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Reconciling Conflicts in Sequential Cropping Patterns Through Plant Breeding: The Example of Cotton and Wheat in Pakistan's Punjab*

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SUMMARY

A cropping systems framework is used to analyze breeding priorities between wheat, a staple food crop, and cotton, a cash crop, which are increasingly grown in a sequential double cropping pattern in Pakistan's Punjab. Survey and experimental data are presented to show how conflicts in harvesting of cotton and planting of wheat are being resolved through earlier cotton varieties and wheat varieties that perform well over a range of planting dates. However, changes in cotton pest management and price relationships between cotton and wheat call for continuous review of breeding priorities.

INTRODUCTION

The current burst of activity in farming systems research has been important in imparting a farmer orientation and holistic approach to the development and dissemination of improved technology. The farming systems approach to research has been most successful in establishing strong on-farm research programs to adapt technologies to the conditions of local farmers. However, to develop a farmer orientation throughout the research system, it is important that information from on-farm research be fed back to

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conventional commodity and disciplinary research programs conducted on experiment stations. Unfortunately, this linkage is often not well established and commodity research programs on stations tend to operate somewhat independently of on-farm research teams (Cardoso & Munoz, 1986).

In Pakistan, plant breeders have traditionally developed varieties for each commodity independently of other commodity breeding programs, even where commodities are closely linked in multiple cropping patterns. Although modest attempts have been made in some cases to incorporate a cropping systems perspective in setting breeding priorities, these are often quickly outdated by changes in cropping patterns brought about by increasing cropping intensity and changing price relationships. Hence, setting of breeding priorities for crops produced in complex multiple cropping systems requires constant reference to the current and projected situation of farmers.

This paper describes the process of reconciling conflicts in the cotton–wheat cropping pattern of the southern Punjab in Pakistan. A brief overview of the system is provided and then the implications for development of cotton and wheat varieties to fit these systems are discussed. Finally, some recent changes in cotton management are reviewed as they pose new challenges to cotton and wheat breeders and cropping systems researchers.

THE COTTON–WHEAT SYSTEM

The cotton–wheat system is the dominant cropping system of southern Punjab Province and much of Sind Province of Pakistan. Data for this paper were collected from surveys conducted in 1985 in Multan District of the Punjab. These surveys were undertaken at the diagnostic stage of an on-farm research program in wheat. An informal survey was conducted by a multidisciplinary team of wheat scientists, cotton scientists and social scientists. This was followed by a formal survey at harvest time of 150 farmers where more detailed quantitative data on wheat production were collected for a specific field, together with data on cotton management practices and yields for the same field in the preceding season. Details are given in Akhtar *et al.* (1986).

Agriculture in the study area depends on irrigation—both canal and private tubewells. Average farm size is 8·2 ha but with 58% of farmers cultivating less than 5 ha. Cotton, a cash crop accounting for 76% of *Kharif* (summer) area, is planted in May–June and harvested from September up to January. Wheat, the main food staple, occupies 80% of *Rabi* (winter) cropped area. The optimal date for wheat planting is mid-November with harvesting in late April. Temperatures in February–March in the flowering and grain

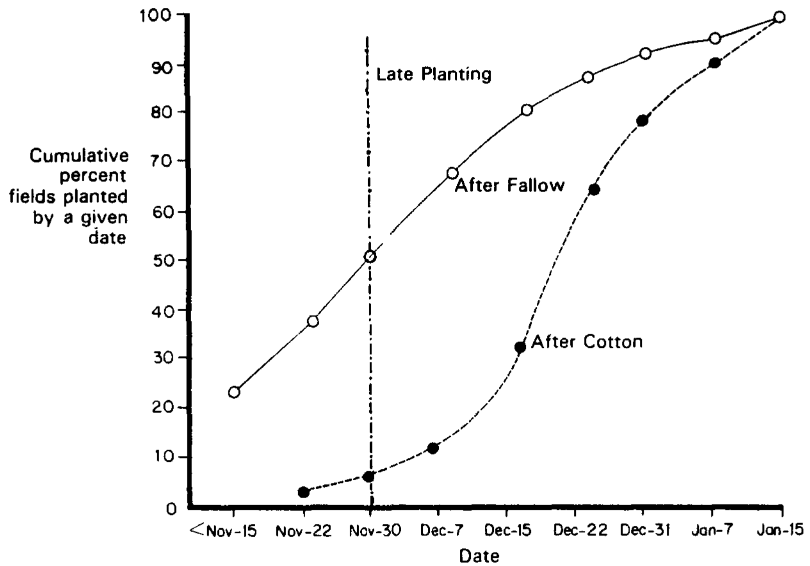


Fig. 1. Cumulative distribution of planting date of wheat by previous crop, cotton–wheat areas, 1985.

filling stages of the wheat crop are quite variable. Early arrival of hot weather depresses wheat yields, particularly for late planted fields.

Traditionally, wheat and cotton have been grown as single crops. However, cropping intensities have increased rapidly in the last decade with increased pressure on land, greater availability of tubewell water, the introduction of early maturing semi-dwarf wheat varieties since 1966, and, more recently, introduction of earlier cotton varieties. Cropping intensities jumped from 114 in 1971 to over 130 in 1983. In our survey in 1985, wheat was planted after cotton in 50% of fields and after fallow in only 30% of fields.

The major conflict in the cotton–wheat cropping pattern is the prolonged harvesting of cotton resulting in late planting of wheat. Wheat after cotton was planted, on average, 19 days later than wheat in other rotations. Indeed, two-thirds of wheat fields planted after cotton were planted after 15th December when the risks of yield losses are very high (Fig. 1). Cotton picking is staggered over a period of at least two months with farmers, on average, making 3·6 pickings at 15- to 20-day intervals. Cotton yields are highest for the first picking and thereafter decline with successive pickings. At the same time, picking charges, which are set as a proportion of the harvest, increase with the number of pickings.

Farmers appeared rationally to weigh up the benefits of an additional cotton picking with the costs in terms of late wheat planting. They estimated that the yields of the last cotton picking averaged 200 kg/ha. From

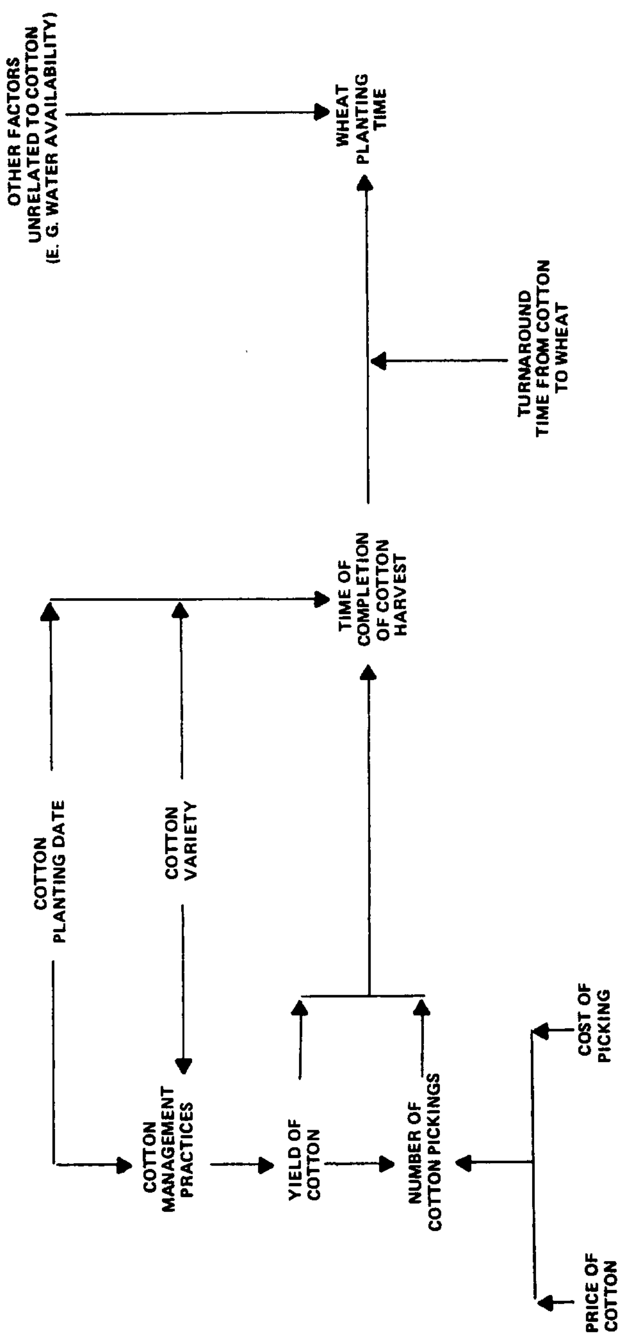


Fig. 2. Schematic representation of factors affecting wheat planting time in cotton–wheat rotation.

TABLE 1
Comparison of the Economics of One Additional Cotton Picking versus the Loss in Wheat Yield due to Late Planting, Cotton–Wheat Area, 1985

Farmers' estimate of yield of last picking of cotton	200 kg/ha
Net cotton yield (less harvesting cost, 25%–50%)[a]	100–150 kg/ha
Value of net cotton yield (Rs. 4·75/kg)	Rs. 475–713/ha
Loss in wheat yield due to late planting—15 days at 30 kg/day[b]	450 kg/ha
Net wheat yield loss (less 33% harvesting, threshing and transport costs)	300 kg/ha
Value of wheat yield lost (Rs. 1·68/kg)	Rs. 500/ha

[a] Cost of cotton picking varies with the stage of harvest. The proportion received by harvest labour is highest for the last picking.
[b] Two-thirds of loss for wheat grown under optimal conditions.

experimental data, we estimate (see later section) that wheat yields under farmer conditions decline on average by 30 kg/day for every day's delay in planting after mid-November. Given these assumptions, Table 1 shows that the benefits of the last cotton picking easily outweigh the loss in wheat yields due to late planting. However, as we shall see below, the fact that cotton is a cash crop and wheat is a food crop may alter farmers' willingness to trade-off in purely monetary terms.

A complex of factors potentially influences the timing of cotton harvest and hence planting time for wheat (Fig. 2). Leaving aside for the moment cotton variety, which is discussed in the next section, the most important of these factors are the yield of cotton and the date of planting of cotton. This is expressed by the multiple regression analyses presented in Table 2. Higher yields of cotton delay completion of the cotton harvest and delay wheat planting since higher yields of cotton increased the number of pickings (correlation coefficient of 0·21 and significant at 5% level). The yield of the last picking was also highly significantly and positively correlated with total cotton yield ($r = 0{\cdot}61$) so that higher yielding fields are more likely to make it worth while for the farmer to take a last cotton picking and delay wheat planting. Likewise, analysis of time series data indicates a significant negative relationship between wheat yields and the prices received for the previous cotton crop (Hamid *et al.*, 1987), again pointing to the trade-offs between making a final cotton picking and planting wheat on time.

TABLE 2
Multiple Regression Analysis of Factors Affecting Time of Planting for Wheat and Time of Completion of Cotton Harvest

Independent variables	*Definition*	*Dependent variables*	
		Date wheat planting (weeks after 1st Oct)	*Date finished cotton harvest (weeks after 1st Oct)*
1. *COTPLANT*	Date cotton planting (weeks after May 1st)	0·976 (2·90)***	0·974 (2·79)***
2. *COTYLD*	Yield cotton (t/ha)	2·636 (2.63)**	2·713 (2·62)**
3. *PLANT*YLD*	Interaction term of *COTPLANT* and *COTYLD*	−0·441 (2·22)**	−0·467 (2·28)**
4. *NIAB78*	Dummy variable = 1 if cotton variety = NIAB78	−0·483 (1·38)	−0·538 (1·49)
5. *TURNAT*	Turn-around time cotton to wheat (weeks)	0·285 (0·98)	
Constant		3·456	2·601
R^2		0·19	0·15
n		73	73

t – values given in brackets. **, *** denote significance at 5% and 1% levels, respectively.

Because of these relationships the conflict between higher cotton yields and higher wheat yields is potentially greatest for large farmers. Management practices of large farmers lead to significantly higher cotton yields and hence a greater incentive to delay wheat planting or not plant wheat at all following cotton. In 1984, large farmers achieved cotton yields 40% above small farmers largely due to the greater use of pesticides (Table 3). (The correlation between the number of pesticide applications and yields was 0·46 and highly significant). (On average, large farmers (> 10 ha) planted wheat 4 days later than small farmers (< 10 ha), but this difference was not significant. Even with a sample of 150 farmers, the number of large farmers planting wheat after cotton in the sample (16) is too small for meaningful analysis.)

The regression analyses in Table 2 also show that the planting date for cotton significantly influences the date of completion of the cotton harvest and the time of planting of wheat. Every one week's delay in planting of cotton delays the planting of wheat by one week (denoted by the value of the coefficient of 0·976 for *COTPLANT* in Table 2). Since wheat matures in April, conflicts in the cotton–wheat system might be resolved by earlier planting of cotton in May. In fact, about half of cotton preceding wheat was

TABLE 3
Differences in Cropping Intensity, Cotton Yields and Management, and Wheat Yields by Farm Size

	Small farmers (<*5 ha*)	*Large farmers* (>*10 ha*)	*Significance level*
% *Rabi* area in fallow	19·6	36·6	<0·01[a]
% plant cotton in May	37	63	0·15[a]
Average number of sprayings for cotton	2·9	3·8	0·03[b]
Average cotton yield (t/ha)	1·49	2·09	<0·01[b]
Average wheat yield (t/ha)	2·17	2·20	0·81[b]

[a] Chi-squared test.
[b] *t*-test.

planted in May compared to the optimum planting period of the first two weeks in June. However, early planted cotton is also not recommended since a significant reduction in yields has been recorded in date of planting experiments.

The negative interaction term for cotton yield and cotton planting date in Table 2 is more difficult to interpret. It most probably reflects the fact that cotton planted during the optimal period gives higher yields without extending the harvesting period proportionally. The turn-around time between cotton and wheat only has a small effect on wheat planting date in Table 2. This is, to some extent, to be expected since farmers who are late in harvesting cotton attempt to reduce the turn-around time to compensate partially for the delay in wheat planting (correlation coefficient of −0·20). Turn-around time was one week or less in 25% of fields and 10 days or less in nearly two-thirds of fields. While this is not a long delay, the option of zero tillage for wheat, which has proven successful after rice in Pakistan, does offer the opportunity to reduce somewhat conflicts in the cotton–wheat cropping sequence.

CHOOSING COTTON AND WHEAT VARIETIES FOR THE COTTON–WHEAT SYSTEM

Cotton varieties

The dominant cotton varieties grown by surveyed farmers were MNH93 (40% of fields) and NIAB78 (56% of fields). MNH93 is a variety developed and released in the year 1980 and was the recommended variety of the research and extension system. MNH93 represented an advance in earliness

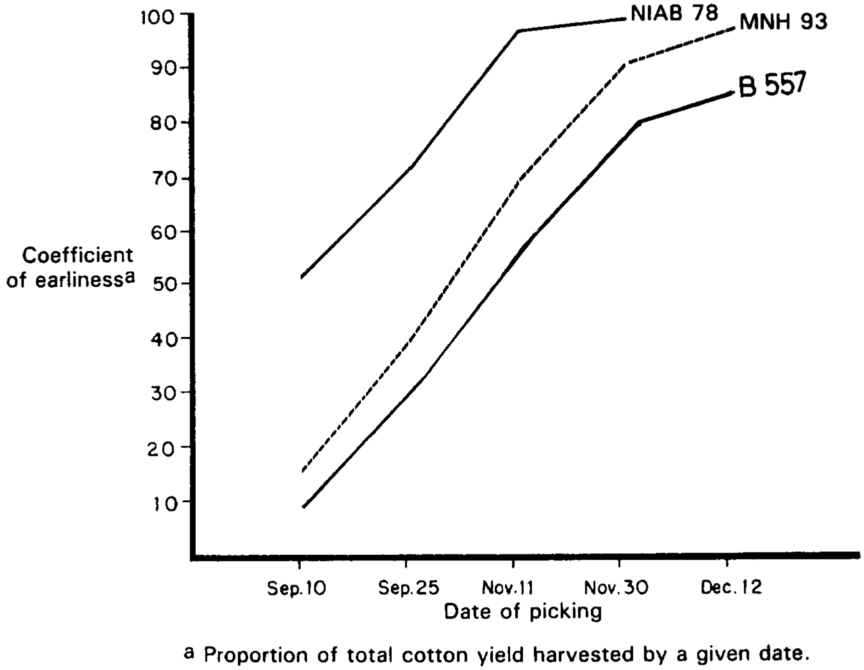


Fig. 3. Coefficient of earliness of different cotton varieties, 1980. Source: NIAB, Faisalabad.

compared to the variety previously grown by farmers, B-557. (The Coefficient of Earliness in Fig. 3 shows the proportion of total cotton yield harvested by a given date). Meanwhile, an even earlier variety, NIAB78, was developed by non-conventional breeding methods at the Nuclear Institute of Agriculture and Biology (NIAB) (see Fig. 3). In addition to earliness, NIAB78 is also generally higher yielding than MNH93, although it was subject to small price discounts for quality in the early years of adoption.

Because the quality characteristics of NIAB78 were initially disputed, research and extension did not recommend that planting of this variety. However, it became apparent that farmers were already widely growing the variety and it was finally officially approved in 1983. By 1985, it covered 40% of the Punjab cotton area and an even higher proportion (56%) of cotton grown in cotton–wheat crop rotations. The regression in Table 2 shows that fields of wheat planted after NIAB78 do tend to be planted earlier, although the effect is not statistically significant. Even earlier varieties are now being tested by NIAB for possible future release.

The availability of increasingly earlier varieties of cotton has been a major factor in the sharp increase in cropping intensity in the area, from an index of 113 in 1971 to 134 in 1985. This has largely been accomplished by planting wheat after cotton in place of leaving land fallow in the *Rabi* cycle.

Wheat varieties

Wheat breeders have, until recently, emphasized evaluation of varieties at optimum planting dates—that is, in November. For late planting, earliness was assumed to be a desirable characteristic and hence the variety Sonalika was recommended for late planting.

Most farmers stagger wheat planting over two or more planting periods according to crop rotation. Dividing the planting period into 15-day intervals, Table 4 shows that even small farmers often plant in more than one period. Nearly one-third of farmers spread planting of wheat over a period of four or more weeks.

To accommodate these differences in planting dates, many farmers, especially large farmers, planted more than one variety (Table 5). Farmers also tended to substitute the earlier variety, Sonalika, for their main variety, WL-711, for late planting (after December 1st) but even then, over half of late planted fields were planted to WL-711 or other 'normal' season varieties (Table 6). There were also many farmers who planted the same variety over several planting periods. These data suggest that farmers will accept multiple varieties to fit different planting dates but it would be a distinct advantage to have a variety that can be used successfully at all planting dates. This is reinforced by the fact that wheat planting dates shift substantially from year to year depending on the cotton harvest. For example, after the very poor cotton crop of 1983, wheat was generally planted much earlier than in the following year, when a record cotton crop was harvested.

TABLE 4
Number of Planting Periods for Wheat for Individual Farmers, Cotton–Wheat Areas, 1985

	Number of planting periods[a] per farmer			
	One	*Two*	*Three or more*	*All*
	(Per cent of farmers)			
Farm size group				
<5 ha	48	50	2	100
5 to 10 ha	30	63	7	100
>10 ha	11	66	23	100
All	36	56	8	100

Chi-squared = 23·8. Probability = 0·0001.
[a] Planting periods defined in 15-day intervals—up to Nov. 30, Dec. 1–Dec. 15, Dec. 16–Dec. 31, after Jan. 1st.

TABLE 5
Number of Wheat Varieties Planted by Farmers in Different Farm Size Groups, Cotton–Wheat Areas, 1985

	% farmers planting				Average number planted
	One variety	Two varieties	More than two varieties	All	
False size group					
<5 ha	77	21	2	100	1·3
5 to 10 ha	70	22	8	100	1·4
>10 ha	44	39	16	100	1·8
All	68	25	7	100	1·4

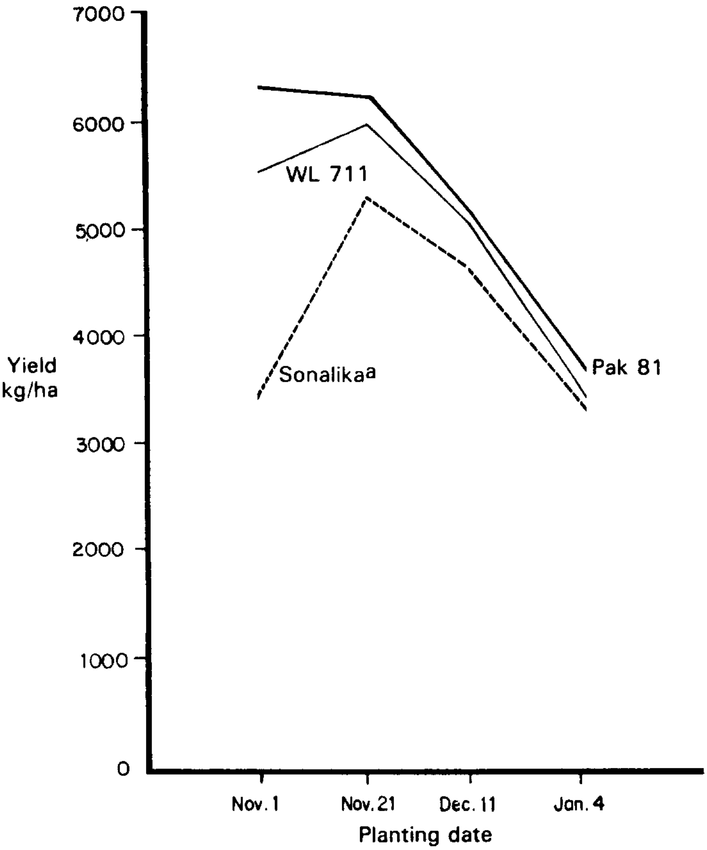
Chi-squared = 23·8. Probability = 0·0024.

Recent evidence suggests that some medium- to longer maturing varieties previously recommended only for normal planting, such as Pak 81, perform better than early varieties when planted late. Figure 4 shows that even the farmers' standard variety, WL711, which was not recommended for late planting, seems to do better than the early variety, Sonalika, at all dates of planting. Regression analysis of losses in yields to late planting suggest that although the yield loss/day under optimal conditions for Sonalika is 43 kg/ha/day compared to 56 kg/ha/day for Pak 81, the higher yield potential of Pak 81 offsets this decline in yields. Under farmer conditions, we estimate that yield losses are about two-thirds of those under optimal conditions, i.e. about 39 kg/ha/day. (Assuming that the relative yield loss

TABLE 6
Wheat Variety by Planting Date, Cotton–Wheat Areas, 1985

	% fields planted with variety			
	Non-recommended[a]	New recommended[b]	Sonalika	All
Planting date				
November	78	11	11	100
Dec. 1st to Dec. 15th	72	15	13	100
Dec. 15th to Dec. 31st	50	14	36	100
January	32	21	47	100
All	63	14	23	100

Chi-squared = 20·5. Probability = 0·0023.
[a] WL-711.
[b] Punjab 81, Pak 81.



[a] Duncans Multiple Range Test (5% level) indicates that Pak 81 is significantly higher yielding than Sonalika at all dates of planting, and higher yielding than WL 711 for the dates, Nov. 1st and Jan. 4. WL 711 significantly outyields Sonalika at all planting dates except Jan 4.

Fig. 4. Effect of planting date on wheat yields, cotton areas, 1981–82 to 1984–85. Source: Punjab Seed Corporation.

under farmer management is the same as observed under optimal conditions.)

On the basis of these new findings, wheat breeders have now established a multi-locational trial to test all promising varieties over a range of planting dates and climatic conditions. Efforts will be made to screen varieties that do well across a range of planting dates and environments.

PLANT BREEDING FOR A MOVING TARGET

While breeders of both cotton and wheat are conscious of the importance of fitting varieties to the cropping pattern, they must also keep abreast of changes in cropping patterns and in crop management (Maxwell, 1986). Two of these changes are discussed below: (a) changing prices and (b) more intensive management of the cotton crop.

Changing price relationships

The trade-off between cotton and wheat yields (Table 1) indicates that major resolution of these conflicts will come from wheat because of the relatively higher profitability of cotton. The rapid adoption of NIAB78 cotton variety was probably due more to its higher yields than to earlier maturity. However, a reduction in cotton prices relative to those of wheat might alter this strategy. Returning to Table 1, the break-even ratio of cotton to wheat prices is about 6·0. At this ratio, the value of the last cotton picking would be equivalent to the value of wheat yields forgone from delayed planting. Only in three years of the last twelve has the cotton–wheat price ratio fallen to, or below, this ratio. However, recent increases in domestic wheat prices and a general long-term stagnation in cotton prices due to world market conditions may lead to a significant drop in the cotton–wheat price ratio in the future. In this case, cotton breeders might want to place greater pressure on selection for earliness than they have in the past.

Improvements in cotton management

Several studies (e.g. Aslam, 1983; Cheema & Haq, 1984) demonstrate the substantial variation in cotton yields and management between farmers. A large part of this variation is due to the capital intensity and complexity of pesticide use in cotton. As a result there are substantial differences between small and large farmers in pesticide use and cotton yields, while for the same farmers we found no difference in wheat yields by farm size (Table 3).

The very poor cotton harvest in 1983 focused attention on the low use of pesticides by small farmers. As a result, private and public efforts have recently been strengthened to improve management of the cotton crop, especially in the use of pesticides. Pesticide use more than *doubled* in 1984 compared to 1983 and increased a further 12% in 1985. Much of this increase seems to have occurred on small farms and the yield gap between small and large farmers has narrowed (Table 7). Since small farmers widely use the cotton–wheat double cropping pattern, increases in cotton yields on small farms will lead to a further delay in wheat planting and lower wheat yields.

If wheat is treated as a cash crop, this new situation should lead to a decline in wheat area, especially in the cotton–wheat rotation. Wheat yields of about 1·7 t/ha are required just to cover variable costs and in fields planted

TABLE 7
Ratio of Pesticide use on Cotton and Ratio of Yields of Large Farmer Compared to Small Farmers, 1979 and 1984

	Year	
	1979	*1984*
Pesticide use ratio	2·4	1·3
Yield ratio	1·7	1·4

Source: Aslam (1983) and Akhtar *et al.* (1986).

very late (after Dec 15th) yields barely exceed this level under farmers' management. It is hypothesized that farmers who have surplus wheat would be willing to substitute other crops, while farmers who are in food deficit or are borderline self-sufficient would be less flexible in their decision to switch to other crops. To estimate the breakeven point in wheat production for self-sufficiency, wheat sales, *S*, were regressed against total wheat production, *P*, with the following result:

$$S = -3{\cdot}85 + \underset{(14{\cdot}7)^{***}}{0{\cdot}82P}$$

$$R^2 = 0{\cdot}87 \qquad n = 104$$

t – values in brackets – *** significant at 1% level

From this equation, $S > 0$ for $P > 4{\cdot}7$ tonnes. Assuming average yields of 2·3 t/ha, farmers with over 2·0 ha of wheat are in a surplus situation and would have flexibility to change cropping patterns. Since 60% of farmers fit this criterion, there is a strong justification for stepped up efforts to find more productive cropping patterns, such as cotton–sunflower or cotton–maize. Earlier varieties of sunflowers and cold tolerance of maize are required to fit into these cropping patterns. Plant breeding efforts might be better invested in developing more appropriate varieties of these crops rather than wheat for late planting. Currently it seems that some farmers, especially large farmers, leave land fallow rather than plant wheat (the correlation between the proportion of land left fallow and the proportion of late planted wheat is −0·16 and significant at the 5% level).

CONCLUSIONS

Commodity research programs in regions where multi-cropping is common need to continuously monitor the cropping patterns in which the commodity is produced. In particular, changes in cropping intensity and in management practices in one crop can have important implications for varietal selection for the next crop in the cropping sequence. Plant breeding programs for different crops in the sequence must effectively communicate with each other in order to develop strategies for resolving conflicts and promoting more efficient cropping patterns.

In the particular case of cotton and wheat in Pakistan discussed in this paper, newly released varieties have had the appropriate characteristics for the cotton–wheat system. With better availability of farm level data, explicit attention is now being given to developing wheat varieties that do well over a range of planting dates—a desirable characteristic for small farmers in the cotton–wheat system. In addition, we have suggested that with rapid changes in cotton management, emphasis should be placed on breeding for substitute crops, mainly oilseeds and maize to replace late planted wheat for medium and large farmers.

The methodology used in this study is particularly appropriate for monitoring multiple cropping systems. Field specific data on a cropping sequence (in this case cotton–wheat), have allowed a detailed exploration of the interrelationships over time between crops in the sequence.

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