizers (Hussain and Byerlee, 1991). This situation is compounded in Pakistan because the level of formal education among farmers, which might substitute for extension, is low. Although the extension system has recently been reorganised under the guise of the Training and Visit system, this does not appear to have been particularly effective (Hussain and Byerlee, 1991).

In marginal areas, the public sector has had relatively little direct impact through technology development and dissemination. Most successful technologies, such as new varieties, have spilled over from irrigated areas into areas where they are at least partially adapted. The low resource base, poor infrastructure and variability of marginal areas compounds the difficulties of developing technologies specifically for marginal areas. More recently, some NGOs in marginal areas have successfully organized farmers, conducted adaptive research, multiplied seed, established marketing channels and provided inputs and extension advice (World Bank, 1987; Ahmad *et al.*, 1990).

The FSR programmes have highlighted the need in both favoured and marginal areas to move away from the single-factor approach that has been applied in the past, which assigns a 'leading role' to irrigation or high-yielding varieties, implicitly to the exclusion of other factors. The evidence from this study is that single factors will no longer provide widespread payoffs or breakthroughs. Rather there is a need to combine smaller incremental changes in several factors. In this context, FSR is a particularly appropriate research strategy that is highly complementary to traditional commodity or disciplinary research. By placing a premium on efficient management and conservation of resources in the favoured environments, and by exploiting the potential in marginal areas, FSR can play a vital role in ensuring growth in food grain productivity and in the incomes of small farmers in Pakistan in the coming decades.

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