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Coordinated Wheat Programme, Pakistan Agricultural Research Council (PARC)
International Maize and Wheat Improvement Center (CIMMYT)

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FOREWORD

I wish to congratulate the Coordinated Wheat Program of PARC and CIMMYT for publishing this report synthesising on-farm research results on wheat in the rice-wheat cropping system of the Punjab. The rice-wheat rotation in Pakistan is represented by 1.5 million hectares which is approximately 20% of the wheat acreage in the country.

Food production in Pakistan must increase at a rate of 3% per annum to meet the demand of the growing population. To increase both the production of wheat and the productivity of the rice-wheat system is, therefore, a national priority.

Research results indicate that a large yield gap exists between average farm yields and yields obtained by progressive farmers. This yield gap ranges from 2 to 3 tonnes per hectare, indicating opportunities which must be exploited.

The Wheat Program of PARC along with CIMMYT, in association with a multi-disciplinary team of scientists, initiated on-farm research on wheat in the rice zone of Punjab some 5 years ago. This was aimed at understanding and describing the major characteristics of the rice-wheat system as well as the identification of major production constraints related to wheat.

This was followed by a large number of experiments from 1984-85 to 1987-88 addressing the most important constraints. The resultant findings substantiate ways to improve productivity of wheat in the area. A rich set of data is presented which hopefully will be of great value for the researchers, extension workers and policy makers. A similar approach, where on-farm research is undertaken with a systems perspective will lead to improved productivity and sustainability of other cropping systems in Pakistan.

Dr. Amir Mohammed,
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EXECUTIVE SUMMARY

This report presents the results of five years of on-farm studies on wheat production in the rice-wheat zone of the Punjab. The work was started in 1983-84 with an informal diagnostic survey and a formal survey at harvest time to explore farmer production practices and causes of low wheat yield in this cropping system. On the basis of the findings of that survey, an on-farm experiment program was developed to seek ways to improve the productivity of wheat in this area. The following is a summary of the work conducted from 1984-88.

1. The surveys indicated that the low yield of wheat sown after rice was associated with 1) late planting of wheat, 2) poor crop stands, 3) weeds (especially *Phalaris minor),* and 4) imbalanced fertilizer use.

2. To find solutions for the above issues, 136 on-farm experiments were conducted over 51 locations in the rice-wheat zone from 1984 to 1988, covering tillage methods, variety, chemical weed control, and fertilizer (NPK) responses.

3. The fields selected for experiments were those where the previous crop was either IR-6, Basmati-370, or Basmati-385 rice.

4. Most experiments were researcher managed and designed to obtain quantitative data on the potential yields of wheat sown after rice. Most experiments were non-replicated within locations. Data for individual sites were combined for analysis across locations.

5. Tillage methods were studied with an eye toward reducing land preparation costs and ensuring the timely planting of wheat after the rice harvest. In a series of experiments on large plots at 42 sites over 4 years, zero tillage was found to reduce land preparation costs by 100% and total planting costs for wheat by 87% relative to conventional tillage methods. While zero tillage resulted in only 6% higher yields than conventional methods when crops under both treatments were planted at the same time, wheat planted under zero tillage *immediately* after the rice harvest produced 24% higher yields than wheat planted under conventional tillage. This difference is due to the nearly 24-day post-harvest period required for conventional tillage/planting operations and to improvements in several other yield related factors in wheat under zero tillage: 16% more tillers, 19% better germination, and 43% less weeds.

6. Wheat varieties are developed and recommended for specific planting dates (early, normal, and late). Managing cultivars with different recommended planting dates is difficult for farmers. Two groups of varieties were tested from 1984-88 to identify varities that are suitable for a wider range of planting dates. Group

one included Pak-81, Kohinoor, and Punjab-85, which are recommended for early-to-optimal planting. The second group included Blue Silver, Faisalabad-83, and Faisalabad-85; all recommended for late planting. In a pooled analysis of all varieties when planted at the recommended time (mid-November), varieties from group one showed significantly higher grain yields than those from group two. Pooled analysis of all the varieties under a late (mid-December) planting showed non-significant differences in yield between the two groups. Kohinoor, Punjab-85, and Pak-81 (the first group) obtained respective yields of 4.0, 4.0, and 4.1 t/ha when planted at the recommended time, and 3.3, 3.6, and 3.1 t/ha when planted late. Blue Silver, Faisalabad-83, and Faisalabad-85 (the second group) obtained respective yields of 3.1, 3.5, and 3.7 t/ha when planted at the recommended time, and 2.9, 3.0, and 3.2 t/ha when planted late. This demonstrates that some late maturing varieties with high yield potential can be used by farmers at early, normal, and late planting dates.

7. *Phalaris minor* was the most important weed identified in the rice-wheat area and reduced yields by an average 400-500 kg/ha in heavily infested fields. Several herbicides were tested at 14 locations over the 1984-87 period. In the pooled results, the use of Dicuran-MA increased average yield almost 1 t/ha (34%) over that of treatments where no herbicide was used. Dicuran-MA gave promising results even when broadcast in a urea or sand mixture, and was also effective at 50% and 75% of the recommended dose. Broadleaf weeds--*Chenopodium album* and *Rumex acetosella*--were important in some fields, but were controlled effectively with Dicuran MA.

8. Fertilizer trials were conducted to obtain N, P, and K response curves for wheat following rice. Four points on the response curve were obtained with treatments varying from 0 to 210 kg/ha for nitrogen, from 0 to 150 kg/ha for phosphorus, and from 0 to 150 kg/ha for potash. Forty-three fertilizer experiments were conducted in farmers' fields over the 1984-88 period. The data were pooled for regression analysis using year, planting time, weed control, and tillage methods as dummy variables. The results show that nitrogen fertilizer has a significant effect on wheat yields, and phosphorus or potash no effect. Late planting (after November 15) reduced yields by 30 kg/day/ha. Weed control increased yields by a significant amount (279 kg/ha). Fertilizer efficiency under zero tillage was less than that under conventional methods, apparently because the fertilizer is not incorporated into the soil under zero tillage, resulting in losses by denitrification. The economics of fertilizer use in the experiments was also analyzed at different marginal rates of return. Results at MRR=0.5 suggest an optimal dosage of 124 kg/ha of nitrogen on wheat sown after rice.

9. The report ends with a discussion of the implications of these results for technology transfer, and suggestions are given for future research. Five major near term research topics are identified:

- Delayed and sub-optimal plant stand establishment
- Inadequate plant nutrients
- Inadequate soil/water management
- Losses to pests/diseases/weeds
- Low profitability

Long term issues discussed include the effects of nutrient depletion and specific biotic constraints (pests/diseases) on sustainability.

Chapter I
INTRODUCTION

Over the past two decades, increases in agricultural productivity in Pakistan have been brought about largely by the spread of high yielding varieties, increased fertilizer use, and greater availability of irrigation water. By the mid-1980s, semi-dwarf wheat varieties had been adopted on almost all irrigated land, over 100 kg/ha on average of fertilizer was being applied to wheat, and it was becoming increasingly difficult to find new sources of irrigation water.

It is now recognized that the growth of the agricultural sector, and wheat production in particular, will depend on changes in other management practices, such as better tillage and plant stand establishment, more timely planting, control of weeds and pests, and the more efficient use of fertilizer and irrigation water. These changes in crop management need to be tailored to fit each of the major cropping systems that involve wheat in Pakistan. Within each system, specific management requirements will often depend on soil type, availability of irrigation water and other location-specific factors. Hence, there is an increasing need for location-specific, farmer-focused research to develop and spread appropriate crop management practices.

This report focuses on an important cropping system in the Punjab: rice-wheat. It is estimated that the rice-wheat zone of that province covers an area of 1.1 million ha, concentrated in the districts of Sialkot, Gujranwala, Sheikhupura, Lahore, Kasur, and Gujrat. There, 72% of the wheat is grown in rotation with rice, and wheat yields are low compared with those of other cropping systems in the Punjab. For example, the average yield of wheat in Sheikhupura and Gujranwala was only 1.6 t/ha in 1984-86, compared with 2.1 t/ha in the nearby Faisalabad District. At the same time, wheat yields are more variable in the rice-wheat zone than in other zones (Hamid et al. 1987).

These low yields reflect the special problems of growing wheat after rice. The need to convert from the flooded and puddled soils required by rice to the well-drained conditions necessary for wheat presents special management difficulties (Hobbs et al. 1988). Despite these problems, this cropping system has continued to expand in response to the increased availability of irrigation water and other inputs and to the growing pressure of population on land.

In order to develop improved crop management practices for wheat grown after rice in the Punjab, the Wheat Programme at NARC initiated the "On-farm Research Project" in collaboration with CIMMYT in 1983-84. The design of the research program followed the standard methodology described in various publications (e.g. Byerlee et al. 1982, Hobbs et al. 1988). In 1983-84, a diagnostic survey of the area was conducted by a multidisciplinary team including social scientists, agronomists, breeders, and extension experts. The objectives of this survey were to understand and describe the major characteristics of the rice-wheat system, with particular emphasis on wheat management, as well as to identify production constraints and to design on-farm experiments that would address the most important constraints. These surveys contained an "informal" component where researchers visited farmers and their fields to gain a firsthand understanding of the area, and a "formal" component where quantitative data on crop management and system variables were collected from a sample of 150 fields. The survey formed the basis for a four-year, on-farm experimental program.

Beginning in 1984, 136 experiments were carried out in the area. The design and treatments for trials changed from year to year as information was accumulated and analyzed. By 1988, researchers believed that sufficient experimental data was available to formulate recommendations. Larger verification/demonstration plots were then established at several sites.

This report synthesizes the information collected from both the surveys and the experiments, and develops a specific set of recommendations for improving the productivity of wheat in rotation with rice in the study area. Suggestions are also given for further research to clarify specific issues and refine recommendations.

Chapter II

THE DIAGNOSTIC SURVEY AND THE DESIGN OF THE ON-FARM EXPERIMENT PROGRAM

The diagnostic survey, conducted from February through April of 1984, consisted of a compilation of secondary data, an informal survey, and a formal survey. Full details of survey methodology and results are described in Byerlee et al. (1984). The diagnostic survey formed the basis for the experiment program conducted from 1984 to 1988. Shortly after the diagnostic survey, farmers adopted several important changes in the management of the rice/wheat system, and these were monitored through further special-purpose surveys. This chapter summarizes the findings of the various surveys and outlines the rationale behind the priorities selected for the on-farm experiments.

Agroclimatic Circumstances in the Study Area

Soil variation in the area has major implications for cropping pattern, production practices, and research. The Soil Survey of Pakistan places soils of the Upper Rechna Doab--which includes most of the rice-wheat area--into three major classes of normal soils and two classes of saline sodic soils (Table 2.1). The normal soils are sub-classified according to soil texture and drainage. Imperfectly drained clay and silty-clay soils are quite suitable for rice but less fit for wheat. Well drained loams and silt-loams are suitable for all types of crops, but their lighter texture makes them less appropriate for rice production. Finally, there are substantial areas of saline-sodic soils that are unsuitable for any type of crop farming.

Table 2.1. Area under different kinds of soils in Upper Rechna Doab

Soils	Area (ha)
Normal soils (non-saline no sodic)	
1. Well drained loams, silt loams, silty clay loam and some sandy soils	251,400
2. Moderately well drained, seasonally imperfectly drained clay and silty clays	123,100
3. Imperfectly drained clays and silty clays (includes some loams and clay loams)	41,457
Saline-sodic soils	93,024

Source: Soil Survey of Pakistan

Farmers of the area have their own soil classification terminology, such as *mehraa, halki mehraa, bhari mehraa*, and *rohi.* In the diagnostic survey these classes were grouped into three types as shown in Table 2.2. Based on this grouping, the distribution of heavier and lighter soils in the fields studied closely followed the figures given by the Soil Survey of Pakistan. While farmers' classifications are admitted to be only approximations, they helped to explain different management practices and to select on-farm research sites.

Though the area is served by a good irrigation canal system, rainfall in the rabi season is an important supplement to irrigation water for wheat production. Annual rainfall ranges from 800 mm in Sialkot District to 425 mm in Sheikhupura District. About one-third of the annual rainfall is received during the rabi cycle, but this varies substantially from year to year (Table 2.3).

Wheat yields are also affected by high temperatures at flowering and the early grain filling stage, in late March and April. Temperatures vary considerably in these months. When hot weather arrives early, the effect on yield is particularly important for late-sown wheat. In 1984-85, March was much warmer than the long term average for that month.

The Rice-Wheat Cropping System

Wheat and rice account for over 80 percent of the cropped area in the rice-wheat tract of the Punjab. Kharif and rabi fodder crops, along with some sugarcane and vegetables, are planted on the remaining area. Common cropping patterns and planting and harvesting dates are shown in Figure 2.1.

Two major rice varieties are used: IR-6 and Basmati. Basmati rice is grown on about 85% of the rice land. The 1984 survey shows that about half the wheat fields were planted late (40% after December 1 and 10 % after December 15th). Possible reasons for late planting include:

- The time needed to prepare a good seedbed from a puddled rice field
- Late harvest of the previous rice crop
- Insufficient soil moisture for proper land preparation
- Too much water in heavy soils after rice or if rainfall occurs in November
- Lack of inputs and farm machinery
- Delayed planting to allow weed germination and destruction

Table 2.2. Farmers' classifications of soil types in the fields surveyed

Soil type	Local terms	Percent of fields
Clays	Rohi, Rohi Mehraa	47
Clay loams and loams	Mehraa, Halki Mehraa, Bari Mehraa	46
Saline patches	Kalar (usually rohi)	7
All		100

Table 2.3. Monthly rainfall at two sites in the rice-wheat area, 1984-88

	1984-85		1985-86		1986-87		1987-88	
Month	Lahore	Sialkot	Lahore	Sialkot	Lahore	Sialkot	Lahore	Sialkot
July	138.0	248.3	162.5	221.8	222.6	190.7	105	90.0
August	0.0	170.0	75.3	162.8	134.4	419.9	62	194.0
September	456.2	96.4	10.5	33.9	60.6	55.5	3	27.0
October	n.a.	0.0	n.a.	100.0	n.a.	8.0	n.a.	9.0
November	5.9	6.1	0.0	13.0	0.0	30.7	0	0.0
December	4.1	4.43	16.8	85.0	9.4	33.3	0	0.0
January	8.8	0.14	5.3	6.1	28.7	8.0	5	54.0
February	0.0	14.0	43.0	61.6	56.6	54.5	28	21.0
March	9.7	6.9	23.0	52.0	21.8	34.2	108	39.0
Total	28.5	30.7	243.1	317.7	124.4	168.7	145	123

Source: Meteorological Department, Lahore.

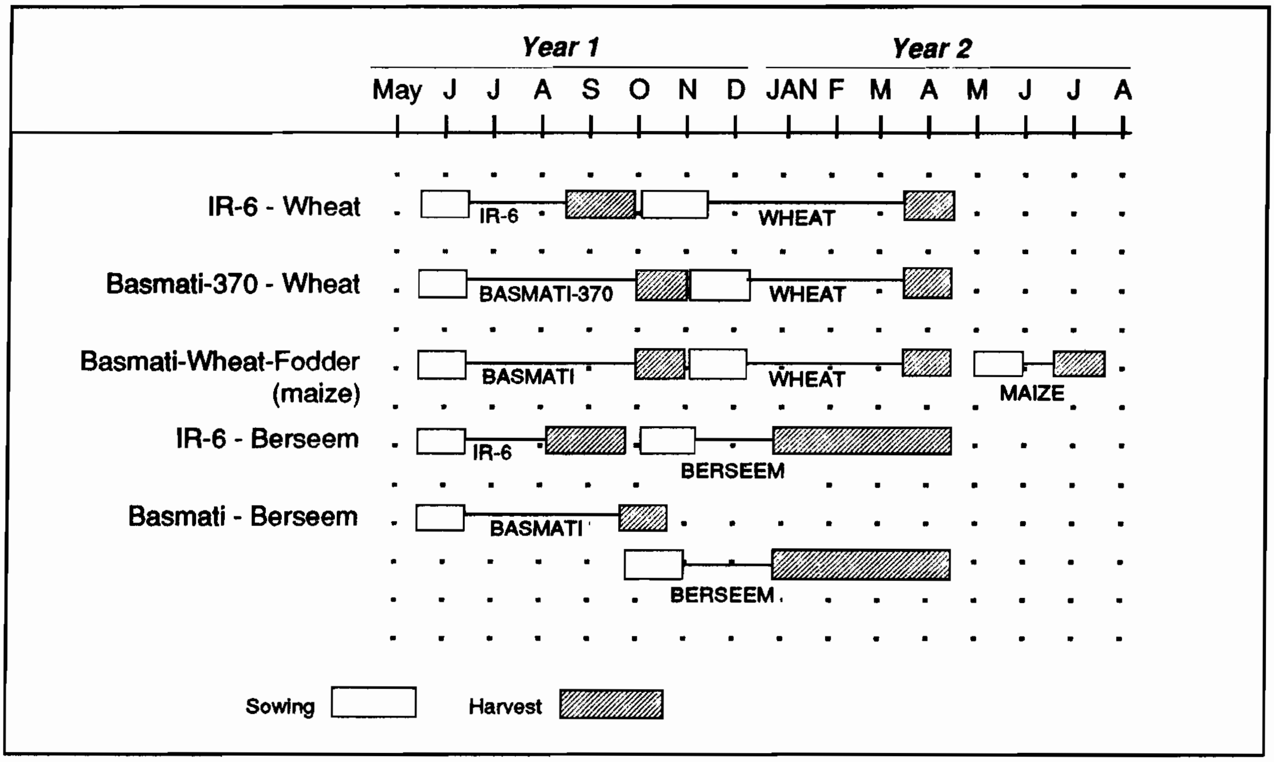

Figure 2.1. Major cropping patterns in Punjab Province

By far the most common reasons would be the first (especially in heavier soils) and the second. Both are related either to delays in rice planting[1]; the use of late maturing rice varieties; labor scarcity at rice harvest time; or post-harvest rice threshing and drying performed in the field prior to tillage for wheat planting. If it rains during planting, an even longer wait is required before the field is in proper condition, resulting in poor land preparation, late sowing of wheat, and a poor crop stand. This can be costly, since it is estimated that for each days' delay in planting after November 20, there is a 1% decline in wheat yield (Hobbs et al. 1988).

Wheat Production Practices

Table 2.4 summarizes the main wheat production practices described in the 1984 diagnostic survey. Land preparation is generally poor for wheat after rice, especially in areas of heavy soils. Farmers may cultivate six to eight times without achieving soil conditions adequate for planting, and wheat stands are often poor as a result.

[1] Basmati rice is photo-sensitive, so that any delay in planting results in a smaller delay in reaching maturity.

Table 2.4. Summary of the main practices observed for wheat production in the 1984 diagnostic survey

Production practices	Low yielding fields (<1 t/ha)	High yielding fields (>2.5 t/ha)	Statistical significance (Prob.)
Average number of plowings	5.2	6.9	.01
Percent use new approved varieties	7	29	.07
Percent plant after December 1st	45	32	.38
Average dose of N (kg/ha)	55	84	< .01
Average dose of P_2O_5 (kg/ha)	41	43	.81
Average number of irrigations	2.6	3.5	< .01
Percent pre-irrigated	32	57	.08
Average days to first irrigation	30	25	< .01

Almost all the farmers broadcast seed and then cover it using a cultivator and a plank. Drilling is not practiced because the soil clods and rice stubble left by poor land preparation hamper the performance of available drill types. The standard seed rate in the area is about 100 kg/ha, although higher rates are used for late planting.

According to the 1984 survey, the wheat variety Yecora was grown by 58% of farmers and Blue Silver by 18%. Both of these varieties were released in the early 1970s and Yecora is banned because of its susceptibility to leaf and stripe rust.

The most common fertilizer dosage was 1 bag/acre of DAP at planting time, followed by 1 bag/acre of urea with the first irrigation, for a total application of 80-57-0 kg NPK/ha. This is considerably below the Punjab recommendation of 132-111-0 kg/ha, especially for phosphate. Farmyard manure was applied to wheat fields by only 10% of the farmers, nearly always on land they themselves own rather than on rented land, and usually on fields close to the village.

With inadequate land preparation, poor crop stands, and the prevalence of a single rotation (rice-wheat), weeds--particularly the grassy type--have become a major problem in the rice-wheat area. *Phalaris minor* and to a lesser extent *Avena fatua* and *Lolium temulentum* are important weeds. Broad-leaf weeds, especially *Chenopodium album*, *Medicago denticulata*, *Rumex acetosella* and *Melilotus alba* are also common.

In the diagnostic survey of 1984, 28% of the sampled fields had serious *Phalaris minor* infestations. Multiple regression analysis of yields across fields indicated an average loss of 429 kg/ha in fields seriously infested by *Phalaris minor*.

Few farmers practiced hand weeding, and mechanical control with a bar harrow was not practical, since wheat is not planted in rows. Some farmers used the *Dab* method, where weeds are allowed to germinate in irrigated fields and then killed by extra cultivation before planting. For *Phalaris minor* and *Avena fatua* this delays wheat planting beyond the optimum date, since both weeds require cool weather to germinate. Crop rotation, especially planting berseem in the rabi season, was a widely-used and very effective weed-control measure, but the limited fodder market prevented frequent rotation with berseem. In the 1984 survey, 77% of wheat fields had been planted continuously to wheat in the rabi season for three or more years.

An average of three irrigations were applied to wheat. Rains in February and March, when they occur, help reduce mid-season moisture stress for wheat following rice. After Basmati rice, farmers normally planted in "wadwater" conditions; that is, they irrigated the standing rice crop to provide moisture for planting wheat. However, after other crops and after fallow, farmers used the *rauni* method (irrigation prior to planting). Pre-irrigation is preferable, since crop residues can be incorporated more easily, and there is a greater opportunity to control weeds.

In either case, the timing of the first irrigation after planting wheat is very critical. Farmers irrigated their fields 10-20 days after germination, causing waterlogging at a critical stage and yellowing in the seedlings. It is suggested that this problem can be avoided by delaying the first irrigation to 30-35 days after sowing so that seedlings are less sensitive.

Major Factors Limiting Productivity and the Design of the Experiment Program

The principal factors identified from the diagnostic survey as limiting production are listed in Table 2.5. After Basmati rice, wheat was planted late with relatively poor land preparation and poor stands. Continuous rotation with rice was common. Weed problems were severe in many fields. Multiple regression analysis of yield differences in the 150 fields sampled confirmed most of these effects (Table 2.6). In addition the level of nitrogen applied had a highly significant effect on yields, while phosphorus applications had no effect. The equation also showed that the adoption of the new variety Pak-81 significantly increased yields.

Table 2.5. Summary of major problems in wheat production and possible responses

Problem	Causes	Farmer response	Possible research and extension responses	
			Intermediate-term	Long-term
Poor stand	Poor land preparation, crop residues. Farmer broadcasts seed. Moisture condition at time of seeding often not appropriate. Insufficient time after Basmati rice. Waterlogging and seedling injury if irrigate too early.	Attempts more tillage operations if possible. Waits for drying out of land to plant, causing late planting. Irrigates later and drains field after 24 hours.	Higher seed rate. Apply 1st irrig. later when seedings less sensitive to waterlogging.	1. Better land preparation through alternative tillage implements. 2. Direct drilling in crop residues. Zero tillage. 3. Alternative cropping patterns.
Late planting	Insufficient time after harvest of Basmati rice and drying of rice in fields. The need to wait for appropriate moisture conditions.	Reduces land preparation. Favors IR-6 or earlier maturing rice varieties.	Screen wheat varieties for late planting and rice varieties for earlier maturity	Direct drilling and zero tillage (as above). Alternative cropping patterns including rice and non-rice crops
Variety	Use of discarded variety, Yecora, which is susceptible to rust and also offers poor competition for weeds because of short stature.	Seeks to change variety but encounters seed distribution and extension problems .	Verification/ demonstration of new varieties. Set up seed distribution.	Study of seed distribution system and possible alternatives for reaching the farmer.
Weeds	*Phalaris* is a major weed of wheat. Growth is encouraged by poor stands and practice of continuously cropping wheat. Little hand weeding because of labor costs. Equipment not available for herbicide application.	1. Rotates with berseem to clear weeds. Limited by area of berseem. 2. Late planting and pre-irrigation to germinate weeds before wheat. However late planting itself produces lower yields.	1. Herbicide application in seriously infested fields. (Cost at current prices is about 500 kg/ha of wheat.) Broadcast herbicide and reduce rate.	1. Better stand to choke early weed growth. Higher seed rate. 2. Mechanical control with bar harrow if wheat is drill planted. 3. Canal maintenance to limit distribution of weed seed. 4. Study other ways to apply herbicide.
Poor drainage/ land leveling leading to waterlogging and uneven distribution of water	Puddling of rice fields leads to hard pan which inhibits drainage in wheat.	Priority given to practices which lead to a good rice crop at the expense of wheat.	1. Try use of deeper tillage (break hard. pan.)	1. "Dry" planting or rice which eliminates puddling. 2. Use of green manure/ crop rotation to improve soil structure. 3. Precision levelling of larger fields.
Poor application of N-fertilizer	1. Many fields with poor stands and weeds lead to reduced N-response. 2. Farmers often lack information on appropriate fertilizers and doses. Ratio of N to P_2O_5 in wheat is often too low. 3. Poor distribution of fertilizer in the field.	N-levels are continuing to increase. However, doubtful if higher dose of N is profitable unless stands are improved and weeds controlled.	Extension efforts on balance of $N:P_2O_5$. Possible reduction of P_2O_5 in favor of N. Analysis of fertilizer experiments by cropping pattern. Simple experiments to test P_2O_5 response.	1. Improved stands and weed control will lead to improved fertilizer response. 2. Possible mechanical fertilizer application to improve distribution in the fields.
High cost of harvesting and threshing	Harvesting, threshing, and marketing account for 30% of total returns.	Some mechanical reaping to save harvest labour.		Analysis of constraints and implications of large scale mechanical harvesting using reapers and combines.

Table 2.6 Regression of yield on management practices and cropping history in wheat production

$$Y = 873 + \underset{(4.44)^{**}}{60.0\,N} - \underset{(2.31)^{**}}{.316N^2} - \underset{(3.24)^{***}}{.505N{*}P} + \underset{(2.15)^{**}}{331\,VARIETY} + \underset{(1.80)^{*}}{40.0\,TILLAGE}$$

$$- \underset{(1.67)^{*}}{319\,ONEIRR} - \underset{(1.41)}{158\,LATEPLANT} + \underset{(1.65)^{*}}{280\,PREVCROP} - \underset{(3.21)^{***}}{407\,CONTWHEAT}$$

$$- \underset{(3.34)^{***}}{429\,PHALARIS} + \underset{(1.43)}{165\,LOAMSOIL}$$

N = 141 $R^2 = .49$

t - statistics are given in brackets. (significance levels: *10%, **5%, ***1%)

Where:

Y= yield (kg/ha)
N = nitrogen applied
P = phosphorus applied
VARIETY = 1 for newer approved variety (e.g. Punjab-81); 0 otherwise
TILLAGE = number of tillage operations
ONEIRR = 1 for fields with only one irrigation, 0 otherwise
LATEPLANT = 1 for fields planted after December 1st; 0 otherwise
PREVCROP = 1 for fields planted to a crop other than rice; 0 otherwise
CONTWHEAT = 1 for fields without any rotation for the last three or more years; 0 otherwise
PHALARIS = 1 for fields with substantial or serious *Phalaris* infestation; 0 otherwise
LOAMSOIL = 1 for loams and clay loams; 0 otherwise

Table 2.5 summarizes the various problems, farmers' responses to each, and possible courses of action for research and extension. Clearly, the on-farm research program had to prioritize from this list on the basis of the resources available for research. Thus, four major areas of research were selected.

Tillage/planting method Direct drilling under zero tillage was considered a potential solution to the problems of poor land preparation, poor stand, and late planting. The availability of an imported drill suitable for direct drilling also enabled testing of this approach. It was recognized that zero tillage might require changes in production practices such as fertilizer application, weed control, and rice stem borer control[2], and experiments or studies were designed to provide information on these issues as well.

[2] The rice stem borer population may be related to the amount of rice stubble left standing in the field over the rabi season.

Weed control The frequently high losses to weeds, especially *Phalaris minor*, and the inadequacy of farmers' weed control methods (e.g. rotation and pre-irrigation) suggested the need to examine the appropriateness of chemical weed control. At the time of the diagnostic survey, it was estimated that the main grassy weed herbicide, Dicuran MA, would require a yield increase of about 500 kg/ha to make its use profitable for farmers. Hence chemical weed control experiments were designed to examine methods and doses of application that would reduce costs.

Variety The widespread use of rust susceptible varieties suggested the need to verify and demonstrate newly released varieties under farmers' conditions. Since much of the wheat was planted late, performance of varieties at late as well as recommended dates was an important criterion for varietal selection.

Fertilizer The high response to nitrogen and the apparent lack of response to phosphorus observed in the diagnostic survey suggested the need to examine optimum doses of fertilizer in the rice-wheat rotation. This led to a series of fertilizer experiments designed to test N and P response over a wide range of application levels.

This experimental program--which focused on tillage, weed control, variety, and fertilizer use--addressed all the major wheat production problems listed in Table 2.5, with the exception of drainage, levelling, irrigation, and the high costs of manual harvesting. It was recognized that the program emphasized short term solutions and that longer term experiments were also needed, especially to identify problems in the continuous cropping of rice and wheat and to test more appropriate crop rotations.

The diagnostic survey also identified considerable variation within the rice-wheat area for such factors as soil type, irrigation and water availability, and farm size. The technological components included in the experiments are applicable across this range of variation, and experiment sites were selected to represent both heavy and light soils. However, emphasis was placed on areas with good access to irrigation water. No attempt has been made in this report to determine the effect of soil type on recommendations for farmers, but further work in the rice-wheat area should focus on recommendations for sets of farmers operating under homogeneous conditions, especially soil type.

Recent Changes in the Rice-Wheat System

In the period following the diagnostic survey of 1984, several important changes occurred in the rice-wheat system. These included the adoption of combine harvesters and of a new, earlier maturing rice variety, Basmati-385, which facilitated the timely planting of wheat, and the adoption of new wheat varieties.

In the early 1980s, the Agricultural Development Bank of Pakistan began to finance loans to local entrepreneurs for the purchase of combine harvesters. By 1987 an estimated 250 combines were operating in the rice-wheat area (Smale 1987), early on in the hands primarily of large-scale farmers able to afford the outlay. Within the focus of this study, the major advantage of combine use was more timely harvesting and threshing of rice. Farmers estimated that rice fields were cleared 30 days earlier through the use of combines than by hand harvesting. The adoption of this technology, however, was deterred by the fact that farmers received lower prices for machine harvested rice due to grain breakage and straw loss.

More timely planting of wheat was also aided by the release of the new rice variety Basmati-385 in 1986. This variety matures an average of 14 days earlier than Basmati-370. Much of that additional time was used by farmers for more careful seedbed preparation; thus, wheat after Basmati-385 was planted only 6 days earlier than wheat after Basmati-370, on average. The mean yield of Basmati-385 was 48% higher than that of Basmati-370 (Sharif et al. 1989), with an aroma and cooking quality equivalent to those of the older variety. Basmati-385 was adopted very rapidly, covering 71% of the rice area by 1988 (Sharif et al. 1989). The widespread use of this variety should allow more time for land preparation and planting of wheat, although this effect is partially cancelled out by the growth in area sown to Basmati rice--from 66% of all rice land in 1985 to 86% in 1987--which displaced early maturing IRRI varieties.

Even with the use of combine harvesters and the new Basmati rice variety, there is still considerable risk of late planting of wheat, especially if rains occur in November. Research is currently underway to quantify the impact of these changes on the date of planting of wheat.

Finally, another important change in rice-wheat production was the adoption of new wheat varieties. Special purpose surveys from 1985 to 1988 (Heisey et al. 1987) documented the spread of the variety Pak-81 since its release in 1981. By 1988, the variety covered over half the wheat area, largely in substitution of Yecora. Nonetheless, the adoption of wheat varieties released in 1983 and 1985 has been negligible. The on-farm experiments described in this report were designed to test the performance of the new varieties.

Chapter III

MANAGEMENT OF THE ON-FARM EXPERIMENT PROGRAM

Four types of experiment were set up in 1984-88 to address each of the main production concerns of the rice-wheat zone: 1) tillage, 2) variety, 3) chemical weed control, and 4) fertilizer. The methods of field selection, planting, and management were similar for each experiment type and are described in this chapter, while the specific designs and treatments for each experiment are given in the following chapters.

Site and Field Selection

The impossibility of covering the entire zone was clear from the outset. Hence, experiments were concentrated in the Gujranwala, Sialkot, Daska, Gujrat, Hafizabad, and Sheikhupura areas in three or four major clusters shown in Figure 3.1. These clusters were selected on the basis of differences in soil type (ranging from heavy clay loams to lighter loamy soils), proximity to a research station or sub-station, easy access to the main Islamabad-Lahore highway and, most importantly, the availability of farmers interested in cooperating in the experiments. All experiments were sown on fields where the previous crop was either IR-6 or Basmati rice. In the first two years of the program, an attempt was made to balance sites equally between fields planted after IR-6 or Basmati rice. However, by 1986-87, IR-6 rice area had decreased dramatically, and the program switched its focus to production constraints for wheat following Basmati rice, by far the dominant crop in the area.

Table 3.1 summarizes the number of locations planted each year under each experiment type.

Table 3.1. Summary of types of experiments conducted and number of locations in each year, 1984-88

Year	Number of locations	Type of experiment				Total (expmts.)
		Tillage	Variety	Fertilizer	Herbicide	
1984-85	8	8	9	8	5	30
1985-85	15	15	12	10	10	47
1986-87	13	13	6	9	3	31
1987-88	15	6	7	15	-	28
Total	51	42	34	42	18	136

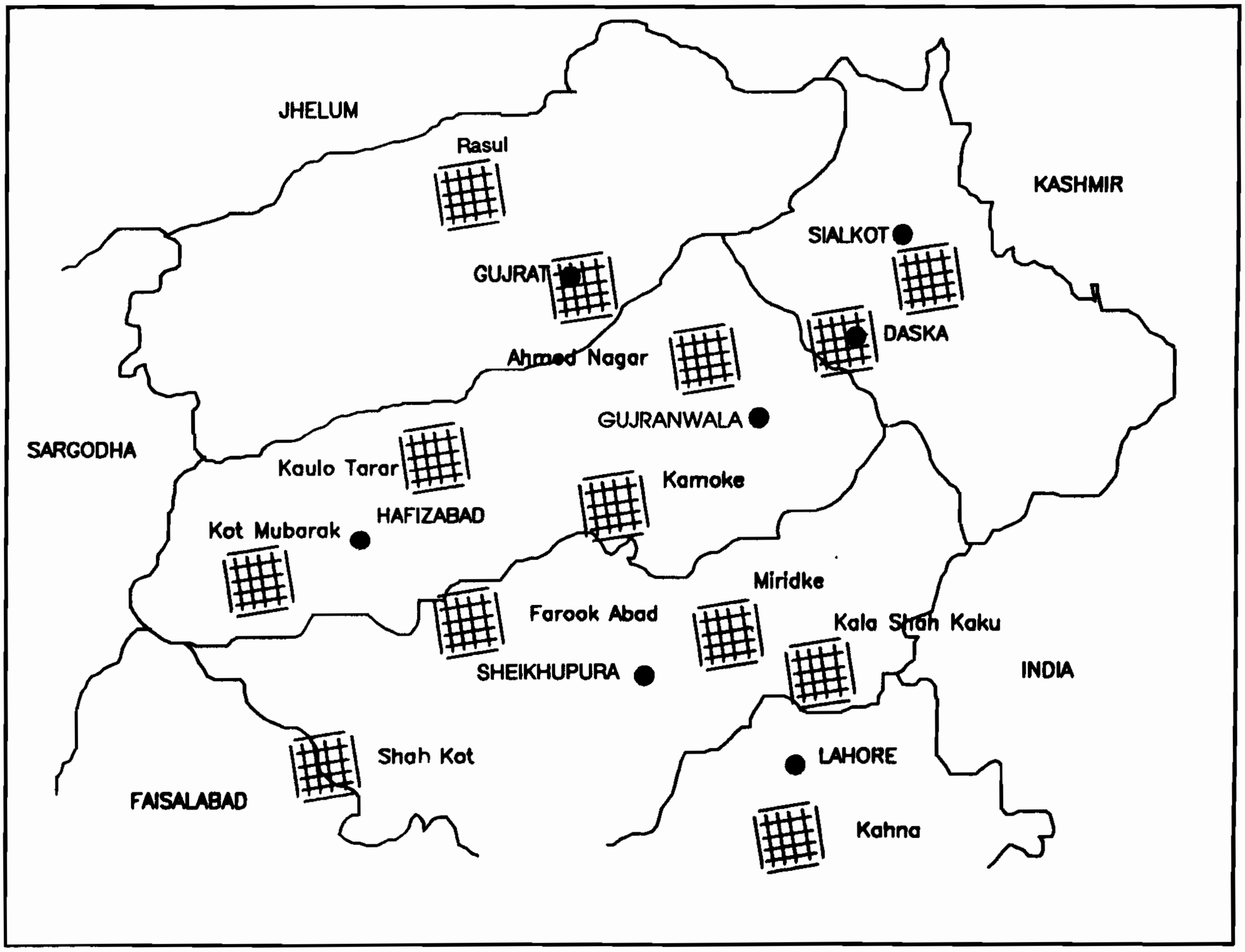

Figure 3.1. Locations in the study area where experiments took place

Management of the Experiments

Most operations in the experiments except land preparation were performed by researchers. Herbicide treatments were superimposed after crop emergence in plots usually 20 m long by 3.6 m wide on farmers' fields selected for uniform crop stand and weed population.

In general, the experimental program employed large plot sizes. For example, tillage studies were performed on plots of 0.2-2.0 ha, depending on the size of the field and the interest of the farmer. For tillage, herbicide, and variety trials, large plots were used both for experiments and as demonstrations to farmers. In the case of fertilizer trials, where there were 9 to 10 treatments, plots in all years were at least 100 m^2. All experiments, including the zero tillage studies, were planted with an Aitchison no-till seed drill equipped with inverted T-openers.

In the early years of the on-farm experiment program, all seed, fertilizer, and herbicide inputs and equipment were provided by researchers. In the later years, especially for large tillage demonstration plots, farmers provided all inputs.

Experimental Design

All experiments were unreplicated and data were analyzed across locations. Normally, an incomplete factorial design was used for the fertilizer trials.

Recording Harvest Data

For the large tillage experiment plots, yield was estimated by taking four 3m^2 samples for each treatment at harvest. In all other experiments, four 2m^2 samples were taken. One of the four samples from each treatment was randomly selected to count tillers/m^2. Bundles were then wrapped in cotton bags to avoid grain loss, transported to a nearby research station or other appropriate site, and dried in the sun. Afterwards, they were weighed and threshed with a Hege or Winter-steiger combine. A sub-sample of the threshed, sun dried grain was taken to estimate 1000-grain weight.

All field-book data were transferred to computer files for analysis with the MSTAT statistical package

Economic Analysis of Results

Experimental data pooled across sites and years were subjected to economic analysis of the type described in CIMMYT (1988), in order to generate recommendations for area farmers. Yields were adjusted downward by 10% to reflect differences between experimental practices and plot sizes and those of farmers. All prices were based on the 1987-88 seasonal averages. From the farm gate price for wheat of Rs 2/kg, 30% was subtracted to account for harvesting, threshing, and transportation costs as estimated in Byerlee et al. (1984). Given the lack of an effective credit program in the area, it was assumed that a minimum marginal rate of return on investment of 100% was needed to induce farmers to adopt new technology.

Chapter IV

TILLAGE SYSTEM EXPERIMENTS

Introduction

As described in Chapter 2, major emphasis in the experiment program was placed on testing and evaluating zero tillage for growing wheat after rice. It was hypothesized that zero tillage could provide important advantages in addressing the major problems for wheat in the rice-wheat system, including poor land preparation, late planting, poor stands and high land preparation costs. Previous, limited research (Ellis et al. 1979, Sykes 1977, Baliyan et al. 1984) on zero tillage with direct drilling suggested the feasibility of this technology for wheat production. At the same time, it was hypothesized that if zero tillage were impracticable, then deep tillage with a moldboard plow to break up the hard pan after rice might be another way to reduce costs and improve rooting and yield in wheat planted after rice.

Over the four-year period covered by this research program, some 43 experiments were conducted in the study area to evaluate, verify, and demonstrate zero tillage (and to a lesser extent deep tillage). After the early years, when the main emphasis was on evaluating the feasibility of alternative tillage options, the design and focus of these experiments switched to the verification and demonstration of zero tillage, which had by that time proven extremely successful.

Types of Tillage Experiments

In all experiments, zero tillage was compared with farmers' conventional practices. In zero tillage plots no land preparation was done and wheat was planted directly in the standing rice stubble with an Aitchison Seedmatic drill. The farmer prepared an adjacent plot in the conventional manner, usually involving 4 to 8 cultivations and plankings, followed by broadcasting of the wheat seed and a further operation to cover the seed. Seed rate, fertilizer levels, number of irrigations, and weed control were constant across treatments and followed official recommendations. In the 1984-85 experiments, the zero tillage plot was planted when the farmer planted the rest of the field. Half the sites had been previously planted to IR-6 rice and half to Basmati rice. In later years zero tillage planting was done as soon as feasible after rice harvest, regardless of when the farmer planted. The selection of sites favored fields previously planted to Basmati rice (by that time grown on 85% of the rice land in the study area).

After the promise of zero tillage for rice-wheat systems became clear, later experiments were designed to test important implications of this new technology. Specifically, 1986-87 and 1987-88 experiments compared broadcasting of nitrogen fertilizer on the surface to placement with the drill. Later studies also explored the possibility of zero tillage on wheat affecting the following rice crop, since the intact rice stubble provided a potential breeding ground for the rice stem borer.

In 1984-85 and 1986-87, a deep tillage treatment was also included in the tillage systems experiment. This involved a moldboard plowing followed by a rotavator plowing or two cultivations. Planting was done with the same Aitchison Seedmatic drill and all other management factors were kept constant.

Summary of the Results of Zero Tillage Experiments

Table 4.1 summarizes information on grain yield and tillers/m^2 across 42 locations and four years of experiments. In 1984-85, farmers' tillage gave significantly higher yields than zero tillage, a fact explained by the researchers' inexperience in managing seed depth, fertilizer application, and row spacing with the new drill (which was originally set to the conditions of New Zealand, from where it had been imported). In 1985-86, conventional and zero tillage were compared on larger plots at 15 locations for similar planting dates, and resulting yields were not significantly different. In 1986-87 and 1987-88, zero tillage produced significantly higher average yields than conventional tillage across 19 sites--probably due to the fact that in those years zero tillage plots were planted on average 24 days[3] before the farmer's crop.

Table 4.1 also shows that in three of the four years of experiments, wheat under zero tillage with direct drilling produced a significantly higher number of tillers/m^2 than that under conventional tillage.

Over all 42 sites and 4 years of experiments (Fig. 4.1), zero tillage provided only 6% higher yields, a non-significant difference. However, in the last two years of experiments when planting dates were allowed to differ between treatments, zero tillage yields were 24% higher than those obtained under conventional practices. Moreover, the principal expected outcome of zero tillage was not to increase yields, but rather to reduce farmers' land preparation and planting expenses and thereby enhance the profitability of the rice-wheat system, an objective which it certainly achieved.

A comparison of zero and conventional tillage at recommended and late planting dates In the 1985-86 cycle, 5 of the 15 locations were planted at the recommended time (early- to mid-November) and 10 were planted late (mid-December). Results presented in Table 4.2 show significantly higher grain yield for the zero tillage treatment than that of conventional tillage, for sites planted at the recommended time. However, for late planted sites there was no significant yield difference between treatments. There were 16% more tillers/m^2 in zero tillage plots planted on the recommended date. The longer growing season provided by planting in November apparently enabled better tillering under zero tillage.

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[3] The time required to perform conventional tillage operations

Table 4.1. A comparison of the effects of zero tillage and farmer practices on wheat yield and tillering at 42 locations in on-farm experiments, 1984-88

		Grain yield (kg/ha)			Tillers/m²		
Year	No. of locations	Zero tillage	Farmers' practice	Significance	Zero tillage	Farmers' practice	Significance
1984-85	8	3032	3275	5%	264	275	n.s.
1985-86	15	3600	3516	n.s.	253	232	1%
1986-87	13	3791	3509	2%	260	236	3%
1987-88	6	4279	3560	1%	290	261	8%
Average	-	**3675**	**3465**	**n.s.**	**267**	**251**	**n.s.**

Table 4.2. A comparison of the effects of zero tillage and farmer practices on wheat yields and tillering at recommended and late planting dates,1985-86

	Recommended planting (5 locations)		Late planting (10 locations)		Average	
	Yield (kg/ha)	Tillers/m²	Yield (kg/ha)	Tillers/m²	Yield (kg/ha)	Tillers/m²
Zero tillage	3782	236	3509	263	3600	253
Farmers' practices	3267	204	3460	246	3516	232
Significance	1%	2%	n.s.	n.s.	n.s.	n.s.

The effect of zero tillage at different planting times In 1986-87 and 1987-88, planting date was varied with treatment. Zero tillage plots were planted as soon as possible after the harvest of Basmati rice, regardless of when the farmer planted the rest of the field. At six sites this resulted in zero tillage plots being planted an average 24 days earlier than the conventional tillage plots (Table 4.3). At the other 7 locations, the difference in planting was only 3 to 4 days (Table 4.4).

Data on yield for each tillage treatment are summarized in Tables 4.3 and 4.4. As would be expected, at the six locations where the differences in planting date were 10 days or more, significantly higher yields were obtained on the zero tillage plots than on the conventional tillage plots. The average yield gain at these locations was 25%, equivalent to 30 kg/ha for every day's delay in the date of planting or about 1% per day. These results are consistent with other studies which address the effect of delayed planting on wheat yields (Hobbs 1985).

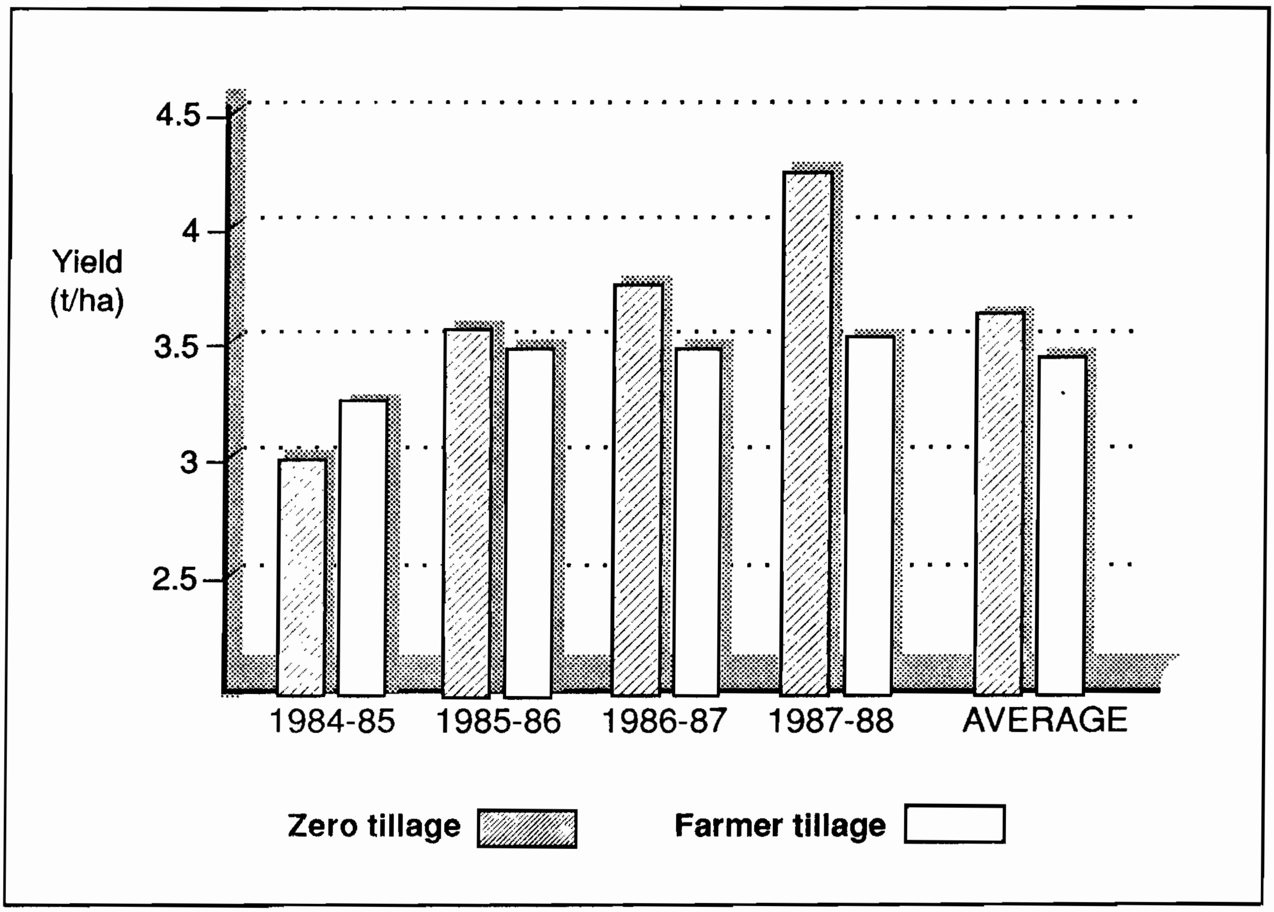

Figure 4.1. A comparison of yields under zero tillage and conventional tillage, 1984-88

At the seven locations where planting dates varied little between tillage treatments there was no difference in yields between the two treatments.

Effect of zero tillage on plant emergence and weed population In 1985-86, plant density and weed population data were collected soon after emergence. As shown in Table 4.5, seed planted under zero tillage had 19% better emergence than that planted using conventional methods, since in the latter case seeds are sometimes buried too deeply to emerge. Even more significant were the 43% lower weed densities observed when direct drilling was used in place of conventional methods. This can be explained by the fact that conventional land preparation disturbs the soil, bringing new weed seeds to the surface, and that the rice stubble and higher wheat seedling densities found under zero tillage simply leave less room for weeds.

Table 4.3. The effect of zero tillage on planting date and yield, 1986-87.

Location	Yield (kg/ha) Zero tillage	Yield (kg/ha) Farmer practice	Days difference between zero tillage planting and farmer practice
Mundir Sharif	4245	2660	33
Ashraf Maujianwala	2689	2198	22
Daska site-I	3842	2735	13
Daska site-II	3143	3209	10
Daska site-III	3838	3420	44
Ahmad Nagar	4308	3526	20
Average	**3677 a**	**2598 b**	**24**

Figures followed by different letters are significant at 5% level using DMRT.

Table 4.4. The effect of zero tillage on yield with planting date held relatively constant, 1986-87

Location	Yield (kg/ha) Zero tillage	Yield (kg/ha) Farmer practice	Days difference between zero tillage planting and farmer practice
Aslam Gujrat	3909	3770	4
K.S.K. farm (early)	5543	5306	3
Sheikhupura	3113	3575	5
Ahmad Nagar	4320	4791	0
Ashraf Maujianwala	3770	3739	3
K.S.K. farm (late)	3225	4391	5
Daska	3334	2297	5
Average	**3888**	**3981**	**4**

Effect of fertilizer placement and timing in zero tillage plots Table 4.6 summarizes the results from two locations in 1986-87 where three methods of nitrogen application were compared in zero tillage plots: 1) placement with the drill at the time of planting, 2) broadcasting at the time of planting, and 3) broadcasting with the first irrigation. In all cases, phosphorus was applied by broadcasting at the time of planting but not incorporated.

Nitrogen placement at planting and broadcasting at the first irrigation gave equivalent results, whereas broadcasting at planting resulted in significantly lower yields (Table 4.6). It is likely that volatilization of the nitrogen broadcast under dry conditions resulted in significant nitrogen loss. These results support other evidence

Table 4.5. Effect of zero tillage on plant emergence and weed population, 1985-86

Method	Plants emerged/m² (11 locations)	Number of weeds/m² grasses (6 locations)	Number of weeds/m² broadleaf (6 locations)	Total
Zero tillage	114	59	54	113
Farmer practices	96	72	90	162
Significance	< 5%	< 5%	< 5%	7%

from Pakistan and elsewhere showing that nitrogen can be conveniently broadcast at the first irrigation without any loss in yields (Majid et al. 1988).

Comparison of deep tillage with other tillage and planting methods Deep tillage was tested as an alternative soil preparation method, with the primary benefit of breaking up the hard pan created by puddling for rice planting. The results over two years summarized in Table 4.7 show that deep tillage with a moldboard plow had no significant effect on yield, and actually resulted in significantly fewer tillers/m² than zero tillage. This may have been the result of deeper planting in the deep plowed, rotavated plots.

The economics of alternative tillage methods Although zero tillage with direct drilling in the experimental program was performed by an imported drill, this drill could easily be adapted and manufactured in Pakistan at a considerably lower price. In consultation with agricultural engineers, it was estimated that a locally adapted and manufactured device suitable for direct drilling would cost Rs 30,000 to 35,000, compared with about Rs 12,000 for currently available rabi drills; that is, direct drilling with a locally produced device would entail roughly double the expense of conventional drilling practices. However, because the former technology eliminates all land preparation costs, overall savings in the case of sowing wheat come to 87% (Rs 700/ha) of the cost of conventional planting methods (Table 4.8). In addition, if direct drilling results in wheat being planted an average of 10 days earlier, an additional yield of 300 kg/ha, valued at approximately Rs600/ha, would be obtained.

Thus, whereas deep tillage resulted in yields comparable to those for conventional tillage and also reduced land preparation costs (Table 4.9), direct drilling with zero tillage was much more economical.

Table 4.6. The effect of method of nitrogen application method on yield and tillering under zero tillage, 1986-87

Fertilizer application method	Tiller/m^2	1000 grain weight (gm)	Grain yield (kg/ha)
Placement with the drill at planting	244 a	41.31 b	4784 a
Broadcast at planting	218 b	41.7 b	4094 b
Broadcast with first irrigation	253 a	47.6 a	4581 ab
Significance	5%	5%	5%

Figures followed by different letters are significant at 5% level using DMRT.

Table 4.7. Yield and tillering compared under zero, conventional, and deep tillage, 1984-87

	1984-85			1986-87			Average		
	Zero tillage	Farmer practices (4 locations)	Deep Tillage	Zero tillage	Farmer practices (3 locations)	Deep tillage	Zero tillage	Farmer practices (7 locations)	Deep tillage
Yield (kg/ha)	3085	3157	3186	3970	3731	4074	3527	3444	3630
Tillers/m^2	259	273	261	267 a	225 b	236 b	263 a	249 b	248 b

Figures followed by different letters are significant at 5% level using DMRT.

Discussion

Direct drilling with zero tillage has considerable potential for the rice-wheat rotation. Its major advantages are reduced cost of cultivation, more timely planting, and uniform fertilizer distribution. This technology also appears to reduce weed populations and improve crop stand, as a result of the more uniform and proper seed placement obtained with direct drilling.

A potential constraint on adopting zero tillage for wheat is the stem borer *(Scirpophaga incertulas)*, currently an important pest of rice. Farmers are presently required by law (Insect Pest Control Act 1959) to uproot and incorporate rice stubbles by the end of February and to delay planting of rice nurseries until after May 20th in order to destroy the larvae surviving in the rice stubbles before rice planting begins again. Based on research conducted in the 1940s and 1950s, the law is very loosely enforced (Inayatullah and Rehman 1987). Many fields are left with rice stubble after the February limit, including fields sown to berseem (which is nearly always planted directly in standing rice stubble), low lying fields left fallow because they cannot be plowed, and poorly

Table 4.8. **Economic comparison of zero tillage and farmer practices for wheat cultivation**

Operation	Cost in Rupees/ha Zero tillage	Cost in Rupees/ha Farmer practices
Land preparation		
6 Cultivations @ Rs75/ha	-	450
3 Plantings @ Rs 50/ha	-	150
Cost of planting		
2 Cultivations and 1 planting	-	200
Drilling	125	
Broadcasting	-	25
Total	**125**	**825**

Cost advantage of zero tillage over farmer practices = 825 - 125 = 700
Benefits of zero tillage through early planting
20 days (av.) at 30 kg/day/ha = 600 x 2 = 1200
Total benefits of zero tillage over farmer practices = 1900

Source: Wheat Programme, NARC, Islamabad

Table 4.9. Costs of zero tillage and deep tillage for wheat cultivation, 1987

Operation	Cost in Rupees/ha Zero Tillage	Cost in Rupees/ha Deep Tillage*
Land preparation		
1 moldboard	_	240
1 rotavator	_	173
Planting		
Drilling	125	81
Total	**125**	**494**

Cost advantage of zero tillage over deep tillage = 369
Benefits of zero tillage through earlier
planting (20 days at 30 kg/day/ha) = 1,200
Total benefits of zero tillage over deep tillage = 1,569

* Source: Crop maximization programme, PARC Islamabad.
Source: Wheat Programme NARC, Islamabad

prepared wheat fields where much stubble remains on the surface (Table 4.10). Rice stem borer larvae survive in these fields (Table 4.11). Against this background and with the possibility of implementing zero tillage in wheat production, an integrated approach to stem borer control that combines cultural and chemical methods is required.

Figure 4.2 presents a model for adopting zero tillage which takes into account key questions faced by farmers when making such a decision. However, implementing this model requires further research on the rice stem borer, upgrading extension advice on stem borer control, and changing the Pest Control Act to reflect current realities.

Table 4.10. Percentage infestation of stem borers in rice stubble

Year	Fallow field (unplowed)	Berseem fields	Wheat fields
1981	72.0	46.4	28.7
1982	67.6	36.8	26.7
1983	66.4	31.8	19.6
Average	**68.7**	**38.3**	**25.0**

Source: Department of Plant Protection, Karachi

Table 4.11. Changes in rice stem borer population (no/m²) at different stages of development, March-May, 1987

	Live larvae		Dead larvae		Pupae	
	Zero tillage	Farmers' practice	Zero tillage	Farmers' practice	Zero tillage	Farmers' practice
March	3.5	0.8	0.5	0.4	0.1	0.04
April	13.4	0.6	2.1	1.5	0.2	0.05
May	0.6	0.1	3.5	4.3	4.7	2.20
Mean	**5.8**	**0.5**	**2.0**	**2.1**	**1.7**	**0.76**

Source: Inayatullah and Rehman 1987.

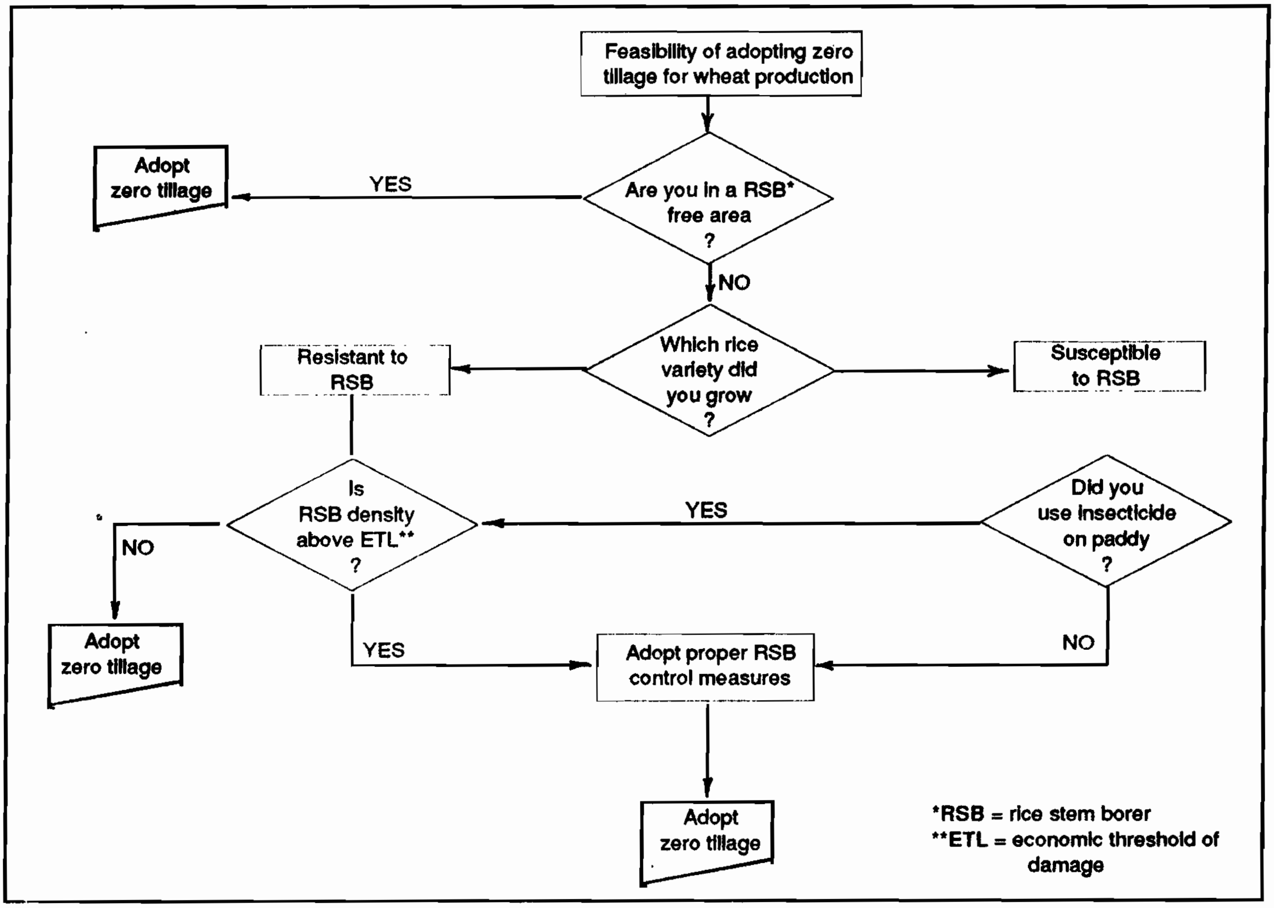

Figure 4.2. Suggested model for adoption of zero tillage

Source: Inayatullah and Rehman 1987

Chapter V

WHEAT VARIETY EXPERIMENTS

Introduction

There were two major reasons for including variety as a factor in the experimental program. First, the diagnostic survey of 1984 identified Yecora as a dominant variety in the area. Released in the 1970s, Yecora was already a non-recommended variety because of its susceptibility to both leaf and stripe rust. The 1984 survey indicated that only 16% of the wheat area was being sown to new rust resistant varieties, despite the release of a continuous stream of new varieties throughout the 1980s. Recent studies have shown that the time between the release of a variety and its general adoption by farmers is longer in Pakistan than in other comparable wheat-growing areas (Heisey 1989). Hence, there was a need to evaluate new varieties in terms of both yield and of acceptability to farmers.

A second major reason for the varietal experiments was to evaluate the performance of different varieties over a range of planting dates. The diagnostic survey clearly showed that wheat planting extended from early November until late December or even early January. Wheat breeders have typically developed and recommended varieties for specific planting periods, categorizing them as early, normal, and late-planting.

Managing several cultivars and different planting dates is difficult for farmers, so the experimental program arranged to test new materials at different sowing times and select "broad-spectrum varieties"--those performing well over a range of planting dates in different crop rotations.

Methods

In the first year of the program, 1884-85, distinct varietal groups (normal season and early maturing) were sown at recommended and late planting dates, corresponding to mid-November and mid-to-late-December, respectively. In 1985-86, this was changed to test the same varieties at these two different planting periods and results of these experiments are reported here. In each case, only newly-released varieties of both early- and late-maturing plant types were used. The main check was the early maturing variety Blue Silver. The varieties tested and their characteristics are summarized in Tables 5.1 and 5.2.

The varieties Pak-81, Blue Silver, Kohinoor, and Faisalabad-83 were included in all experiments from 1985 to 1988 across 25 locations. Of this group, Pak-81 and Kohinoor are fairly late maturing varieties recommended for early-to-medium sowing. Faisalabad-83 is an early maturing variety developed to replace Blue Silver for late planting. In 1986-87, two newly released varieties, Faisalabad-85, an early maturing variety, and Punjab-85, a late maturing variety, were also included in the experiments.

Table 5.1. Characteristics and year of release of wheat varieties included in experiments, 1984-88

Varieties	Year of release	Leaf rust resistance	Stripe rust resistance	Maturity
Blue Silver	1971	No	No	Early
Pak-81	1981	Yes	Yes	Late
Kohinoor	1983	Yes	Yes	Medium/late
Faisalabad-83	1983	Yes	Yes	Early
Faisalabad-85	1985	Yes	Yes	Early
Punjab-85	1985	Yes	Yes	Late

Source: Coordinated Wheat Programme, NARC.

Table 5.2. Number of locations planted and varieties tested at recommended and late planting dates, by year, 1984-88

	1985-86		1986-87		1987-88	
	Recommended	Late	Recommended	Late	Recommended	Late
Number of locations	*5*	*7*	*5*	*1*	*5*	*2*
Variety						
Pak-81	√[a]	√	√	√	√	√
Blue Silver	√	√	√	√	√	√
Kohinoor	√	√	√	√	√	√
Faisalabad-83	√	√	√	√	√	√
Faisalabad-85	-	-	√	√	√	√
Punjab-85	-	-	√	√	√	√

[a] √ = variety was planted at the number of locations given under each column heading

The varieties were planted in long strips of 100 to 150m². Fertilizer was applied at a rate of 120-60-0 kg NPK/ha, and seed rate was 100 kg/ha for all varieties and sowing dates. Where weeds were a problem, Dicuran MA or Tribunal herbicide was applied at officially recommended dosages.

Of the 25 locations, 15 were planted from November 10 to 20th, and 10 were planted from December 15 to 30th.

Results

Results over 25 locations from 1985 to 1988 and 13 locations for 1986-88 are summarized in Table 5.3. For the first three years, Pak-81 and Kohinoor were clearly superior at the recommended planting date. This is not surprising, since these varieties were developed for planting at the recommended time, whereas Blue Silver and Faisalabad-83 are recommended for late planting only. More significant, however, is the fact that the same four varieties evaluated at the late planting date showed no difference in yield (Fig. 5.1). In other words, the late maturing materials recommended for early planting did just as well as the early maturing ones at the late planting date. Pooled over the 25 locations of both recommended and late planting, the best varieties were Pak-81 and Kohinoor, outyielding the check variety Blue Silver by 20%.

Pooling results for six varieties tested during 1986-87 and 1987-88 leads to similar conclusions (Table 5.3). Again, the late maturing varieties Pak-81, Kohinoor, and Punjab-85 gave significantly higher yields when planted at the recommended time. For late planting, there was no significant difference between the six varieties, although Kohinoor gave the highest yields. These results confirmed the fact that late maturing varieties with high yield potential perform as well as early maturing varieties, when planted late.

Little progress seems to have been made in increasing yield potential of early maturing varieties. The new varieties recommended for late planting, Faisalabad-83 and Faisalabad-85, do not provide significantly higher yields than Blue Silver.

The data for individual years summarized in Table 5.4 confirm the results of the pooled analysis. In each year, when sown at the recommended time, the late maturing varieties generally outperformed the early maturing ones; whereas, for late planting there was generally no difference between the varieties, except in 1987-88, when Kohinoor significantly outyielded the others. Over all years, average yields for early planting were 11 to 17% higher than those for late planting. This suggests an average

Table 5.3. Yield (kg/ha) of different varieties planted at recommended and late dates, by year, 1985-88

	1985-88			1986-88		
	Recommended	Late	Average	Recommended	Late	Average
No. of locations	*15*	*10*	*25*	*10*	*3*	*13*
Variety						
Blue Silver	3119 c	3210	3116 b	3109 d	2983	3880 c
Pak-81	3900 a	3206	3685 db	4002 ab	3253	3829 a
Kohinoor	3918 a	3326	3739 d	4039 ab	3607	3939 a
Faisalabad-83	3567 b	3301	3433	3516 cd	3057	3410 bc
Faisalabad-85	_	_	_	3691 bc	3198	3577 ab
Punjab-85	_	_	_	4149 a	3153	3919 a
Significance	< 5%	n.s.	< 5%	< 5%	n.s.	< 5%
Average	3626	3261	3493	3751	3208	3620

Figures followed by different letters are significant at 5% level using DMRT

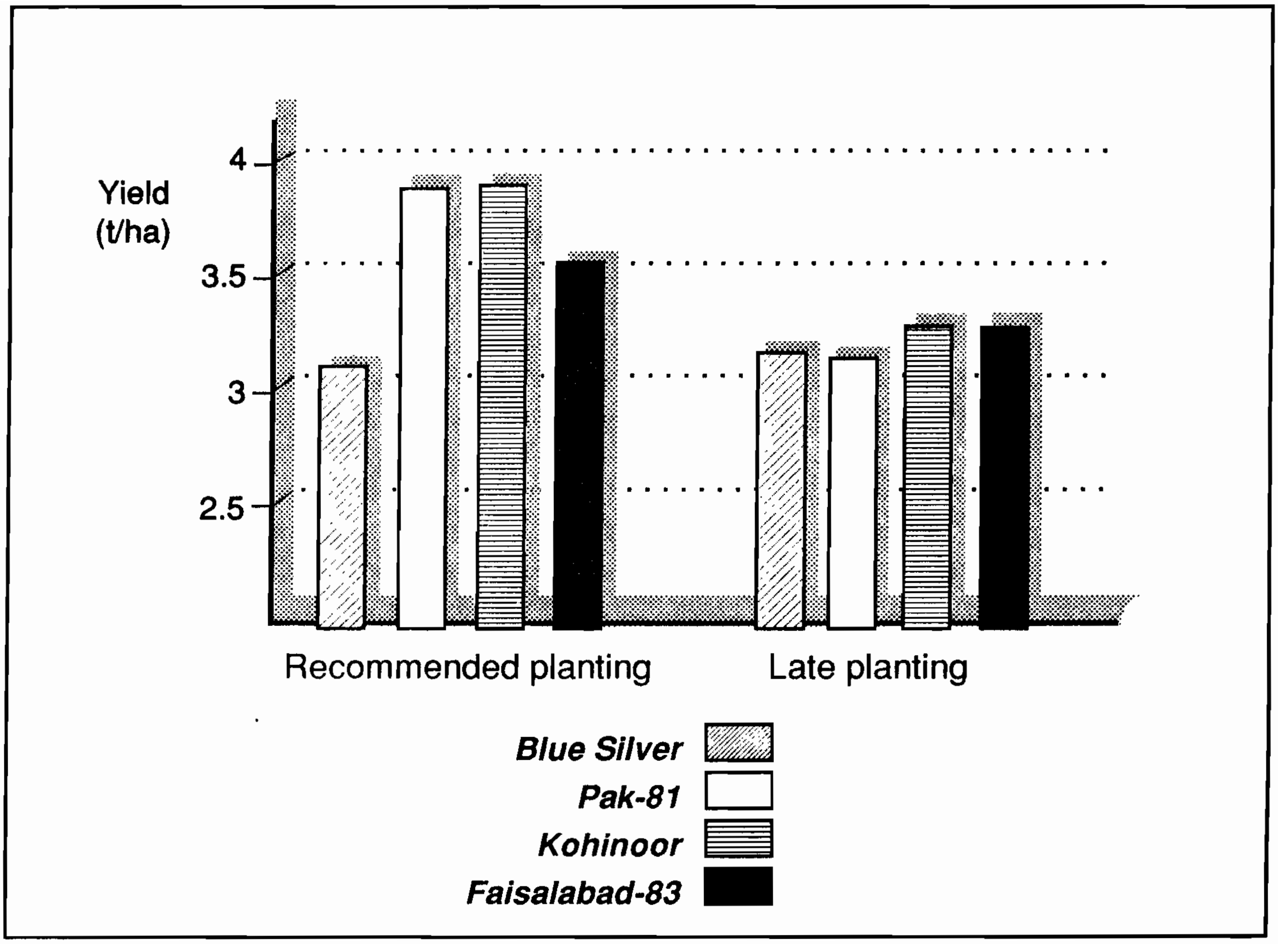

Figure 5.1. Performance of four varieties at recommended and late planting dates, 1985-88

12-18 kg/ha/day loss in yield for every day's delay in planting. Table 5.3 gives the average yield loss for the four varieties tested from l985 to l988. The greatest loss occurs in the late maturing Pak-81 and Kohinoor, and the smallest loss in the early maturing Blue Silver. However, the high yield potential of the late maturing varieties allowed them to provide yields equivalent to those of the early maturing varieties when both were planted late.

Discussion

Pooling the results for all varieties across experiments, the late maturing materials Pak-81 and Kohinoor gave 18% and 20% higher yields than the check variety Blue Silver, and 7.3% and 8.9% higher yields than the new variety, Faisalabad-83, which is recommended for late planting. The higher yields of the late maturing varieties

Table 5.4. Yield (kg/ha) of different varieties planted at recommended and late dates, by year, 1985-88

	1985-86			1986-87			1987-88		
	Recom-mended	Late	Average	Recom-mended	Late	Average	Recom-mended	Late	Average
Number of locations	10	7	12	5	1	6	5	2	7
Variety									
Blue Silver	3.14 b	3.31	3.24 b	2.78 d	2.46 c	2.73 d	3.43 d	3.24 ab	3.38 c
Pak-81	3.69 a	3.19	3.39 ab	3.86 a	3.78 a	3.85 a	0.44 b	2.99 a	3.81 a
Kohinoor	3.68 a	3.21	3.40 ab	3.46 bc	3.70 a	3.50 b	4.62 a	3.56 a	4.31 a
Faisalabad-83	3.67 a	3.41	3.52 a	3.21 c	2.91 b	3.16 c	3.82 c	3.13 b	3.62 b
Faisalabad-85	-	-	-	3.38 bc	3.72 a	3.44 bc	4.00 bc	2.94 b	3.70 b
Punjab-85	-	-	-	3.73 ab	3.42 ab	3.68 ab	4.57 a	3.02 b	4.12 d
Significance	< 5%	n.s.	< 5%	< 5%	< 5%	< 5%	< 5%	< 5%	< 5%

Figures followed by different letters are significant at < 5% level using DMRT

is due entirely to their better performance when sown early; however, a major conclusion is that these varieties also perform as well as the early varieties when planted late. That is, a farmer would have nothing to lose by using the late maturing varieties regardless of the planting date.

It can be concluded from the results of the variety experiments that the emphasis in breeding, varietal selection, and extension programs should be placed on identifying high-yielding varieties which can be grown over a range of planting dates. With the addition of heat tolerance during grain filling, the major problem with the late planting of long duration varieties would be minimized. The lack of progress in developing high-yielding varieties for late planting suggests that greater payoffs may be obtained through work on yield potential than through pursuing gains in maturity.

Concentrating on a few varieties suitable for planting over a range of planting dates would facilitate seed production, dissemination and extension work to speed the spread of new varieties. In fact, since the start of the program, Pak-81, which performed very well in these experiments, has spread rapidly throughout the study area and by 1987-88 was being sown on half of the wheat land (Sharif et al. 1988).

Chapter VI

WEED CONTROL EXPERIMENTS

Introduction

In the diagnostic survey, weeds were identified as a major yield constraint in the rice-wheat rotation. The most important weed identified was the grassy species *Phalaris minor*, locally called Dumbi grass. Serious infestations of this weed were observed in about one-third of the wheat fields and were estimated to cause a loss in yield of 400 to 500 kg/ha in these fields. It appears to have become widespread only over the last decade. In early development stages its resemblance to wheat makes it very difficult to control manually. As noted in Chapter 2, the only widespread method used for its control is crop rotation, but this practice is inadequate for all but the smallest-scale farmers. Other grassy weeds also present to a lesser extent were wild oats (*Avena fatua*) and *Lolium temulentum*. Broad-leaf weeds were also present in many fields, especially *Chenopodium album*, *Melilotus alba*, *Medicago denticulata* and *Rumex acetosella*. However, these broad-leaf weeds apparently cause relatively little loss in yields because they occur with less intensity than the grassy types.

The experimental program described here involved the use of chemical weed control to supplement farmers' current methods. Specifically tested were the effectiveness of different herbicides and the dosage of the most promising herbicide. Also, since the recommended practice for application requires a backpack or tractor-mounted sprayer, other application methods (such as broadcasting the herbicide in powder form) were studied. Broadcast applications, if effective, would be very appropriate for small-scale farmers.

Materials and Methods

From 1984 to 1987, 18 herbicide experiments were conducted in farmers' fields where wheat followed rice. In the first two years of the program, all treatments were superimposed as strips on farmers' fields after crop establishment.

A bicycle-wheel sprayer and motorized back pack power sprayer were used to apply treatments. The herbicide was mixed with water and applied at a rate of 250 l/ha with a 1.8 m, four-nozzle boom and at a pressure of 35 to 40 psi. In the broadcast treatments, herbicides were thoroughly mixed with urea and sand and broadcast by hand using gloves. Care was taken to achieve a uniform application. Except in the first year, an equal amount of urea was applied to all other treatments, so that the total application of nitrogen was uniform across the experiment.

Economic analysis was made assuming costs of Rs 75 /ha for spray application and 25 Rs/ha for broadcast application. Spray cost estimates were based on commonly observed rental rates for pesticide sprayers.

Results

Results summarized in Table 6.1 show that in the first year, when various products were tested, herbicides developed for both grassy and broad-leaf weeds permitted significantly higher wheat yields than other herbicides. Applications of the herbicides which control only broad-leaf weeds caused no significant increase in yields. Weed counts taken one month after spraying indicated that Dicuran, Tribunil, and Tolkan (all substituted urea compounds) gave an average 73% control of weeds in the field. This was to be expected, since *Phalaris minor* was the major weed in these experiments. Overall, Dicuran-MA applied in any manner appeared to be the most promising herbicide. The highest yield was obtained by broadcasting Dicuran-MA plus urea. Part of this yield increase could be attributed to the small amount of nitrogen (about 10 kg/ha) applied in this treatment but not in the others.

The economic analysis of the 1984-85 experiments is shown in Table 6.1 and Figure 6.1. The only treatment which gave a satisfactory marginal return on capital costs was Dicuran-MA broadcast with urea.

Table 6.1. Description of herbicides used in chemical weed control experiments of 1984-87

Commercial name[a]	Common name	Manufacturer's recommended dose	Price (Rupees)	Weed control spectrum
Dicuran-MA	Chlortoluron + MCPA	2.5 kg/ha	200/kg	Kills grassy and broad leaf weeds
Tribunil	Methabeny thiayuron	2 kg/ha	208/kg	Kills grassy and broad leaf weeds
Tolkan	Isoproturon	2 kg/ha	150/kg	Kills grassy and broad leaf weeds
Illoxan	Diclofop-methyl	4 l/ha	-	Kills only grassy weeds
DMA-6	2,4-D	1.7 l/ha	95/l	Kills only broad leaf weeds
Buctril-M	Bromoxynil + MCPA	1.4 l/ha	120/l	Kills only broad leaf weeds
Envoy	Cyanazine + MCPA	2 kg/ha	90/kg	Kills only broad leaf weeds

[a] All except Illoxan, DMA-6, and Envoy are commercially available in Pakistan

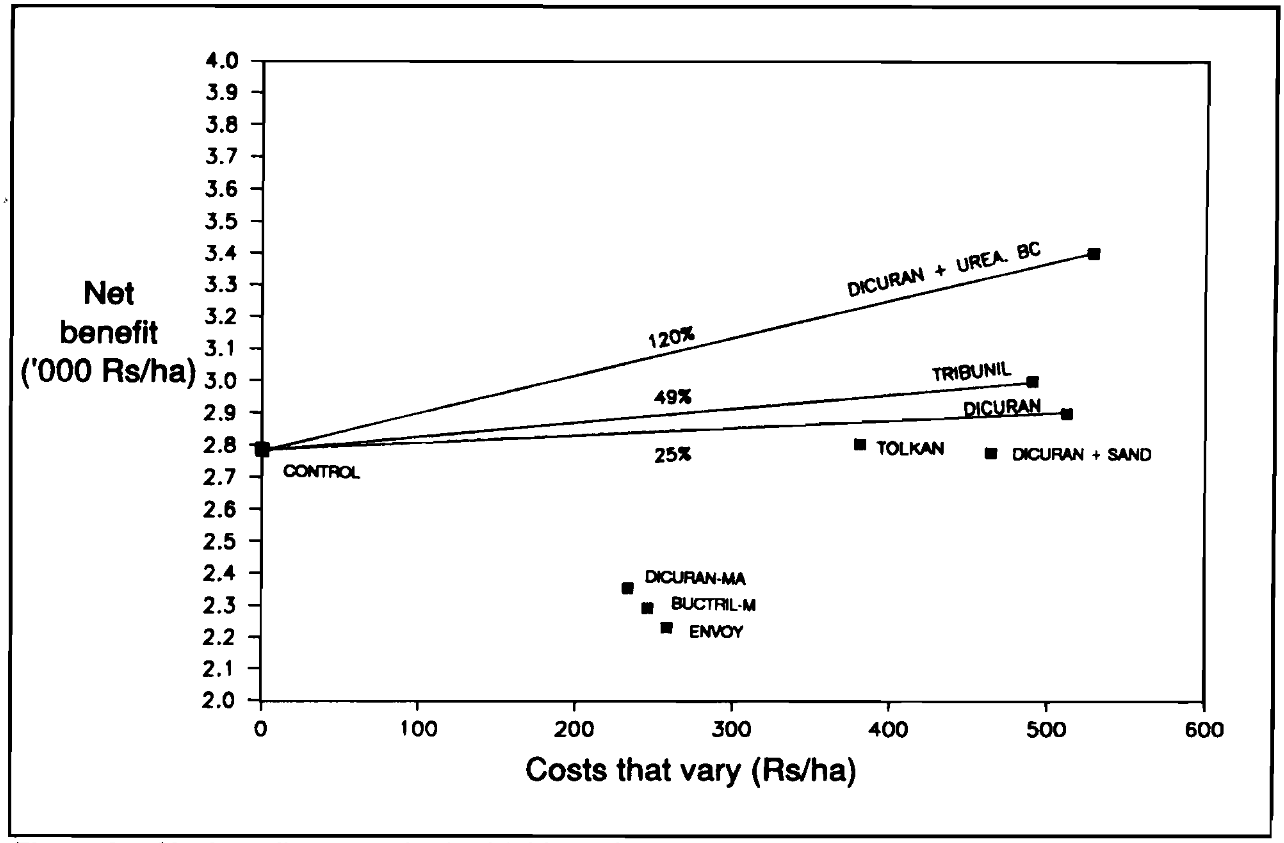

Figure 6.1. Net benefit curves for herbicides, 1984-85

In 1985-86, six experiments were planted to further test the economics of Dicuran-MA sprayed or mixed with urea and broadcast (Table 6.2). Both treatments gave an average of 1 t/ha or more increase in yield over the control. The other treatment in this experiment, Buctril-M, caused no significant difference in yield from the control. In this experiment, Dicuran-MA controlled 90% or more of the weed population. Buctril-M also controlled nearly half of the broadleaf weeds but none of the grassy weeds, and had no effect on yield, which indicates that broadleaf weeds cause little yield loss.

In this experiment both Dicuran-MA application methods gave rates of return of around 200%, more than adequate to recommend the use of this herbicide (Fig. 6.2 and Table 6.2).

In 1985-86, sprayed and broadcast Dicuran-MA applications at 25, 50, and 75% of the officially recommended dosage (1.0 kg ai/ha) were compared. The highest yield was obtained by spraying Dicuran-MA at 75% of the recommended rate (Tables 6.3 and 6.4). Even when applied at 25% of the recommended dosage, however, it resulted in a yield increase of 1 t/ha over the control. In general, broadcasting gave results comparable to those of spraying.

Table 6.2 Description of experiments and treatments of chemical weed control experiments, conducted in rice-wheat areas of the Punjab, by year, 1984-87

1984-85 (5 locations)	1985-86 (10 locations)	1986-87
1. Dicuran-MA, broadcast with urea	*Experiment No. 1 (6 locations)*	1. Dicuran-MA, sprayed
2. Tribunil	1. Dicuran-MA, sprayed	2. Dicuran-MA (half dose), sprayed
3. Dicuran-MA, sprayed	2. Dicuran-MA, broadcast with urea	3. Buctril-M, sprayed
4. Dicuran-MA, broadcast with sand	3. Buctril-M	
5. Tolkan	4. Control	4. Buctril-M (half dose), sprayed
6. Illoxan		
7. Control	*Experiment No. 2 (4 locations)*	5. Control
8. DMA		
9. Buctril-M	1. Dicuran-MA (0.75 of recommended dose), sprayed	
10. Envoy	2. Dicuran-MA (0.50 of recommended dose), sprayed	
	3. Dicuran-MA (0.25 of recommended dose), sprayed	
	4. Dicuran-MA (0.75 of recommended dose), broadcast	
	5. Dicuran-MA (0.50 of recommended dose), broadcast	
	6. Dicuran-MA (0.25 of recommended dose), broadcast	
	7. Control	

Table 6.3. Effects on yield, and economic analysis of herbicides compared in 1984-85 experiments

Treatment	Yield (kg/ha)	% yield increase over control	Weeds/m² a month after application	Percent weeds controlled	Adjusted yield (kg/ha)	Gross field benefits (Rs/ha)	Costs that vary (Rs/ha)	Net benefit (Rs/ha)
1. Dicuran-MA broadcast with urea	3100 a	40	252 b	67	2790	3900	539	3431
2. Tribunil	2790 b	26	204 b	73	2511	3515	491	3024
3. Dicuran-MA	2733 b	23	114 b	85	2459	3443	525	2918
4. Dicuran-MA broadcast with sand	2590 b	17	106 b	86	2331	3263	475	2788
5. Tolkan	2540 bc	15	220 b	71	2286	3200	375	2825
6. Illoxan	2400 cd	9	474 db	37	2160	3024	n.a.	n.a.
7. DMA-b	2070 e	-6	712 d	6	1863	2608	236	2372
8. Buctril-M	2030 e	-8	501 db	34	1827	2558	243	2315
9. Envoy	1990 c	-10	506 ab	33	1791	2507	250	2257
10.Control	2210 de	0	757 a	0	1989	2785	0	2785
Significance	< 5%		< 5%					

Figures followed by different letters are significant at 5% level using DMRT

Table 6.4. Effects on yield, and economic analysis of different herbicides, 1985-86

Treatment	Yield (kg/ha)	% yield increase over control	Weeds/m² a month after application	% weeds controlled	Adjusted yield (kg/ha)	Gross field benefits (Rs/ha)	Costs that vary (Rs/ha)	Net benefit (Rs/ha)
1. Dicuran-MA	4028b	38	24c	97	3625	5075	525	4550
2. Dicuran-MA + urea (broadcast)	4230a	40	80c	90	3807	5330	475	4855
3. Buctril-M	3060c	1	460b	43	2754	3856	243	3613
4. Control	2908c		801a	0	2617	6364	0	3664
Significance	< 5%		< 5%					

Figures followed by different letters are significant at 5% level using DMRT

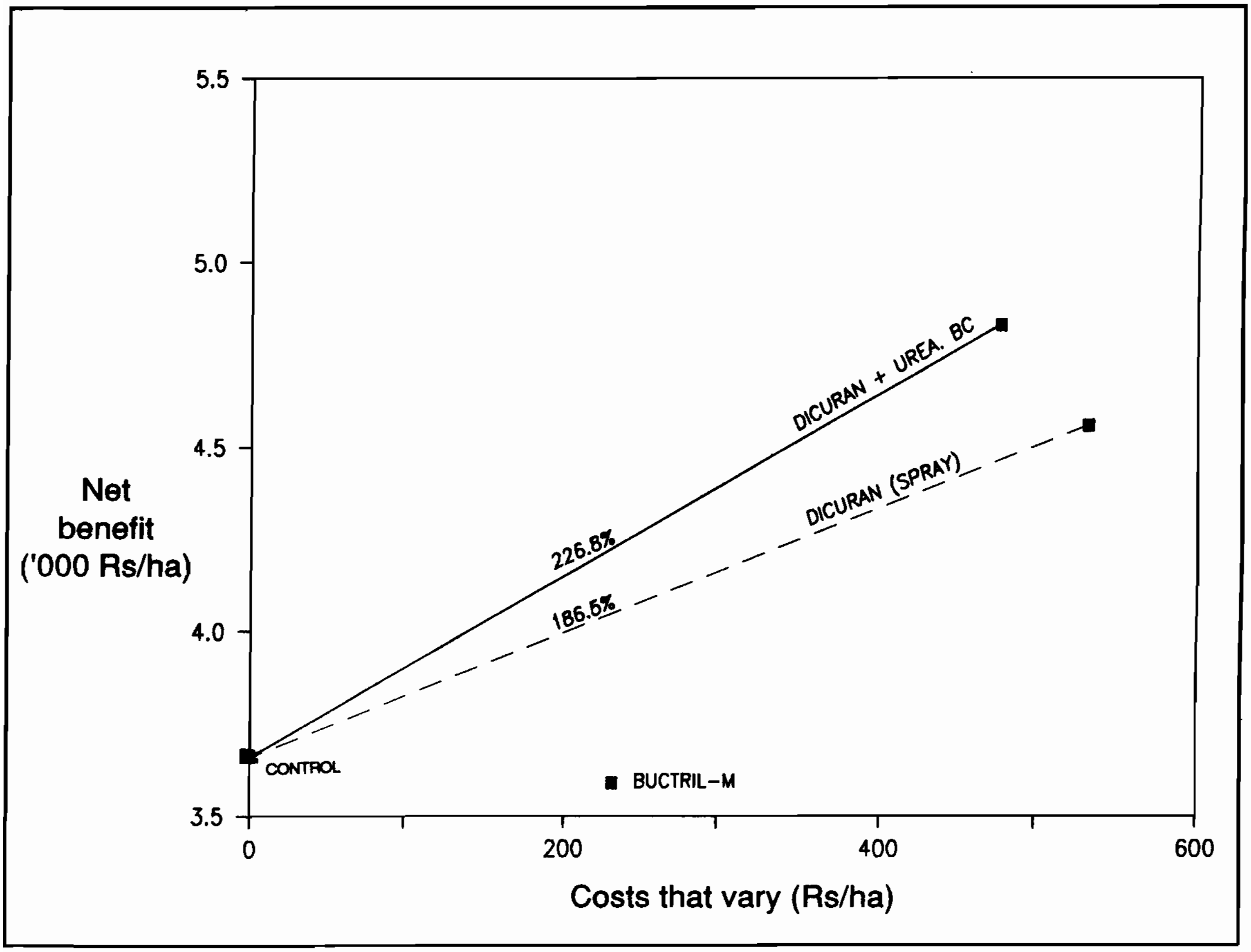

Figure 6.2. Net benefit curves for herbicides, 1985-86

The net benefit curve for this experiment is given in Figure 6.3 and indicates a very high return for the application of even a quarter of the recommended Dicuran-MA dosage. However, in the absence of a serious cash constraint, it would be profitable for the farmer to apply up to 75% of the recommended amount.

In 1986-87, work continued to identify the most economical application rate for Dicuran-MA. Buctril-M was included only to assess damage from broadleaf weeds. Average yield levels in these experiments were considerably higher than in previous years, because recommended levels of all management factors were included in this researcher-managed experiment. The yield increase due to Dicuran-MA was over 1 t/ha, even when only half the recommended dosage was used. Again, the economic analysis given in Table 6.5 and Figure 6.4 indicates that the application of half the recommended amount of Dicuran-MA gave very high returns.

For 14 locations over the three years of the program, three common treatments can be compared: Dicuran-MA at the full recommended dosage, Buctril-M at the full recommended dosage, and the control. In this comparison, Dicuran-MA caused a yield increase of over 1 t/ha, or a 34% increase over treatments with no herbicide. Application of Buctril-M gave no significant increase in yield. Applying Dicuran-MA at the full, officially recommended dosage gave a marginal rate of return of 152% (Fig. 6.5), demonstrating the profitability of this treatment. In fact, in only one of the 14 locations was the yield increase from applying Dicuran-MA less than 450 kg/ha--the production gain that a farmer would need to "break even" when applying Dicuran-MA at the full recommended dosage.

Table 6.5. Effect on yield, and economic analysis of different methods of application and doses of Dicuran-MA, 1985-86

Treatment	Yield (kg/ha)	% yield increase over control	Adjusted yield (kg/ha)	Gross yield benefits (Rs/ha)	Costs that vary (Rs/ha)	Net benefit (Rs/ha)
1. Dicuran-MA (0.75 of recommended dose) sprayed	4310 a	63	3879	5431	412	5019
2. Dicuran-MA (0.50 of recommended dose) sprayed	3710 b	40	3339	4675	300	4375
3. Dicuran-MA (0.25 of recommended dose) sprayed	3620 b	37	3258	4561	187	4374
4. Dicuran-MA (0.75 of recommended dose) broadcast with urea	3870 b	46	3483	4876	362	4514
5. Dicuran-MA (0.50 of recommended dose) broadcast with urea	3730 b	41	3357	4700	250	4450
6. Dicuran-MA (0.25 of recommended dose) broadcast with urea	3650 b	38	3285	4599	137	4462
7. Control	2650 c	_	2385	3339	0	3339
Significance	< 5%					

Figures followed by different letters are significant at 5% level using DMRT

Discussion

Results presented in this chapter clearly establish the important role that chemical weed control can play in increasing yields in the area. In the locations selected, the average yield loss to weeds was more than 1 t/ha; most of this yield loss was caused by *Phalaris minor.* In fields infected by *Phalaris minor* it was economical to control these weeds with chemicals. Dicuran-MA appears to be the best herbicide for this purpose. Although Dicuran-MA also controls some broadleaf weeds, it appears that the use of chemicals specifically developed for broadleaf weeds is not economically justified.

It is feasible to apply Dicuran-MA by the recommended method of spraying or by mixing with sand or urea and broadcasting. Thus, although farmers may not have access to a sprayer, they can still achieve favorable results by applying Dicuran-MA manually. Nonetheless, in this method skill and care are required to ensure that the herbicide is broadcast evenly throughout the field in order to avoid overdoses or patches without any chemical.

Another important conclusion of this study is that small-scale farmers who may not want to risk the relatively large expenditure required to apply Dicuran-MA at the full recommended dosage can use a much lower rate and still achieve good control of *Phalaris minor.*

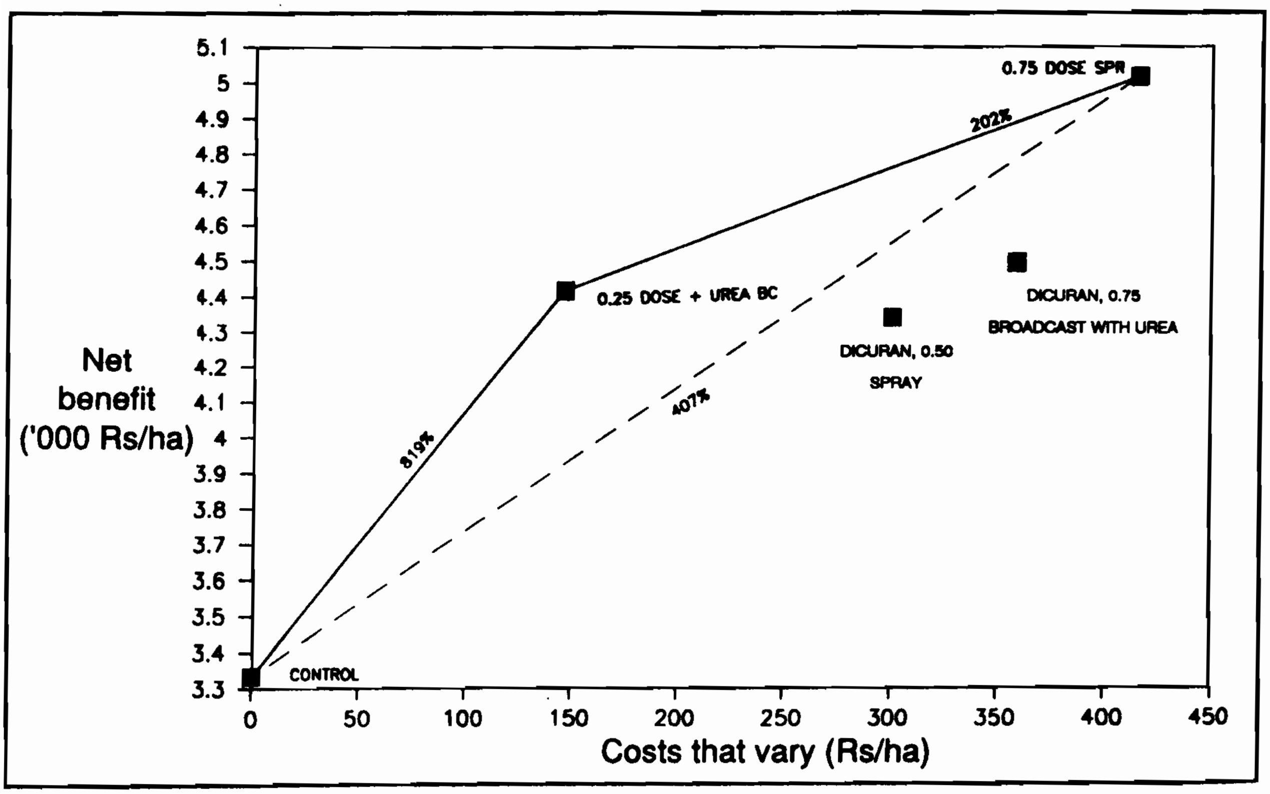

Figure 6.3. Net benefit curves for different Dicuran-MA doses and application methods, 1985-86

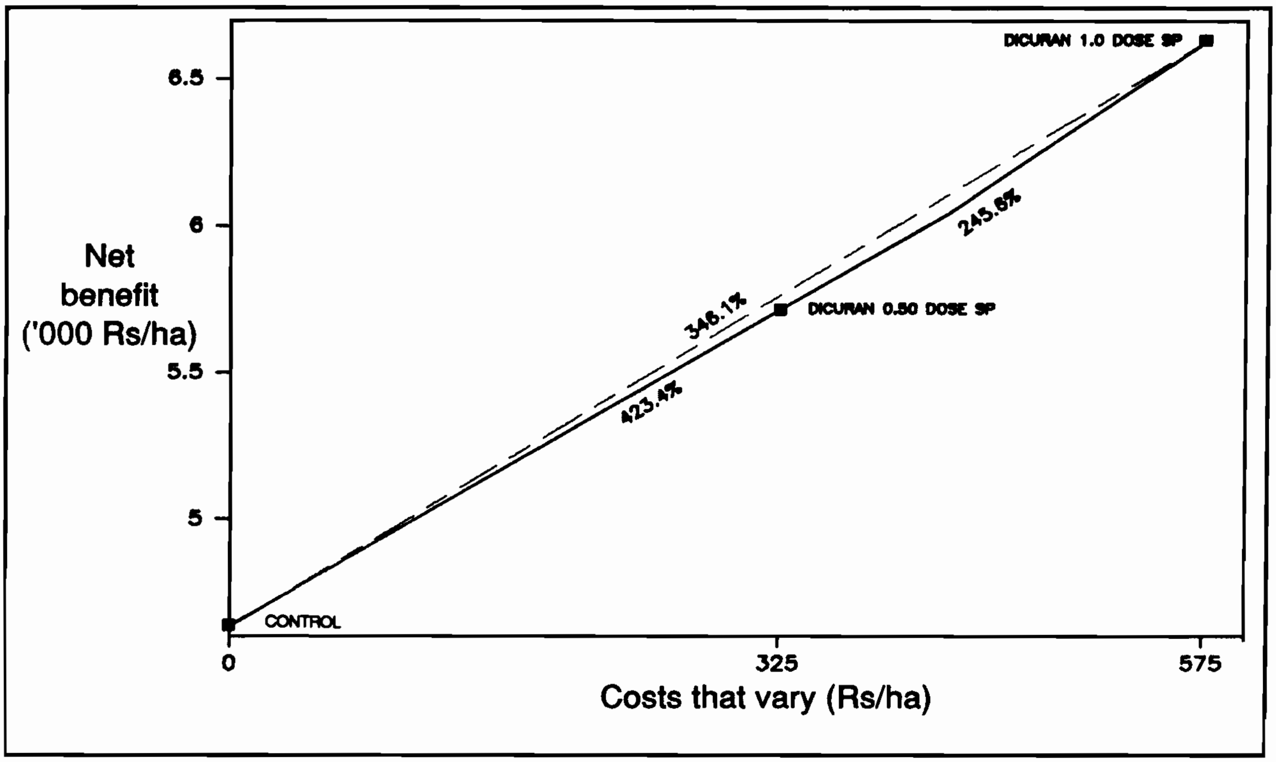

Figure 6.4. Net benefit curves for different Dicuran-MA doses sprayed, 1986-87

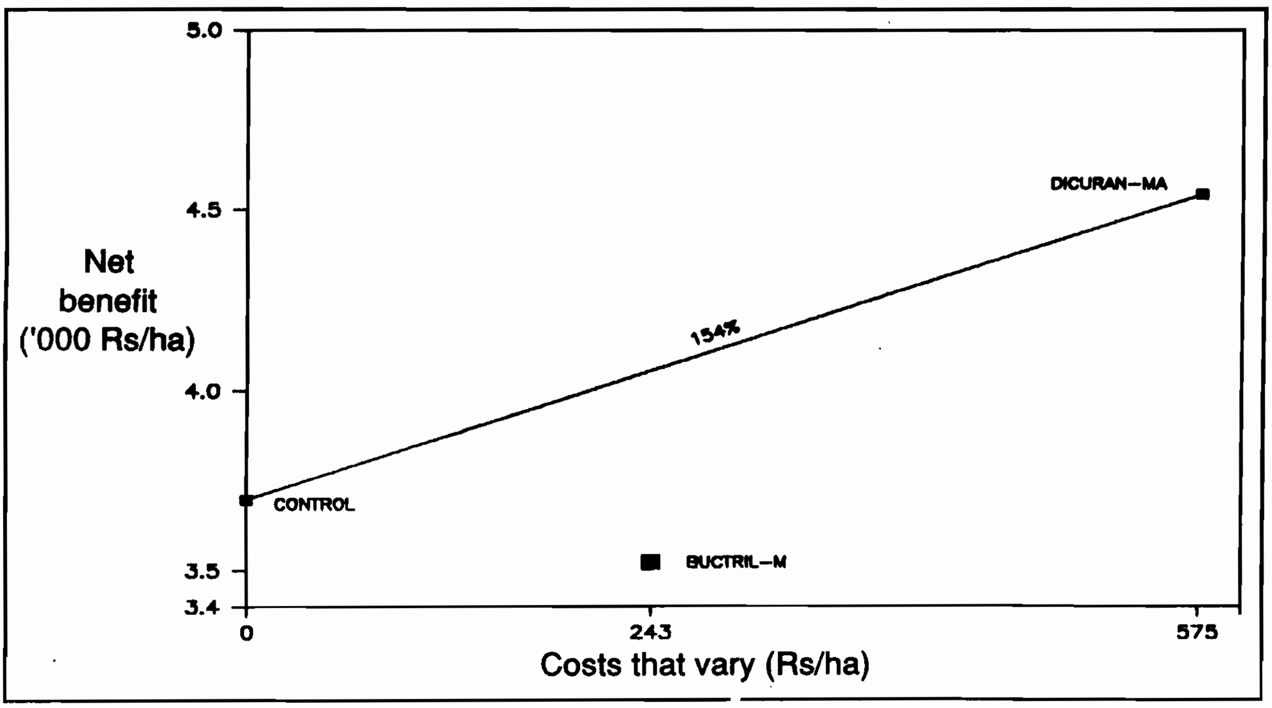

Figure 6.5. Net benefit curve for pooled herbicide experiments, 1984-87

Table 6.6. Yields (kg/ha) under different dosages and methods of application of Dicuran-MA, 1985-86

Method	Control	Dosage 25%	50%	75%	Average
Spray	2650	3620	3710	4310	3880
Broadcast	2650	3650	3730	3870	3750
Average	2650	3635	3720	4090	3815

Table 6.7. Yield and economic comparison of different herbicide trials, 1986-87

Treatment	Yield (kg/ha)	% yield increase over control	Weeds/m² a month after application	% weeds controlled	Adjusted yield (kg/ha)	Gross field benefits (Rs/ha)	Costs that vary (Rs/ha)	Net benefit (Rs/ha)
1. Dicuran-MA	5417 a	47	116 d	91	5143	7199	575	6625
2. Dicuran-MA half dose	5029 b	36	360 c	74	4526	6336	325	6011
3. Buctril-M	4106 c	11	776 b	43	3695	5174	243	4931
4. Buctril-M half dose	3879 c	5	846 b	38	3491	4888	159	4728
4. Control	3679 c	-	1370 a	0	3311	4635	0	4635
Significance	< 5%		< 5%					

Figures followed by different letters are significant at 5% level using DMRT

Table 6.8. Pooled data for yield effects and economic analyses of common herbicides, 1984-87

	Yield (kg/ha) 1984-85	1985-86	1986-87	average: 1984-87	Yield increase over control	Adjusted yield	Gross field benefits	Costs that vary	Net benefits[a]
(No. of locations	5	6	3	14)	(%)	(kg/ha)	Rs/ha		
Treatment									
1. Dicuran-MA	2733 a	4028 a	5417 a	4059 a	38	3653	5114	575	4539
2. Buctril-M	2030 b	3055 b	3879 b	2988 b	2	2689	3765	243	3522
3. Control	2210 b	2908 b	3679 b	2932 b	-	2639	3694	-	3694
Significance	< 5%	< 5%	< 5%	< 5%					

Figures followed by different letters are significant at 5% level using DMRT

[a] Marginal rate of return to Dicuran-MA = 152%

Chapter VII

FERTILIZER EXPERIMENTS

Introduction

Average fertilizer use on wheat increased fourfold in Pakistan over the 1966-76 period--going from 13 to 54 kg/ha--and doubled in the following decade, going to 121 kg/ha in 1985-86 (Chemonics 1985).[4]

Research on fertilizer requirements for wheat has been quite extensive in Pakistan. Yield constraint experiments in irrigated areas have shown that proper application of fertilizer is very important. Yield reductions ranging from 51% to 73% have been observed without proper fertilizer use (Bajwa 1985). This clearly indicates that wheat yield can be substantially increased through efficient use of fertilizer. However fertilizer recommendations for wheat are not generally based on experiments conducted in the context of cropping patterns such as the rice- or cotton-wheat rotations. Response curves for fertilizer use must be determined for these systems under differing soil conditions and over time (Hobbs et al. 1988). The present study attempted to address this issue for the rice-wheat system.

Materials and Methods

In total, 43 fertilizer experiments were conducted on farmers' fields over a four-year period (1984-88) to obtain N-P-K response curves for wheat planted after rice. In the first two years, all fertilizer experiments were conducted using farmers' usual tillage practices; later, some were also conducted under zero tillage. Overall, 33 experiments were sown under conventional tillage and 10 under zero tillage, in order to compare fertilizer requirements for each soil preparation method. The experiments were further categorized into early sown (mid-November and mainly after IR-6 rice), and late sown (mid-December, after Basmati rice) (Table 7.1). To determine the interaction of fertilizer with weeds, some experiments were sprayed with Dicuran-MA herbicide and the rest were left unsprayed. Plots were 100 m^2. The treatments were broadcast by hand on 5m x 20m strips. Soil samples from each field were taken at depths of 0-15 cm and 15-30 cm before treatments. Fertilizer was incorporated with one cultivation under conventional tillage; in the case of zero tillage, fertilizer was applied but not incorporated. Table 7.2 provides the details of the treatments.

[4] Byerlee and Siddiq (forthcoming), however, produced evidence of very low fertilizer use efficiency for the latter period.

Table 7.1. Distribution of number of fertilizer trials each year by planting date and method of weed control

	Total	Recom-mended date	Late date	Zero tillage	Conven-tional tillage	Chemical weed control Yes	No
1984-85	8	6	2	-	8	2	6
1985-86	11	5	6	-	11	7	4
1986-87	9	0	3	3	6	6	3
1987-88	15	11	4	7	8	4	11
Total	43	28	15	10	33	19	24

Table 7.2. Summary of different fertilizer treatments, 1984-88 (kg nutrient/ha)

1984-85			1985-86			1986-87			1987-88		
N	P	K	N	P	K	N	P	K	N	P	K
0	0	0	0	0	0	0	0	0	0	0	0
0	100	0	0	100	0	0	100	0	0	100	50
70	100	0	75	100	0	70	100	0	70	100	50
140	0	0	150	0	0	140	0	0	140	0	50
140	50	0	150	50	0	140	50	0	140	50	50
140	100	0	150	100	0	140	100	0	140	100	0
140	100	75	150	100	100	140	100	75	140	100	50
140	150	0	150	100	100	140	150	0	140	100	100
210	100	0	150	100	150	210	100	0	140	100	150
–	–	–	150	150	0	–	–	–	140	150	50
–	–	–	225	100	0	–	–	–	210	100	50

Estimation of the Response Function

Fertilizer response curves were estimated using regression analysis. Throughout the analysis a basic strategy was the use of appropriate F-tests to test the joint significance of groups of coefficients. These tests, based on the assumptions of homoscedasticity and normality of the error term, can be made by comparing the sum of squared residuals from the regression equation with all variables included [SSR(1)] to the sum of squared residuals from an equation without the variables whose effect is being tested [SSR(2)].

Under the null hypothesis that the latter variables have coefficients all equal to 0, given the error assumptions noted above, the test statistic

$$\frac{[SSR(2) - SSR(1)]/q}{SSR(1)/(n-k)}$$

is distributed as $F_{q, n-k}$, where

SSR(2) = sum of squared residuals from the regression with some variables excluded.

SSR(1) = sum of squared residuals from the regression with all variables included.

q = number of restrictions in the null hypothesis

n = number of observations

k = number of parameters in the unrestricted model

Values of the test statistic larger than the critical value for any given level of significance leads to rejection of the null hypothesis (see, for example, Judge et al. 1982).

Preliminary analysis focused on whether non-applied fertilizer variables, either non-experimental (e.g. previous farmyard manure and previous crop) or experimental (e.g. weed control and planting date) only shifted the intercept of the response surface, or if it changed its shape significantly. Significant changes in the shape of the response surface are important for economic analysis because they imply different economic optima. If a non-fertilizer variable only shifts the intercept of the response surface, economic optima are the same for fields with or without the characteristic in question. Nonetheless, significant shifts in the intercept are important, since if they are omitted in the analysis, estimates of the other coefficients are biased.

Subsequent analysis focused on estimating separate regression equations for each year of fertilizer trials. If the preliminary analysis showed substantial evidence of significant differences in the curvature of the response surface with the presence or absence of an important non-fertilizer variable, (e.g tillage method and planting date) separate equations were estimated for each condition. A combined equation over all years was also estimated.

Calculation of Economic Dosages

Given a quadratic fertilizer response function with no N x P interaction term, e.g.

(1) $Y = a + bN + cN^2 + dP + eP^2$,

optimal levels of N and P can be found. As in the analysis of discrete experimental data (CIMMYT, 1988), these optimal levels reflect farmers' circumstances more accurately if

1. experimental yields are adjusted to approximate farmer yields,
2. field prices of inputs and outputs are used, and
3. a minimum marginal rate of return on expenditure is included.

In this context, optimal input levels can be found as follows:

P_g = field price of output further adjusted for the difference between experimental and farmer yields.

W_N = field price of nitrogen

W_P = field price of phosphorus

R = marginal rate of return in decimal form

The first step is to calculate two new figures, r_N and r_P, as follows:

(2) $r_N = W_N(1 + R)/P_g$

$r_P = W_P(1 + R)/P_g$

Second, if response is as given in equation (1), optimal nitrogen N* and optimal P* are given by

(3) $N^* = (r_N - b)/2c$

$P^* = (r_P - d)/2e$

If either of these formulas gives an amount that is less than zero, the optimal amount is no longer N^* or P^*; it becomes either $N^{**} = 0$ or $P^{**} = 0$.

Finally, the quadratic response function may be estimated with an N x P interaction term as follows:

(4) $y = a + bN + cN^2 + dP + eP^2 + fNP$

In this case optimal N and P may be calculated as follows:

$$(5) \qquad N^* = \frac{2e\,(r_N - b) + f\,(r_P - d)}{4ce - f^2}$$

$$P^* = \frac{r_P - d - fN^*}{2e}$$

As in the expression above, these formulas may give one (or both) results less than zero. For example if $N^* > 0$, $P^* < 0$, the true optima become:

(6) $N^{**} = (rN - b)/2c$

$P^{**} = 0$

Results

Table 7.3 presents the multiple regression analysis of data from eight sites in 1984-85 using planting date and weed control as dummy variables. Results show that applying nitrogen significantly increased yield (a coefficient of 14.8). Phosphorus did not produce a statistically significant response, although P, P^2, and NP were jointly significant and were included in the equation. Late planting had a very significant negative effect on yield (-980 kg/ha) but did not interact with the shape of the response curve. A statistically non-significant yield reduction of 105 kg/ha was observed where no weed control was practiced. The nitrogen response curve is quadratic with a positive response up to 150 kg N/ha (Fig. 7.1). Potassium response was non-significant and, hence, not included in the regression analysis.

In the regression equation from 14 sites used in 1985-86, phosphorus and potassium were dropped as independent variables because of highly non-significant effects (Table 7.3). Nitrogen application produced a highly significant increase in wheat yield (a coefficient of N = 17.74). Again, late planting caused a very significant reduction of 778 kg/ha. Weed control with Dicuran-MA resulted in a highly significant yield increase of 724 kg/ha. The nitrogen response curve is quadratic with a positive response up to 200 kg/ha (Fig. 7.1).

Table 7.3. Regression results of fertilizer experiments on wheat followed by rice

	1984-85	1985-86	1986-87 conven-tional tillage	1986-87 zero tillage	1987-88 conven-tional tillage	1987-88 zero tillage	1984-88 pooled
Constant	1924 (11.261)***	2211 (5.11)***	2855 (13.28)***	2123 (15.33)***	2574 (19.85)***	2350 (20.14)***	1770 (19.22)***
Nitrogen	14.79 (5.88)***	17.74 (3.47)***	21.75 (6.58)***	18.55 (6.02)***	21.14 (10.73)***	15.31 (6.41)***	18.01 (15.51)***
Nitrogen squared	-.0468 (3.29)***	-.04500 (1.59)	-.06942 (2.99)***	-.0449 (2.73)***	-.07098 (6.67)***	-.03385 (2.77)***	-.05287 (8.09)***
Phosphorus	5.193 (1.60)				2.270 (0.72)		.7989 (0.49)
Phosphorus squared	-.04321 (1.67)				-.0265 (1.22)		-.007972 (0.49)
N x P	.03442 (1.73)*				-.03586 (2.30)**		.01641 (1.66)*
Planting date-dummy	-980.0 (7.41)***	-777.8 (3.41)***	-1643 (11.24)***	-1580 (11.79)***	-660.9 (8.95)***		-890.6 (14.98)***
Weed control dummy	-105.3 (0.80)	724.0 (3.07)***			415.2 (4.87)***	-271.6 (2.59)***	279.2 (4.93)***
Zero tillage							-818.8 (13.23)***
Dummy for 1985-86							729.3 (7.09)***
Dummy for 1986-87							691.4 (8.55)***
Dummy for 1987-88							1129 (16.10)***
n	288	121	216	108	352	308	1393
R^2	.42	.29	.51	.72	.60	.34	.49
Probability of F-ratio to enter P P^2, NP	**0.017**	**0.969**	**0.742**	**0.713**	**0.006**	**0.574**	**0.024**

* = 10% significance level
** = 5% significance level
*** = 1% significance level
within parenthesis is t-value

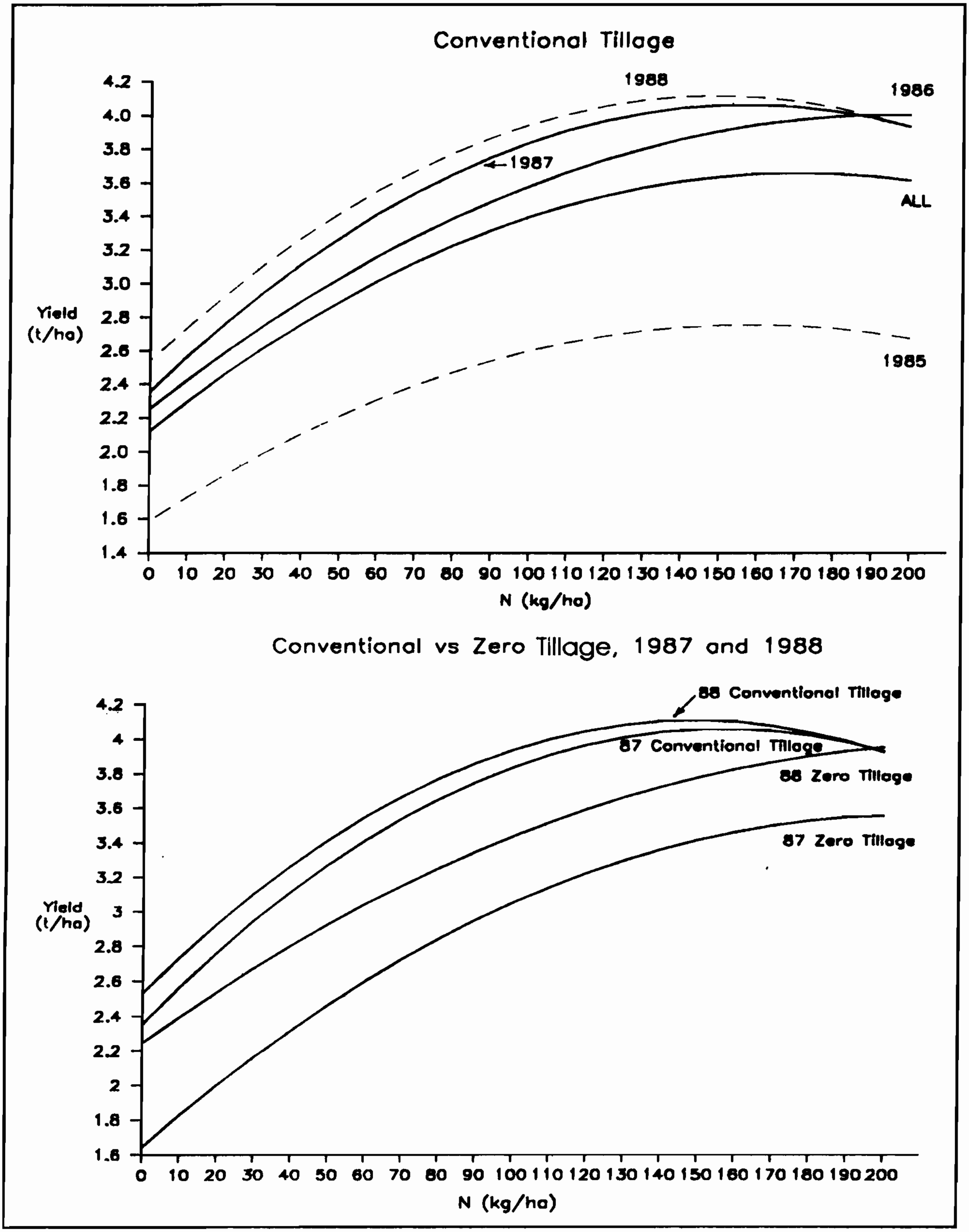

Figure 7.1. Yields under conventional tillage, 1985-88, and zero tillage, 1987-88

In 1986-87 experiments were conducted using two planting methods: conventional (six locations) and zero-tillage (three locations). Response curves were fitted to each tillage/planting method separately. Nitrogen gave a significantly increased yields for both methods up to 150-200 kg/ha (Fig. 7.1). Nitrogen responses were 17% lower for zero-tillage than conventional tillage (N coefficient of 21.75 vs 18.55). This is probably due to the greater volatilization of nitrogen in zero tillage plots, as urea was not incorporated after application. Phosphorus and potassium did not give significant responses in either case. Timely planting gave a very significant response of about 1,500kg/ha. The regression analysis did not include weed control because all trials planted at the normal time included weed control and all late planted trials received no herbicide (i.e., there was perfect multicollinearity).

Results for 1987-88 show a similar response behavior for both tillage/planting methods. The lower yields in the case of zero tillage (and the 38% lower coefficient for N) are again probably due to the fact that the nitrogen fertilizer was broadcast on the surface without incorporation. As in previous years, phosphorus and potassium had no effect on yield in either of the two tillage/planting methods, while planting date had a very significant effect.

Pooled results, 1984-88 Data from four years across 43 locations were pooled for analysis using year, planting time, weed control, and tillage method as dummy variables. The regression equation given in Table 7.3 indicates a significant effect of nitrogen fertilizer on wheat yields but no effect of phosphorus. Planting date had a very significant effect. Late planting reduced yields by an average of 890 kg/ha (30kg/day/ha for each day after November 15). Weed control had a significant positive effect (279kg/ha). The results also show a yield advantage for conventional planting over zero tillage, mainly due to the fact that applied nitrogen was not incorporated in the zero tillage treatments. Finally, dummy variables for the years 1985-86, 1986-87, and 1987-88 were all significant and positive. They indicate that yields were 700-800 kg/ha higher in other years relative to the reference year of 1984-85, when high temperatures were experienced in March.

Economics analysis of fertilizer experiments The economic analyses of fertilizer experiments at different marginal rates of return are given in Table 7.4. In 1984-85 at MRR = 0.5, it was most economical to apply nitrogen at the rate of 98 kg/ha and phosphorus at 30 kg/ha. Based on analyses of the 1985-86 trials, only nitrogen at the rate of 124 kg/ha was recommendable. For 1986-87 trials, analyses suggest the efficacy of nitrogen at the rate of 134 kg/ha in case of zero tillage and at 109 kg/ha for the conventional method. Recommendations formulated on the basis of 1987-88 trial results again endorse higher rates of nitrogen for zero tillage (128 kg/ha) than for conventional tillage (102 kg/ha). From 1985-86 on, phosphorus use was unprofitable because it had a non-significant effect on yields. The pooled analysis suggests economically optimum fertilizer rates of 108 kg/ha of nitrogen and no phosphorus, at MRR = 0.5.

Discussion

The most important results of the fertilizer experiments are the consistently strong response to nitrogen and the lack of response to phosphorus and potassium. Over all years the estimated grain:nutrient ratio for nitrogen application was 18:1 for increments of 50 kg/ha from 0 to 50 kg/ha. There was evidence of a weak response to phosphorus in the first year but in other years no response was observed. The lack of response to phosphorus in the rice-wheat system is interesting given the current official recommendations of 111 kg P_2O_5/ha (Department of Agriculture 1985). We suggest either that the continuous application of phosphorus to both rice and wheat crops has built up residual P_2O_5 or that the characteristic wetting and drying of puddled soils improves P availability. Ninety-three percent of the farmers who responded to the diagnostic survey said that they used phosphorus on wheat at an average dose of 57 kg/ha. At the 43 sites where fertilizer trials were planted, 79% of the farmers had also applied phosphorus to the preceding rice crop at an average dose of 59 kg/ha (Table 7.5). Soil analysis using the Olsen method showed an average of 5.8 ppm of available P_2O_5, which would suggest that phosphorus is not limiting. Similar results on phosphorus response have been recorded in the Indian Punjab (Singh 1987). These findings indicate that farmers should sharply *reduce* phosphorus applications and *increase* the dosage of nitrogen, in the rice-wheat areas of the Punjab. In 1984 farmers used an average of 67 kg/ha of N and 44 kg/ha of P_2O_5. Given the response curve over all years, if farmers had kept to the recommended rate of 110-0 kg N-P_2O_5/ha, they would have increased profits by 1,255 Rs/ha.

It is premature and probably wrong to recommend that farmers completely eliminate phosphorus from the fertilizer package they use for wheat. Further research is needed to work out an efficient strategy of phosphorus application that will maintain

Table 7.4. Fertilizer recommendations (kg/ha) at different marginal rates of return calculated from the response function

	Marginal rate of return					
	0		50		100	
Treatment	N	P	N	P	N	P
1984-85 Conventional tillage	136	68	98	30	64	0
1985-86 Conventional tillage	148	0	124	0	99	0
1986-87 Conventional tillage	125	0	109	0	93	0
1986-87 Zero tillage	159	0	134	0	109	0
1987-88 Conventional tillage	118	0	102	0	87	0
1987-88 Zero tillage	161	0	128	0	96	0
Pooled 1984-88 with P	129	0	108	0	87	0
Pooled 1984-88 without P	146	0	124	0	101	0

fertility levels, and thus yields, in the rice-wheat system. For the moment, the results strongly suggest that farmers should increase the level of nitrogen and reduce the level of phosphorus applied.

The other variables included in the analyses--planting date and weed control--confirm the results from previous chapters. However, while in both cases they shifted the response curve vertically, they did not significantly affect its shape; hence, they had no impact on the recommendations. The negative effect for zero tillage was not observed in the zero tillage experiments where high doses of nitrogen were applied. These results indicate the need to find ways to apply nitrogen that increase its efficiency under zero tillage.

Table 7.5. Summary of fertilizer use on previous rice crops at locations under fertilizer trials for wheat, 1984-88

Year	Nitrogen (kg/ha)	Phosphorus (kg/ha)	% farmers that used fertilizer	Phosphorous available in soil (PPM)	Potassium available in soil (PPM)
1984-85	75	51	88	4.9	253.6
1985-86	75	77	73	6.1	92.1
1986-87	99	56	67	8.3	n.a.
1987-88	90	52	87	3.9	272.9
Average	**85**	**59**	**79**	**5.8**	**206.2**

Chapter VIII

SYNTHESIS AND RECOMMENDATIONS

Each of the preceding chapters has presented the results of the experiments on tillage, weed control, variety, and fertilizer. In this chapter, results are synthesized into a series of preliminary recommendations for the rice-wheat area of the Punjab. For farmers to adopt these recommendations will require the implementation of supporting programs and policies by the provincial and federal governments. Hence, a second section of this chapter provides recommendations for transferring the improved technology to farmers. Finally, although a great deal has been accomplished in the present on-farm research program, much further research is needed to continue to increase productivity in the rice-wheat area. This chapter provides recommendations for that research.

Recommendations to Farmers

Tillage Tillage practices are a very important component of the recommendations for producing wheat in the rice-wheat system. On the basis of the results presented in this report, zero tillage seems to be a very economical and effective method of sowing wheat. Among its advantages are timely planting, improved crop stand, and a substantially reduced cost of land preparation and sowing. The main hindrance to recommending this practice is the Plant Protection Act of 1959, which requires rice stubble to be destroyed in order to control the rice stem borer *(Scirpophaga incertulas)*. It is recommended that this act be amended in order to allow an integrated approach to rice stem borer control that would include both cultural practices and pesticide application. In this integrated approach, zero tillage would be recommended in those areas where rice stem borer is not a major problem (Inayatullah and Rehman 1987).

Variety Three varieties--Pak-81, Kohinoor, and Punjab-85--showed better yield potential when planted at the recommended time and compared favorably to the early season varieties, Blue Silver, Faisalabad-83 and Faisalabad-85, when planted late. On the basis of the present varietal performance study, we believe that high yielding, broad-spectrum varieties such as Pak-81, Kohinoor, and Punjab-85 should be the general recommendation for the area, regardless of the time of planting.

Weed control After three years of study on chemical weed control in wheat sown after rice, we can confidently recommend the herbicide Dicuran-MA for control of *Phalaris minor*, the most important and damaging weed in the area. This chemical can give effective control of *Phalaris* at 50% of the manufacturer's recommended dosage.

It can also be effectively applied, if care is taken, by broadcasting in sand or urea mixtures. The economic threshold for applying Dicuran-MA to control *Phalaris minor* is an approximately 300 to 450 kg/ha yield loss, depending on the dosage. However, to control seed set and the buildup of weed populations, it may be economical to apply Dicuran-MA for lower yield losses.

Fertilizer Applying nitrogen at 110 kg/ha is recommended and should give high returns in all years. The extensive results from the present study indicate that there is no general economical response to either phosphorus or potassium application. We do not recommend the long term elimination of phosphorus or potassium from fertilizer packages. Nonetheless, it is recommended that farmers sharply increase the application of nitrogen to wheat and reduce the rate and frequency of application of phosphorus in the rice-wheat rotation. This can be accomplished within farmers' current total expenditures on fertilizer.

Technology Transfer

Extension demonstrations The recommendations outlined above can be promoted through a more effective and widespread campaign of extension demonstrations. These demonstrations should include the following:

Fertilizer demonstrations These should be designed to show farmers the potential for more efficient fertilizer use within the expenditures currently allocated to this input and could involve, for example, a comparison of three plots where nitrogen and phosphorus were applied in the following ratios: a) 80:40 kg/ha, b) 120:0 kg/ha, and c) 120:40 kg/ha.

Varietal demonstrations These demonstrations should compare two or three of the new varieties with currently used cultivars. Demonstrations should be performed for both early and late planting, and should serve as a means of distributing seed of new varieties at the village level (see below).

Herbicide demonstrations The extension system and the private sector should develop a joint program to conduct demonstrations of grassy-weed herbicides applied with the following treatments: a) full dosage, b) half dosage, and c) full dosage broadcast in a herbicide/urea mixture. These plots should be spread throughout fields that have serious *Phalaris minor* infestations. Field days should be organized to display each demonstration plot.

Seed sales and exchange The rate of adoption of new varieties is still too slow to take full advantage of the results of plant breeding research and to protect effectively against rust epidemics. Policy recommendations to promote the sale of seed of improved wheat varieties are presented in Heisey et al. (1987), and involve increased market promotion by the Punjab Seed Corporation, more sales points, greater participation of private sector distributors, sale of seed in small lots of 5-10 kg, and more widespread information dissemination through extension, radio, etc. A seed exchange system organized around large-scale growers at the village or union council level should also be considered.

Manufacture of a suitable drill for zero tillage It is clear that the promotion of zero tillage using direct drilling will require the local manufacture of an appropriate drill. Manufacture and promotion of the drill should be left largely in the hands of the private sector. Initial conversations with private sector machinery manufacturers indicate the feasibility of producing such a drill locally at a price that is within the reach of local farmers and machinery contractors. The Minister of Agriculture could play an important role by endorsing the concept of zero tillage (and, initially, removing legal constraints to the method, as discussed above) and by encouraging the private sector to take the initiative in this area.

Future Research

The results of the present study are preliminary and further research is needed on the rice-wheat system. This will involve 1) refining recommendations to fit specific, "homogeneous" groups of farmers (i.e., with similar production circumstances) for near term problems and 2) long term study of certain other issues.

Near term research The present study provides broad recommendations for the rice-wheat system of the Punjab. However, factors such as soil type, access to irrigation water, socioeconomic situation, and pest/disease/weed problems vary substantially within the zone. Further on-farm research is needed to develop recommendations that will likely be adopted by groups of farmers with similar production circumstances. Near term research can be divided into five major sub-headings/problem areas, as shown in Figure 8.1.

1. Delayed and sub-optimal wheat establishment This problem is related to poor plant stand, waterlogging due to a plow pan during puddling for rice, poor soil structure after rice harvest, slow drying of soil after rice, dense rice residues, inadequate land preparation and planting implements, and the use of long duration rice varieties.

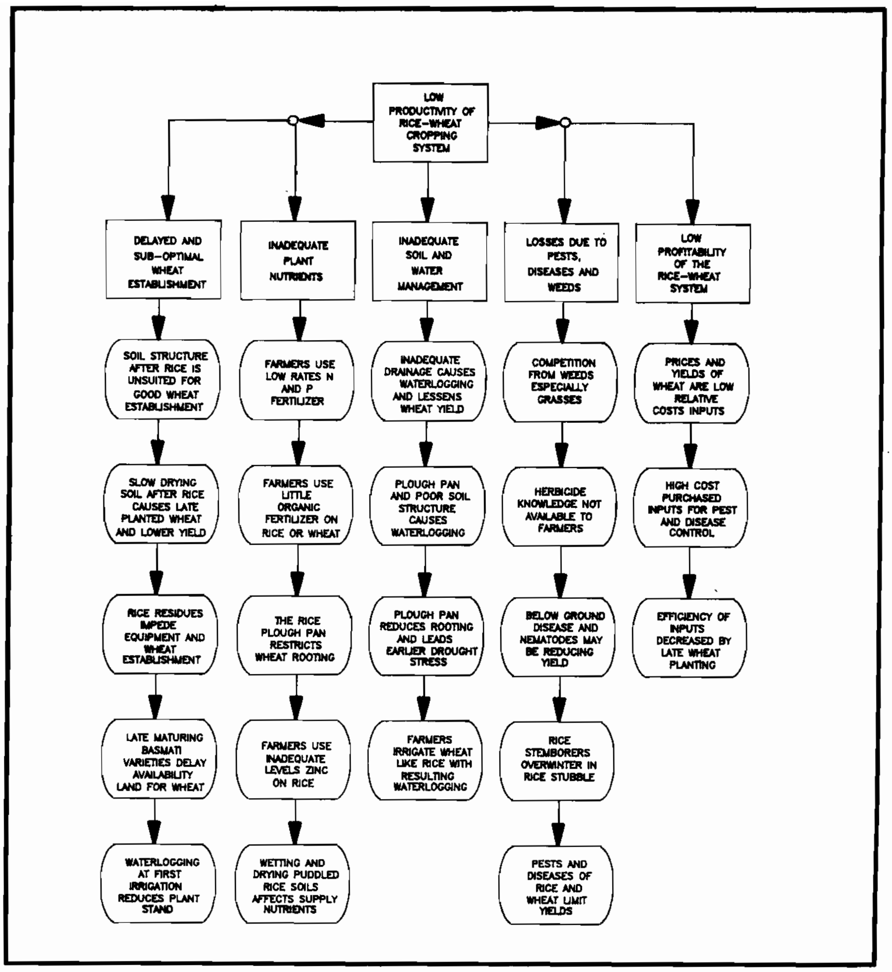

Figure 8.1. Near term research issues for the rice-wheat cropping systems of the Punjab

Continued efforts are required by rice breeders in selecting high yielding, pest/disease resistant, earlier maturing Basmati and improved varieties of rice for this region. The export market for Punjab Basmati rice will play an important role in this breeding effort. The introduction of Basmati-385, an earlier maturing variety than Basmati 370, has helped reduce turnover time from rice to wheat. However, the productivity and pest/disease reactions of this new variety will need to be monitored.

The rice program could also help solve problems of soil structure by developing varieties and technology for dry seeding: if soils were not puddled, the difficulties of establishing wheat would be minimized.[5] Such a solution, however, would be location specific and relevant only to those areas where water tables are high or water for rice is not limiting. Identification of suitable varieties for dry seeding and control of weeds would be major research themes.

Earlier planting, reduced costs, and better establishment could all be achieved by producing a suitable drill and a package of zero tillage practices for wheat following rice. Recommendations for seeding rates and depths, fertilizer dosages and application methods, weed control, and water management need to be developed for such a package.

Early season waterlogging and reduced rooting in wheat caused by the plow pan require further study. Deeper plowing or cultivation using chisels or a slitter could alleviate these problems, but studies will be needed to develop recommendations for different soil types. For some soils, improved tillage and planting implements may be a better answer than zero-tillage. Managing irrigation water so as to provide optimal moisture for early planting (the *wadwater* method) would ensure better stands.

2. Inadequate soil nutrients Nitrogen is obviously the major limiting nutrient in this intensive cropping system. Application of nitrogen by banding in zero-tillage or at the first irrigation are two ways to improve efficiency and reduce costs. Research is needed on how the use of organic and green manures in combination with inorganic nitrogen affects N efficiency.

Phosphorus and potassium produced virtually no response in this study, a circumstance that requires elucidation. The changes in soil properties as waterlogging and drying take place in this puddled soil system may help explain the availability of these elements.

The effect of micronutrients on wheat in this system also requires attention. Zinc is known to be a limiting factor in rice cultivation in alkaline soils, and the roles of boron and manganese require further description. The use of high analysis fertilizers like urea, DAP, TSP, and nitrophos means that S and magnesium may become limiting. Once again, classification of the rice-wheat zone by soil type is necessary.

[5] Another reason for pursuing this line of research is the labor shortage for transplanting rice, a situation that causes delays in transplanting, yield loss (old seedlings), and suboptimum populations in transplanted rice.

3. Inadequate soil/water management The water requirements of rice and wheat are different--rice needs anaerobic conditions and wheat aerobic. The role of drainage and water distribution systems in wheat production, particularly during the early stages of growth, warrants attention. Farmers tend to irrigate wheat like rice, resulting in yellowing, stunting, and reduced yields. Data exist which suggest that delaying the first irrigation 35 to 40 days is less damaging than providing water at crown root initiation, when young seedlings are sensitive to waterlogging.

At the other end of the scale, the plow pan and restricted rooting can cause drought stress, a condition that becomes particularly important during grain filling. At this stage--precisely when temperatures and evapotranspiration are high--irrigation water is often cut off to allow crops to mature.

4) Losses due to pest/diseases/weeds Grassy weeds are causing significant yield losses in both rice and wheat in this system. An understanding of the reasons for variation in weed populations across fields and over time is urgently needed to develop an integrated weed control package. Additional research on the effects of chemical control on weed populations over time is also necessary.

Little work has been done on the diseases and pests that limit yields by attacking the roots of the plant. Work on solarization in Nepal (H. J. Dubin, personal communication) suggests that such losses may be significant. For example, there is little information about the effect of the rice root nematode *(Herschmaniella avenae)* on wheat, though it appears to survive on wheat roots during the winter. Crop rotation is one possible control option: the use of berseem and other legumes may not only replenish soil nutrients but also reduce the populations of parasitic soil organisms. Here, emphasis in research should be on rotational trials (more than one year) as opposed to cropping pattern comparisons.

Other significant pests require study as well. If zero-tillage is to be successful, stem borers must be controlled. The armyworm *(Mythimna separata)* is a new, potentially severe threat to wheat production. Understanding the reasons for population explosions of this insect is essential.

5) Low profitability of rice-wheat systems When wheat is planted late, the efficiency of inputs is undermined, and yields and profitability reduced. The feasibility of alternative crops that can be planted later (such as sunflower) should be evaluated and, in the event that their promise is confirmed, appropriate management recommendations developed for them.

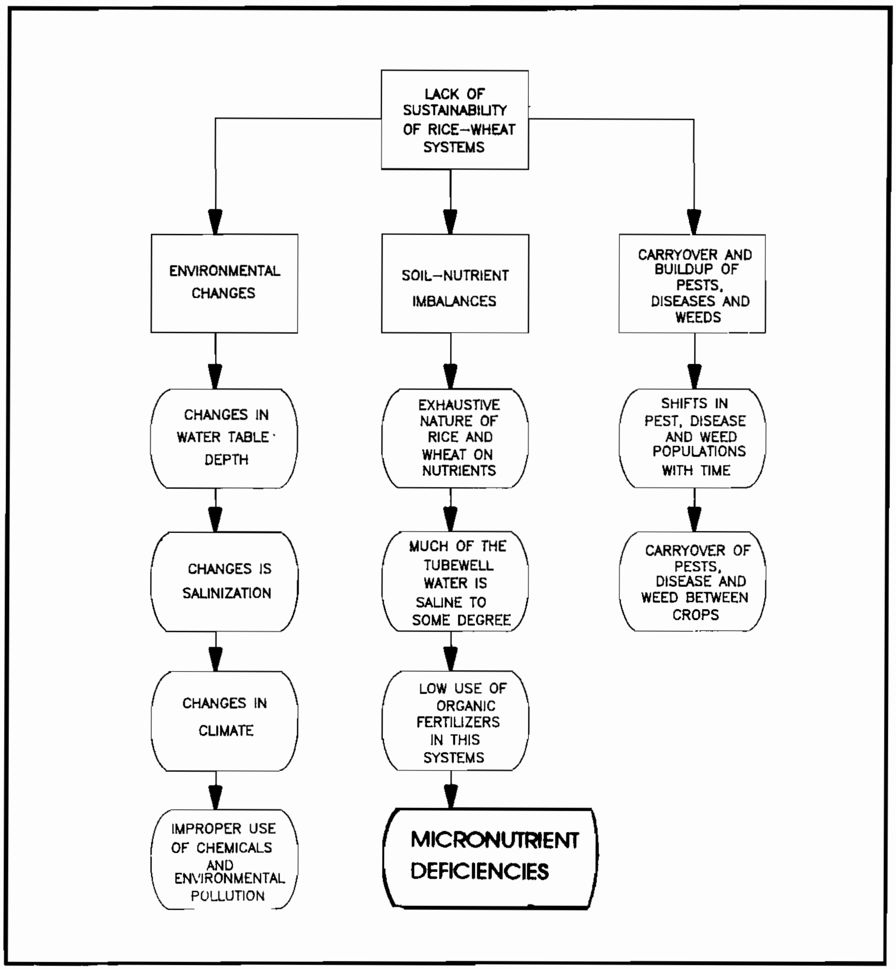

Figure 8.2. Long term sustainability issues for the rice-wheat cropping systems of the Punjab

Long term research The productivity of rice and wheat in the rice-wheat tract seem to be stagnant or declining. Quantifying this phenomenon and gaining insights into the reasons behind it are priorities which should guide the course of any future research on the rice-wheat system. Three major areas command particular interest with regard to this question (see also Fig. 8.2).

1) Soil nutrient imbalances One obvious cause for the apparent decline in productivity of the rice-wheat system is the crops' high nutrient requirements and the resulting soil depletion. The situation is exacerbated by the insufficient use of fertilizers.

Finally, much of the tubewell water applied in the rice-wheat zone is saline and thus contributes to nutrient imbalances and poor crop growth.

The methodology for studying sustainability issues is still in its infancy. Long term trials furnish one possible avenue. Managing such trials so as to minimize experimental error over time is difficult, and the long wait for results makes them expensive. However, long term trials can provide valuable information. Suitable trials should be developed for specific soil situations in the rice-wheat areas. Their initial design should be kept simple and include large plot sizes to allow subsequent splitting, in the event that a particular aspect of the agenda requires further research. A multidisciplinary team of scientists should have free access to all resulting data.

Monitoring specific fields over time is another way to research sustainability issues. This also requires care in field selection and teamwork on the part of biological and social scientists. Multivariate analysis can be used to evaluate results and historical data, where available, may serve to determine trends in various parameters over time.

2) Carryover and the build up of pests/diseases/weeds This issue was discussed in some detail in the section on short term research topics, but here the work would involve monitoring fields over time and analyzing changes in terms of differences in management.

3) Environmental changes This issue includes changes in water table depth, temperature, and salinity, as well as the effects of management and inputs on pollution levels (an aspect whose importance will grow in direct proportion to the use of chemical herbicides and pesticides). It is recommended that research in this area:

- Be conducted on-farm as well as on-station in representative areas of the rice-wheat tract

- Involve a multidisciplinary team of biological, physical, and social scientists--rice and wheat specialists alike--and provide for the participation of farmers and extension workers in the research process

- Include both agronomic and economic evaluation of the results

Continuous monitoring and assessment of this system would be needed to ensure the sustainability of productivity gains, and incentives should be provided that promote an integrated research approach for identifying and solving farmers' key problems over the long term.

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