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DEVELOPING IMPROVED CROP TECHNOLOGIES WITHIN THE CONTEXT OF PAKISTAN'S MULTIPLE CROPPING SYSTEMS

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ABSTRACT: Farming systems approach to research can best be implemented through a strong programme of on-farm research, closely linked to experiment station research programme. Starting with this premise, the paper describes the methodology employed in a collaborative project aimed at improving productivity of wheat in major cropping systems of Pakistan. It presents evidence to show how interactions in the cropping system influence the choice of production technology of wheat.

In the last decade, there has been a rapid expansion of research activities under the general nomenclature of "farming systems research" (FSR). This has been stimulated by two interrelated developments. First, there has been a growing recognition of the complexity of many small farming systems brought about by interactions between farm enterprises over space and over time. Greater emphasis is now placed on improving farm productivity taking into account the total farming system. Second, many practitioners have increasingly emphasized the need to improve the orientation of agricultural research toward the needs of small farmers, in order to define relevant research priorities and to test promising technological improvements under farmers' conditions. There is now general agreement that a farming systems approach to research can best be implemented through a strong programme of on-farm research, closely linked to experiment station research programmes. Nonetheless, there is still considerable diversity in the scope of activities included in farming systems research (especially the number of commodities covered) and in the methodology of on-farm research.

This paper describes the methodology employed in the PARC/CIMMYT Collaborative Wheat Project aimed at improving productivity of wheat in major cropping systems of Pakistan. The methodology is illustrated by selective presentation of some of the research results from irrigated areas, particularly those that show how interactions in the cropping system influence the choice of production technology for wheat.

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Methodology

The research methodology described here departs from methods traditionally applied in Pakistan in three important respects.

1. The research has viewed a particular commodity, wheat, as an integral part of a *cropping system* and analysed technological issues in wheat production in relation to the total productivity of the *cropping system*. A fundamental premise of the approach is that research and extension priorities are specific to each cropping system.
2. The research has been *multi-disciplinary* in character involving both agronomists and economists in the definition of problems, design of research and formulation of technological recommendations. This represents one of the few projects in Pakistan where social scientists have actively participated with biological scientists in this type of research.
3. The research has been *farmer-focused*. Major efforts have been made by researchers themselves to understand first-hand the farmers' situation and observe their problems. At the same time, promising technological alternatives have been tested under farmer conditions.

The farming systems approach used in the programme incorporates two key elements; (a) a *systems perspective* that considers interactions between components of the system in evaluating changes in wheat technology and (b) research in farmers' fields with farmer participation, i.e., *on-farm research*.

System Interactions and the Development of Crop Technologies

The majority of farmers in developing countries make decisions about technology in a very complex environment. Some of the sources (4) of that complexity are (i) long growing seasons, often permitting more than one crop per year and at times encouraging production of a wide variety of crops and often different varieties of one crop, (ii) the importance of risk (due to low farm incomes, uncertain climate and unreliable markets), (iii) the multiple objectives of farm families, who often consume a considerable proportion of their own production, (iv) high dependence on family labour, characterized by competing opportunities and seasonal bottlenecks, and (v) heterogeneity of resources employed (e.g. various types of land and labour).

Given the complexity of farming systems, special emphasis is required in the research design to identify the key interactions which will influence technological choice for a particular crop. It is useful to classify these

interactions into those which represent; (a) biological interactions between crops, (b) biological interactions between crops and livestock and (c) competition and complementarity in resource use between enterprises in meeting farmers' multiple objectives (Table 1).

Table 1. Classification of Farming System Interactions

Type of Interaction	Examples
1. Biological interactions between crops	
(a) Biological interactions in space	i) Intercropping
(b) Biological interactions overtime	i) Conflicts in planting a crop in relation to harvest of pervious 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. Biological interactions between crops and livestock	i) Use of crops and crop residues for fodder.
	ii) Use of farm yard manure as crop nutrient source.
	iii) Use of animals for draught power.
3. Resource competition and complementarity	i) Conflicts in labour use between enterprises.
	ii) Cash flows from sale of one product for purchase of input for another enterprise.
	iii) Competition for irrigation water between enterprises.
4. Meeting multiple objectives of farm-households	i) Choice of multiple crops and production practices to manage risk.
	ii) Planting and storage of food crops to balance seasonal food needs.

Biological interactions in a multiple cropping situation, without intercropping, can be generally classified into time conflicts in the harvesting of one crop and the planting of another, and interactions due to carry-over or residual effects of one crop on succeeding crops. These latter interactions may last for several seasons in a crop rotation, although usually with diminishing effect. Several typs of biological interactions between crop and livestock enterprises are also possible, especially the flows of organic manure and draught power.

Farmers also usually grow several crops in a production cycle to meet multiple objectives of subsistence food and fodder needs, cash incomes and risk aversion. This creates interactions due to resource competition and complementarity. Production practices in one crop may depend on competing labour and draught power in other crops or seasonal food and cash needs.

The importance of these different interactions depends on the type of farming system operated. In land extensive systems with several crops produced in one production cycle per year, interactions due to intercropping and competition for resources will usually be more important than interactions overtime between crops. On the other hand, where farmers are able to produce several crops in a field in a year, with one dominant crop in each season, biological interactions overtime in the crop rotation dominate. Finally, where livestock is an integral part of the farming system (e.g. where livestock fodder is largely produced from crop by-products or where farm yard manure and animal power supply a large part of crop nutrient and draught power, respectively), crop-livestock interactions will need to be investigated in more depth.

Developing Crop Technologies for Multiple Cropping Systems of Asia

In most of Pakistan and elsewhere in Asia, cropping intensities in irrigated areas range from 120 to 200 and continue to increase. There is usually one dominant crop rotation (e.g. rice/wheat) (Table 2). In these cropping systems, interactions between crops within a season in resource competition are usually less important (because of the dominance of one crop) than interactions overtime in crop rotations.

Hence, the research methodology has concentrated on analysing cropping system interactions overtime as a basic factor in developing technologies for the major crop or cropping pattern.

Table 2. Share of Dominant Crop in Cropping Pattern of Selected Irrigated Districts of Pakistan, 1983

	Cropped area wheat in *rabi* season (%)	Cropped area under dominant crop in *kharif* season (%)
Rice/wheat district (Gujranwala/ Sheikhupura)	77	64 (rice)
Cotton/wheat district (Multan)	72	63 (cotton)
Maize/wheat district (Mardan)	66	63 (maize)

The On-farm Research Process

On-farm research is a systematic approach to identifying and solving priority farmer problems. A sequential process is used in which researchers first seek to understand the existing farming system and factors limiting productivity of that system (2,8). This information is then translated into research prorities which form the basis of an on-farm experimental programme. This process can be viewed in five distinct stages shown in Figure 1.

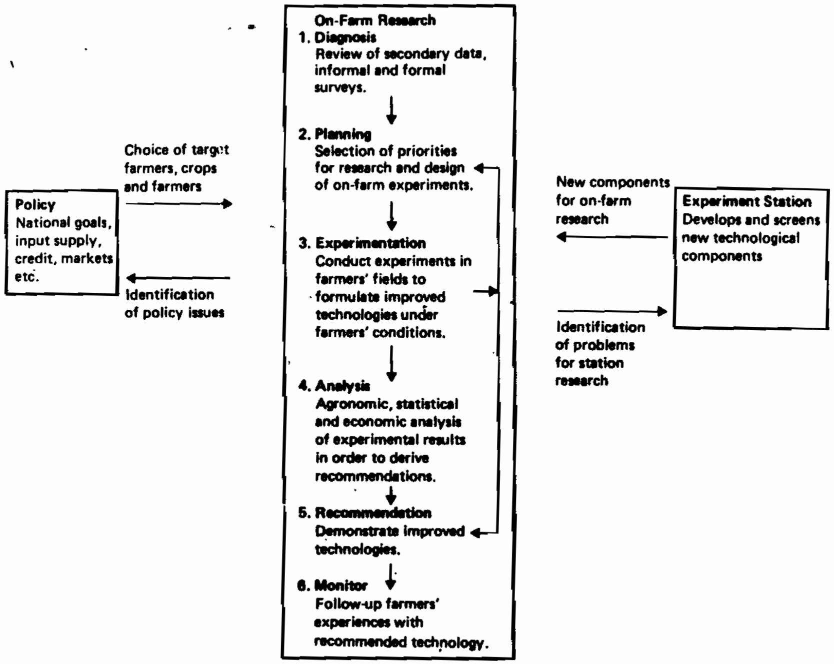
1. **The diagnostic survey**: The objective of this stage is to describe and understand the agro-climatic and socio-economic conditions under which farmers in a given location make decisions, in order to develop an appropriate experimental programme to meet the priority problems of farmers.

In the on-farm research programme in Pakistan diagonosis involved a number of steps. First, a target area representing the major cropping system of interest was selected after discussion with research administrators. The criteria used in this selection were; (a) general representativeness with respect to soils and availability of irrigation water, (b) proximity to a research station, and (c) ready accessibility from a regional town or city[1].

The key step in the diagnostic phase was an informal or exploratory survey. In this survey, a multi-disciplinary team of agronomists and social scientists spent a week or more in the target area in February/March observing farmers' fields and informally talking with farmers, merchants and others

1. The target areas were: Punjab rice/wheat – Ferozwala Tehsil of Sheikhupura District and Gujranwala Tehsil of Gujranwala District; cotton/wheat – Multan District and NWFP maize/wheat – irrigated Mardan District and Malakand Agency.

Fig 1. Stages of On-farm Research



about practices and problems. (no questionnaire was used). The essential task was to arrive at an understanding of the farming system and practices employed in wheat production. Each day researchers met to pool and discuss findings and to focus further efforts on problems in wheat production. Efforts were also made to describe and understand variation in cropping patterns and production practices across farmers in the target area.

This informal survey process was found to be a powerful tool for bringing researchers of different disciplines together and establishing direct contact with farmers and their problems. At the end of the survey researchers, including experienced researchers, had a new perspective on farmers problems and opportunities for solving those problems.

The informal survey was followed by a formal survey which collected key *agronomic* and economic information *on a specific field, including* information on preceding crops. Some important variables describing the whole farming system were also included (e.g. cropping pattern, power resource). The formal survey aimed to quantify key information and test hypotheses developed in the informal survey. The design of the question-

naire was based on the understanding of the system gained in the informal survey. Farmer interviews were conducted at harvest time in the selected field in order to ensure that farmers related information only to that field and to enable agronomic observations, including a yield sample, to be taken. The different categories of information collected are shown in Table 3.

Table 3. Categories of Information Collected in the Formal Surveys

	Field Specific Information	
1.	Production practices for wheat	Operations performed. Timing of operation. Inputs applied. Method of application.
2.	Cropping history	Cropping pattern for previous two years. Practices in previous crop affecting wheat crop (e.g. variety, planting date). Fertilizer history. Turn-around time between crops.
3.	Agronomic observations	Plant stand Weeds Salinity Lodging
4.	Field characteristics	Soil type Tenancy Proximity to village
5.	Wheat grain and straw yield	Random sample of three to five plots $1m^2$ weighed and threshed.
	Farm Level Information	
1.	Resource base	Power source Irrigation system Farm size Market
2.	Cropping pattern	*Rabi* crops grown.

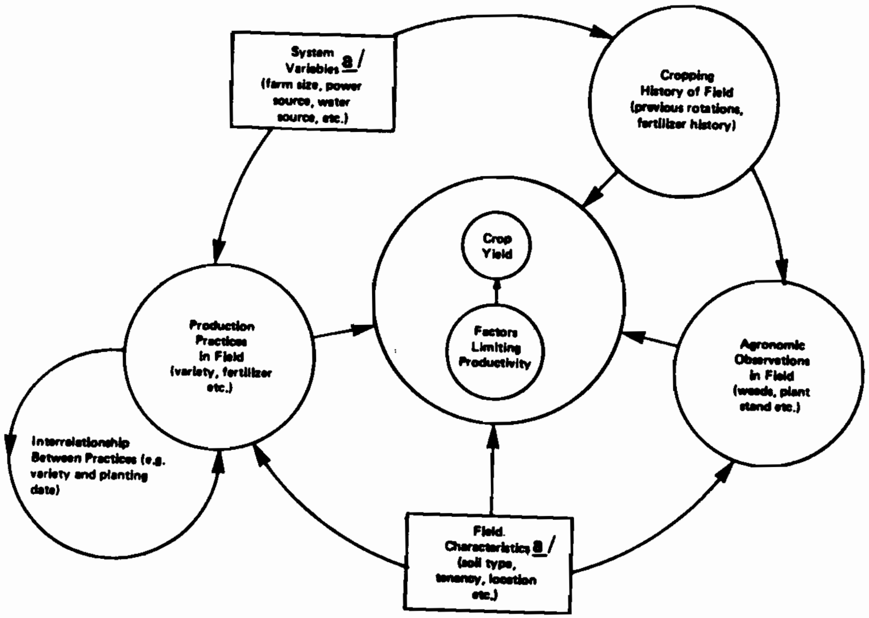
Since the formal survey required considerable skill, especially in taking agronomic observations, agronomists and socal science researchers conducted all interviews and field observations. Hence, there is considerable faith in the quality of data obtained.

Survey data were analysed with the aid of a micro-computer to look at several different types of inter-relationships shown in Figure 2, using two-way and three-way frequency tables, analysis of variance and multiple regression analysis. These relationships included:

1. Relationship between cropping pattern and system variables such as farm size, access to irrigation water, soil type etc.

2. Variation in production practices in the target crop as a function of (a) system variables. (b) cropping history of the selected field, (c) characteristics of the field and (d) other production practices employed in the field.

Fig 2. Schematic Representation of Interrelationships Analysed Using Data Collected in the formal survey



a/ Considered as exogenous variables.

3. Agronomic observations in the selected field as a function of (a) cropping history, (b) characteristics of the field and (c) production practices employed.

4. Yield and prodctivity limiting factors in the selected field as a function of the same set of variables as in (3) above. From 25% to 60% of variation in yields between fields in irrigated areas could be explained by multiple regression analysis.

Data analysis and preliminary reports were completed within a few weeks after conducting the survey in order to be available for the planning of experiments for the next season.

Follow-up surveys have been conducted in each target area. Small surveys in 1985 in the rice/wheat and maize/wheat areas were made to varify key information, monitor change (e.g. varietal adoption) and to provide information on year-to-year variation in farmers, practices and yields due to climatic circumstances. Results of these smaller follow-up surveys have largely supported the results of the indepth initial surveys (9) Special purpose surveys were also conducted in 1986 to analyse farmers knowledge and perceptions on particular technological improvements such as new varieties and fertilizer use. The total survey program is shown in Table 4.

Table 4. Summary of Survey Program for Onfarm Wheat Research

	Punjab Rice/ Wheat	Punjab Cotton/ Wheat	NWFP Maize/ Wheat
Informal survey	Feb. 1984	Feb. 1985	Feb. 1984
Main formal survey	Harvest, 1984	Harvest, 1985	Harvest, 1984
Sample size-formal survey	152	155	150
Supplementary survey	Harvest, 1985	– –	Harvest, 1985
Sample size-supplementary survey	60	–	70
Special purpose survey[a]	Feb. 1986	Feb. 1986	Feb. 1986

a: Focussed on farmers' knowledge and perceptions of recommended practices.

2. **The Planning Stage:** This stage invovled translating the information from diagnosis and from previous cycles experimentation to a set of experiments. Researchers reviewed the problems which limit the productvity of resources committed to the wheat enterprises. Solutions were screened for likely profitability and compatibiity with the farming system (11). The planning stage specified the types of experiments, the experimental design, the number and characterisitstistics of the fields where experiments (including experiments on research stations) were to be planted, and the type of data to be taken. Particular attention was paid to identifying sources of heterogeneity in the area in order to define *recommendation domains* – groups of farmers whose circumstances are similar enough that they will accept more or less the same recommended technology. The concpet of a recommendation domain is critical if research is to be efficiently directed toward specific groups of farmers and well defined research goals.

3. **The Experimental Stage:** Experiments were usually conducted in farmers' fields in order to represent actual conditions under which the technology will be used and also to elicit farmer participation and gain additional insights into farmers' circumstances.

With crop rotations as an explicit variable in the on-farm experimental program, crop responses can be represented by the general function:

$$Y = f\ (X_i, S_j, Z_k),$$

where;

Y is yield of the crop under study,

X_i are production inputs such as fertilizer under the control of the farmer or researcher,

S_j are site specific variables such as soil type and previous crop, which are known or can be measured at the beginning of the production cycle but cannot be altered by the farmer, and

Z_k are random climatic or pest incidence variables that are not known with certainty and cannot be controlled by the farmer.

It can be shown (6) that S_j variables will influence economic optima of X_i variables if there are interactions between X_i and S_j (i.e. $d^2\ Y/dX_i dS_j \neq 0$ in the response function). While farmers cannot control S_j variables, researchers can exert some control of these variables through site selection for experiments. Hence, careful selection of sites and analysis of crop response in relation to sites enables the derivation of recommendations for a crop in terms of variables relating to site characteristics, especially previous crop or fertilizer use in the previous crop.

Although there are a variety of experimental designs appropriate for on-farm research, the experiments can be grouped into three broad categories; (i) exploratory experiments to better define problems, (ii) experiments which test solutions to well defined problems (e.g. given that weed control is a problem, which of the potentially relevant solutions is the most appropriate in this situation?) and (iii) experiments which verify particular solutions and may be used as demonstrations. In the progression from exploratory to verification experiments, the degree of farmer involvement and management, the number of sites, and the size of individual plots all tend to increase. The total experimental program is shown in Table 5.

Table 5. Summary of Onfarm Experimental Program for Irrigated Wheat Areas, Pakistan

	Punjab Rice/ Wheat	Punjab Cotton/ Wheat	NWFP Maize/ Wheat
Type of experiment			
1. Variety – especially for late planting	**	**	*
2. Fertilizer response by crop rotation and planting date	**	**	**
3. Alternative combinations of tillage, planting method and reduced turn-around time.	**	**	*
4. Weed control			
a. broadleaf weed control		*	**
b. grassy weed control	**		*
5. Irrigation scheduling	*		
Number of experiments planted			
1983-84	10	–	58
1984-85	39	–	66

** First priority, * Second priority

4. **The Analysis Stage:** This involved a review of the agronomic responses observed in the experiments, a statistical analysis of the results, and

an economic analysis. Methods of economic analysis were based on marginal analysis using partial budgets (17) or formal response functions in the case of fertilizer. Standard quadratic functions were used as follows:

$$Y = a + \sum_i b_i X_i + \sum_i c_i X_i^2 + \sum_{in} d_{in} X_i X_n + \sum_j e_j S_j + \sum_{ij} f_{ij} X_i S_j$$

where:

X_i represent fertilizer nutrients i (i.e. N, P_2O_5 and sometimes K)

and S_j represent site specific variables, j, usually previous crop, land type and use farm yard manure.

The coefficients f_{ij}, denote interaction between fertilizer response and site variables and enables specific fertilizer recommendations to be derived for given site characteristics (18, 19).

Following standard procedures, optimality is calculated by setting $dY/dX_i = r_i$ where $r_i = P_i/P_y$ and P_i and P_y are the price of fertilizer and wheat, respectively. This "Naive approach" usually followed by economists was substantially modified by incorporating full costs of fertilizer use. That is, for single nutrient fertilizers:

$$r_i = \frac{(P_i + c + t)(1 + m)}{na(P_y - h)}$$

where;

P_i is the price of fertilizer (e.g. urea)
c is the cost per unit for fertilizer application
t is the cost per unit for fertilizer transport
n is the nutrient composition of the fertilizer
a is the adjustment to experimental yields to reflect the difference between farmer and experimental management ($a < 1$)
h is the cost of harvesting, threshing and transporting wheat
m is the farmers' minimum acceptable rate of return on capital

With the exception of m, all these parameters are readily measured. For example, it has been estimated that the cost of harvesting and marketing wheat in Pakistan accounts for about one third of the wheat price received (i.e. $a/P_y = .33$). (Akhtar et al, 1986; Byerlee et al. 1985). The parameter, m, has been estimated in a number of countries to be as high as 2 reflecting capital scarcity and risk aversion (e.g. Moscardi and de Janvry, 1978). Here we followed Perrin et al (1976) and used a value of m = .5. Together, the inclusion of a, h, r, c and m doubles the effective price of fertilizer to farmers and substantially reduces the calculated optimum fertilizer dosage.

Selected Results of Research in Irrigated Wheat Cropping Systems in Pakistan

Wheat in irrigated areas of Pakistan is grown in several different rotations dominated by rice/wheat, cotton/wheat and maize-sugarcane/wheat. Wheat production has expanded rapidly over the last two decades largely due to widespread adoption of semi-dwarf varieties combined with a rapid rise in fertilizer use and an increased supply of irrigation water. However, there is evidence that wheat yields have levelled off in recent years. Almost all farmers in irrigated areas now use semi-dwarf varieties and moderate fertilizer doses of over 100 kg/ha of nutrients in wheat production.

In this "post-green revolution" phase, there is a growing consensus that further increases in productivity will come through previously neglected aspects of wheat production such as weed control, water management, fertilizer efficiency and stand establishment. Moreover, improvements in wheat production technology will need to be done within specific cropping systems considering the productivity of the total cropping pattern rather than wheat alone.

To meet this challenge, wheat agronomists and social scientists in Pakistan have initiated a series of on-farm research projects in selected areas of the country, representing different cropping systems. The research methodology outlined above has been followed and some results of integrated agronomic-economic surveys and on-farm experiments are reported below to illustrate the importance of considering cropping systems in the development of technology for the wheat crop. Detailed results are given in other studies (1,7,11,12,13).

Background Data from the Surveys/Experiments

Tables 6 and 7 summarize some of the major characteristics of farmers and their production practices in the three research areas. As expected, the majority of farmers are small farmers with under 5 ha. of land, with many tenant farmers. Irrigation water is provided by both canals and tubewells

Table 6. Resource Base of Farmers in Irrigated Areas of Pakistan

	Punjab Rice/ Wheat	Punjab Cotton/ Wheat	NWFP Maize/ Wheat
Average farm size (ha)	8.4	8.2	2.7
Percent fields tenant operated	41	37	59
Percent used a tractor	82	57	81
Percent used a tubewell	81	93	13

Table 7. Major Production Practices and Yields for Wheat in Irrigated Areas of Pakistan

	Punjab Rice/ Wheat	Punjab Cotton Wheat	NWFP Maize/ Wheat
Average number of tillage operations	6	5	3
Broadcast seed (%)	98	98	92
Total fertilizer applied (kg nutrient/ha)	121	143	192
Used farmyard manure on wheat (%)	9	4	38
Removed weeds by hand or chemically (%)	10	17	23
Average yield (t/ha)	1.78	2.29	2.78

but inadequate water supplies often combine with heat stress in the critical grain setting and filling stage of February/March to adversely affect wheat yields. Over half of farmers in recent surveys used tractors for at least part of land preparation. Almost all farmers broadcast seed and few removed weeds after planting. Averagewheat yields ranged from 1.8t/ha to 2.8t/ha.

Crop rotations followed in each area indicate that half or more of wheat is sown after one kharif crop – rice, cotton or maize, depending on the area (Table 8).

Table 8. Crop Rotations in Irrigated Wheat Zones of Pakistan, 1984-85

Wheat fields planted after	Punjab Rice/ wheat	Punjab Cotton/ wheat	NWFP Maize/ wheat
			Percent of fields
Rice	72	6	4
Cotton	–	49	–
Sugarcane	1	–	29
Maize and fodder	12	15	59
Fallow	16	30	3
Other (e.g. vegetables)	–	–	5
	100	100	100

Implications of System Interactions for Wheat Technology

In each of the three irrigated areas, interactions over time in the crop rotation are critical in the definition of factors limiting productivity and in screening solutions to these problems. Three of these – variety and planting date, fertilizer response and weed control – are discussed below :

Conflicts in Planting Dates for Wheat in Relation to the Previous Crop: Because of the risk of high temperatures at flowering and grain filling, wheat yields and their stability are quite sensitive to date of planting. Optimal dates of planting for wheat in all areas are in mid-November. However, conflicts with the harvest of the previous crop push the time of planting of wheat of a large number of fields into December and even into January (Table 9). This is most pronounced in the cotton-wheat system where nearly all wheat planted after cotton was late planted (Figure 3). Indeed, 20 percent of fields were planted in January, when yield potential is on average only half of that of "normal" planted wheat. However, farmers are quite rationally choosing to plant wheat late to maximize productivity of the total cropping pattern. Simple economic calculations show that the return to one additional cotton picking is substantially more than the value of wheat yield lost to late planting (1).

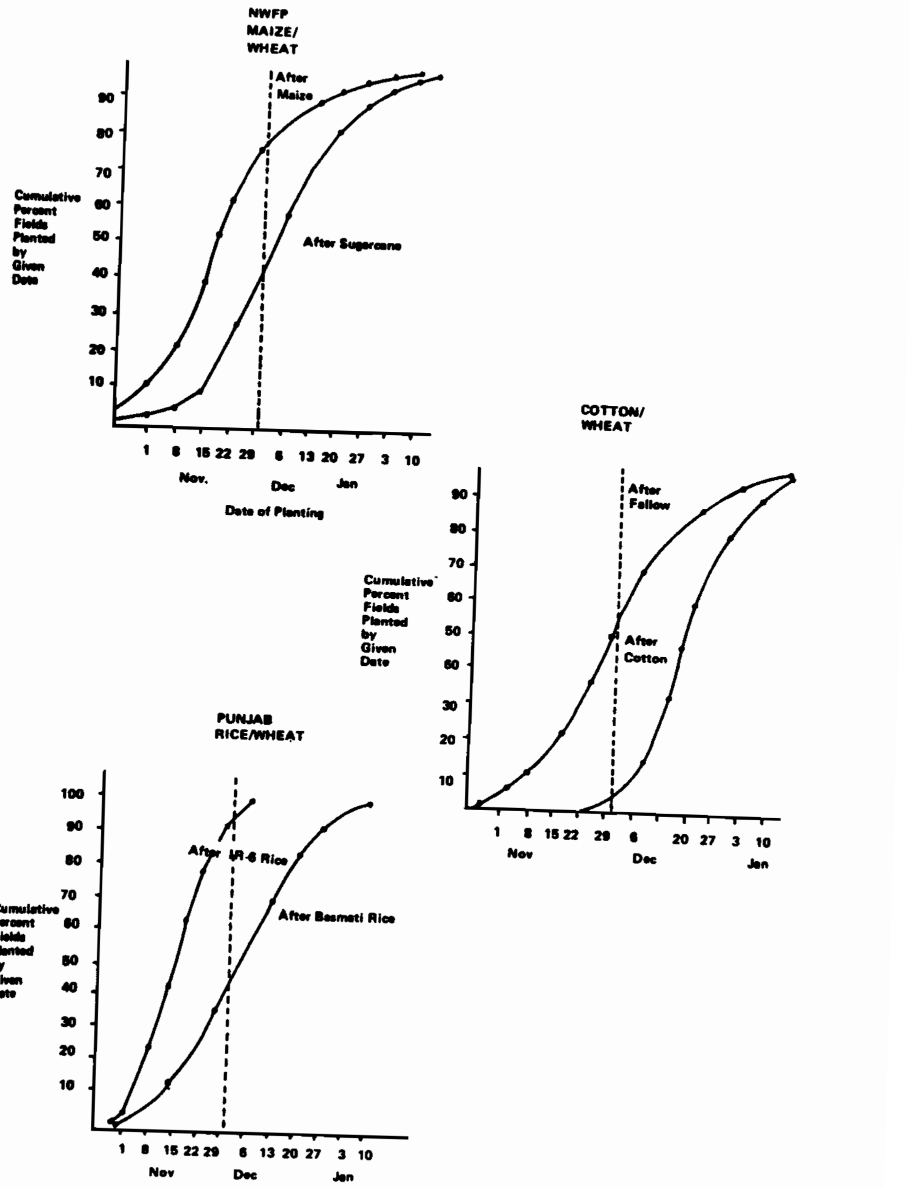
Table 9. Distribution of Planting Dates for Wheat in Irrigated Areas of Pakistan

	Punjab Rice/ wheat	Punjab Cotton/ wheat	NWFP Maize wheat
	(Percent of fields)		
Planting Date			
Normal (before Dec. 1st)	60	29	66
Somewhat late (Dec. 1–15)	30	29	19
Very late (After Dec. 15)	10	41	15
	100	100	100

Recognition of the conflicts in planting dates has a number of implications for developing technologies in these cropping systems. Wheat breeders have until recently emphasised evaluation of varieties at otpimum planting dates. Moreover, for late planting, earliness was assumed to be a desirable characteristic. However, recent evidence indicates that some varieties have tolerance to heat stress and performed well over all planting dates regardless of maturity Fig 4 (10). Moreover, plant breeders working on different crops in a cropping pattern have rarely coordinated efforts to develop varieties which maximize productivity of the total cropping pattern. For example, farmers rapidly adopted an earlier maturity cotton variety NIAB 78, despite the fact that it was not initially recommended by the research service (5).

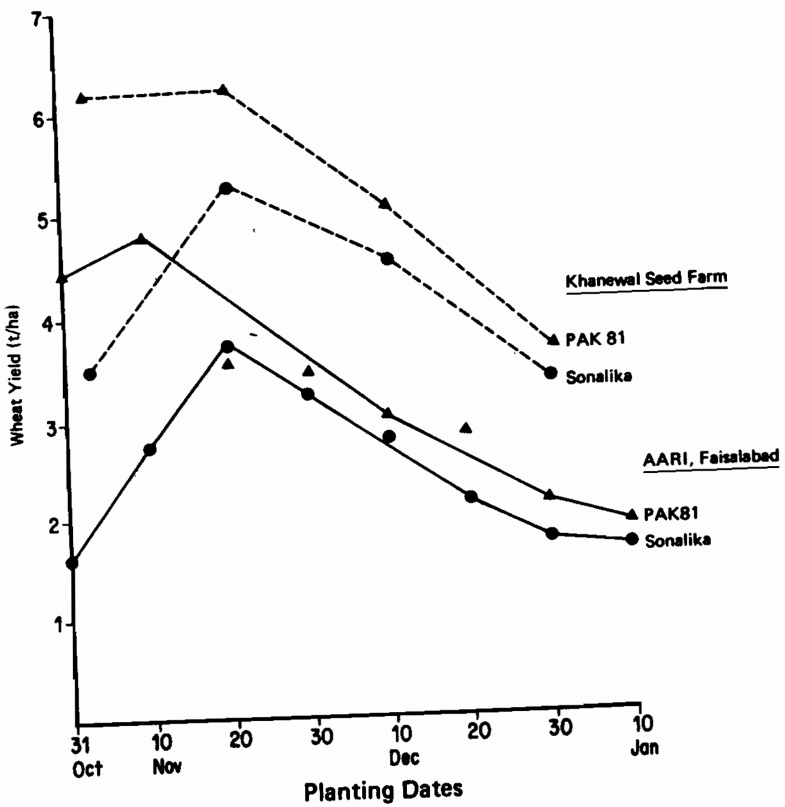
Beyond breeding issues, conflicts can potentially be reduced by shortening the turn-around time from one crop to another. In the rice/ wheat area, especially in heavy soils, this turn-around time may be three weeks or longer as farmers need to remove rice residues and prepare a seed-bed for wheat from the wet puddled soils of the previous rice crop. Recent

Fig 3. Effect of Crop Rotation on Date of Planting of Irrigated Wheat, Pakistan



experiments have shown that direct drilling of wheat with zero tillage can help substantially in alleviating this problem without any loss in yields (13).

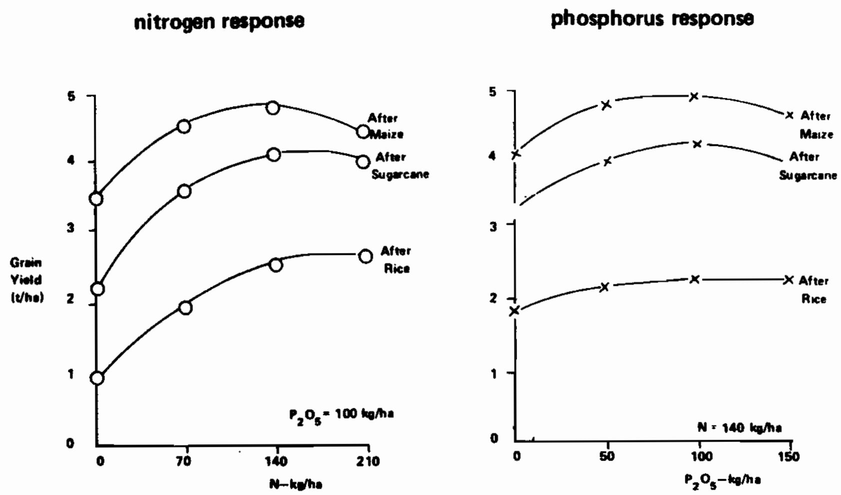
Fig. 4. Effect of Seeding Date on the Yield of PAK 81 and Sonalika Wheat



Fertilizer Response in Multiple Cropping Systems:

Differential responses to fertilizer application by crop rotation have been consistently found in wheat onfarm experiments. Figure 5 shows responses to nitrogen and phosphorous after maize, sugarcane and rice. Economic analysis of these responses indicates an optimum N: P ratio varying from 1.25 in wheat after maize to 3.16 in wheat after rice (Table 10). Researchers have traditionally provided one fertilizer recommendation

Fig. 5. Fertilizer Response Curves for Wheat in Three Different Cropping Patterns



for all irrigated wheat usually based on a 2:1 ratio. Table 10 shows substantial differences between our estimated optima and those currently being recommended. Farmers, on the other hand, have adjusted fertilizer doses to reflect different cropping patterns. Multiple regression analysis showed that previous crop is a significant determinant of farmers fertilizer dose in each of the selected areas. Further work is underway to refine recommendations and also elicit farmers perceptions about pay-offs to increased fertilizer use and changing nutrient balance.

Weed Infestation in Multiple Cropping Systems: In wheat sown contінously in the *rabi* cycle with no weeding, the population of grassy weeds (wild oats and *Phalaris minor)* tends to build up each year. Figure 6 shows the increase in grassy weed infestation as the crop rotation is lengthened. Rotation of wheat with a row crop in the rabi season, which is mechanically or manually weeded, or a fodder crop which is continuously cut provides a means for reducing the population of these grassy weeds. In most irrigated areas of Pakistan, berseem *(Trifolium alexandrina)*, is sown for fodder in the winter and provides an excellent form of control of grassy weeds in subse-

Table 10. Fertilizer Recommendations for Different Cropping Patterns Compared to Farmers' Fertilizer Dose

Rotation	Recommendation Calculated from Response Curve[a]		Current Research Recommendation		Fertilizer Used by Farmers	
	N	P	N	P	N	P
						(kg/ha)
Maize-wheat (NWFP)	103	82	136	57	91	27
Sugarcane-wheat (NWFP)	137	82	136	57	112	37
Rice-wheat (Punjab)	155	49	136	111	77	44

a: Based on response curves and using 1985 prices. The minimum acceptable marginal rate of return on capital for farmers is assumed to be 0.5.

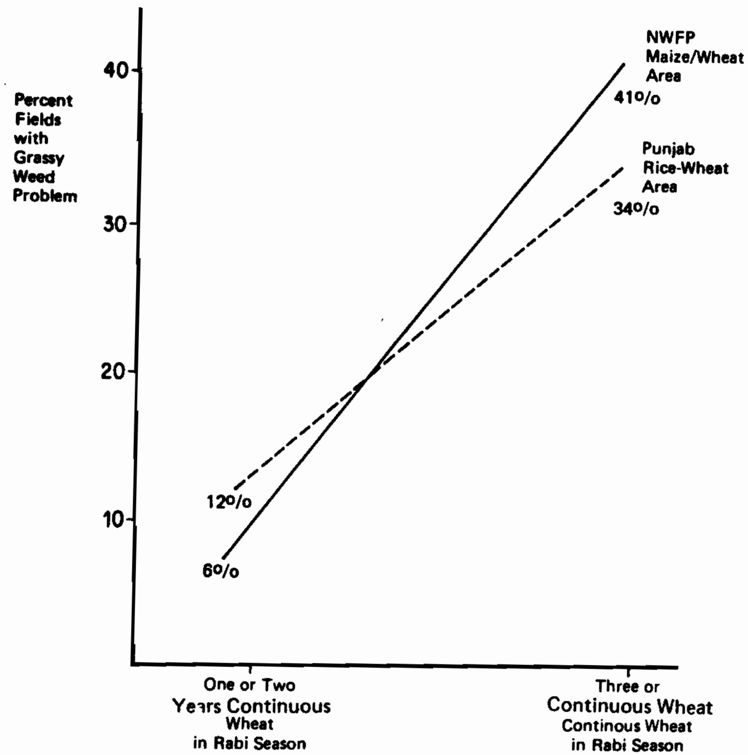
Table 11. Weed Problems and Crop Rotations in Irrigated Wheat Systems in Pakistan

Particulars	Punjab Rice/ wheat	Punjab Cotton/ wheat	NWFP Maize/ wheat
Percent fields with problem weed[a]			
Broadleaf	13	13	35
Phalaris	28	1	11
Wild Oats	6	3	9
Percent fields continuously sown to wheat three or more years in Rabi season	72	51	27

(Continued)

a: Based on researchers scoring of weeds. A weed infestation is defined as a problem if it results in economic loss relative to the cost of a herbicide treatment.

Fig. 6 Effect of Crop Rotation on Grassy Weed Infestation



quent wheat crops. This weed control strategy is, however, only effective for small farmers or farmers who have animals as a cash enterprise. For example, the average length of rotation in the rice/wheat area in the rabi cycle is five years and over 70 percent of wheat fields in this area had been sown continuously to wheat for three or more years. This combined with weed seed dispersal through irrigation systems and mechanical threshers has led to a serious problem of Phalaris infestation in this area (Table 11). In the maize/wheat area, sugarcane and tobacco grown in rotation with wheat have effectively controlled grassy weeds as only 27 percent of fields were sown continuously to wheat for three or more years. (However, broad leaf weeds are a serious problem in this area).

Factors Affecting Yields in Farmers' Fields and Potential for Increasing Productivity

Factors Influencing Yield

Multiple regression analysis of variation in yields was used to establish hypotheses on yield limiting factors in each cropping system. As expected a

Table 12. Summary of Factors Affecting Farmers' Wheat Yields in Irrigated Areas[a]

Particulars	Punjab Rice/ Wheat	Punjab Cotton/ Wheat	NWFP Maize/ Wheat
Positive yield effects			
Nitrogen	**		
Phosphorous		**	**
New improved variety	**	**	**
Number of tillage operations	*		
Number of irrigations	*	*	
Negative yield effects			
Previous crop	* (rice)	** (cotton)	** (sugarcane)
Continuous wheat three or more years	**		
Weed Problem	**b	**c	**c
R^2 of regression equation	.49	.21	.23

a: Based on multiple regression analysis. b. phalaris weed. c. Broadleaf weeds. **Significant at 5% level. * Significant at 10% level.

number of production practices influened yields, although there were differences in each area, particularly with respect to limiting nutrients (Table 12). Previous crop and the number of years continuously planted to wheat were also significant factors in most cases. The continuous planting of wheat had negative yield effects even when weed infestations were included in the equation (Table 12). This suggests other negative aspects of this rotation such as soil structure or other unidentified pest problems.

The "Yield Gap" in Irrigated Wheat Production

It is generally assumed that yields in Pakistan are low and only a fraction of their potential. To some extent, and particularly in NWFP, low wheat yields reflect errors in official statistics. Moreover, the yield gap between farmers' average yields and a feasible *economic* yield of applying known technology is much lower than is usually reported. Table 13 represents feasible economic yields calculated on the basis of on-farm research. The results show that farmers yields are 30–40 percent below potential yields. These yield gaps represent a significant opportunity to increase productivity in all systems. The pay-offs to research and extension efforts which reduce this yield gap are potentially very high.

Table 13. Estimated Yield Gap for Wheat Considering Total Productivity of Cropping Pattern (i.e. Late Planting) and Availability of Irrigation Water

Particulars	Punjab Rice/ Wheat	Punjab Cotton/ Wheat	NWFP Maize/ Wheat
Farmers' average yield (t/ha)	1.8	2.2	2.8
Economic yield potential (t/ha)[a]	3.0	3.0–3.5	4.0
Yield gap (%)	40	27–37	30

a: Based on results of on-farm experiments.

In addition, the yield gap between so-called "progressive" farmers and the small farmer are also less than commonly assumed. Only in the rice/wheat area was there a statisticaly significant difference in yields between small farmers (< 5 ha) and large farmers (> 10 ha) (Table 14). This difference largely reflects better irrigation facilities and a greater use of nitrogen fertilizer by large farmers. In other areas, diffferences are very small or negligible. The scope for transferring the technology of the "progressive" farmer to the small farmer is more limited than commonly assumed.

Table 14. Irrigated Wheat yields by Farm Size Group, Pakistan

Particulars	Farm Size Group		
	< 5 ha	5–10 ha	> 10 ha
	(Yield t/ha)		
Punjab rice/wheat	1.74[a]	1.57[a]	2.14[a]
Punjab Cotton/wheat	2.26	2.40	2.27
NWFP maize/wheat	2.78	2.86	3.16

a: Differences between small farmers (< 5 ha) and larger farmers (> 10 ha) are significant at the 5 percent level only in the rice/wheat area.

Conclusions and Implications

The experiences in implementing a farming systems research approach in Pakistan and elsewhere has identified a number of important elements in the successful development of more appropriate technology for farmers. First, the concept of a recommendation domain is essential to refining research priorities and formulating recommendations. Cropping pattern is probably the single most important variable in defining recommendation domains in Pakistan. The cropping pattern had a consistently significant influence on all wheat production practices across all three cropping systems. Within a given cropping system, there are usually additional criteria for determining recommendation domains, particularly access to irrigation water. Second, on-farm research by starting with the farmers current situation, forces research to focus on those stepwise changes which are acceptable to farmers when added to the current farmer practice (3). In contrast the "package" concept has encouraged research aimed at further refining the "package", which is largely irrelevant to farmers given the wide difference between the package technology and farmers' technology. Third, the on-farm research has had a number of implicatons for designing experiment station research. For example, emphasis is now being placed on designing longer terms crop rotation trials to better understand interactions over-

Table 15. Summary of Effects of Crop Rotation on Farmers' Production Practices for Wheat[a]

Particulars	Punjab Rice/ wheat	Punjab Cotton/ wheat	NWFP Maize/ wheat
Rotations Compared	Wheat after rice compared to wheat after fodder	Wheat after cotton compared to wheat fter fallow	Wheat after sugarcane compared to wheat after maize
Wheat Production Practice			
No. of tillage operations	–ve (**)	–ve (**)	–ve (**)
Percent late planted	–ve (**)	–ve (**)	–ve (**)
Total fertilizer applied	+ve (**)	+ve (**)	+ve (**)
Weed population	+ve (**)		–ve (**)
Yield	–ve (**)	–ve (**)	–ve (**)

** Coefficient of regression significant at 1 percent level
a. Based on multiple regression analysis.

time in major cropping patterns (e.g. the implications of zero tillage in the wheat crop for the succeeding rice crop, especially the potential build up of insect pests if rice residues are not removed). In addition the tendency for wheat yields to decline in a continuous cropping pattern suggests the build up of disease or other pests which need to be analysed in long term trials. These trials will require collaboration of scientists across commodity programmes.

Finally, and most importantly, th experience and information gained by researchers in the diagnostic surveys and in experimentation in farmers' fields allows a clearer understanding of the constraints under which farmers operate and a sharper definition of research priorities. In many cases, these problems are quite different to those observed on experiment stations.

Despite these advanages, the obstacles to establishing and institutionalizing a well focussed and relevant on-farm research effort are formidable (14, 15, 16). The success of the green revolution has rightly added prestige to the discipline of plant breeding and many research systems now have well established breeding programs. Unfortunately, agronomic research is often a neglected discipline with few incentives for relevant problem solving research. In addition, social science programs in agricultural research institutes are still in their infancy. The national coordinated crop research programs of Pakistan as yet do not include social scientists.

On-farm research also requires a decentralized research process with field-based teams having the responsibility of designing and implementing the research program, analysing data and making recommendations. Only through a decentralized system will researchers have the flexibility to address the specific problems of target farmers in their area. This requires drastic changes in the "top-down" system of research planning characteristic of many countries.

Finally, as on-farm research programs develop and solutions to particular problems begin to emerge, the widespread adoption of these improvements will require strong support from extension systems and input distributors – whether public or private. In addition, these research efforts have generated a unique set of data on local farmer circumstances and crop response under farmer conditions. This offers an opportunity to provide new insights and a stronger micro-level data base for policy analysis.

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