

# **Role of Tractors, Tubewells and Plant Breeding in Increasing Cropping Intensity in Pakistan's Punjab**

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(Accepted 25 January 1989)

**ELSEVIER**

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## Abstract

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Cropping intensity in the cotton-wheat areas of Pakistan's Punjab is well below its potential, and also significantly lower than in neighbouring areas of India's Punjab. Analysis of annual cropping intensity indicates that access to irrigation water is the major factor explaining differences in cropping intensity in a cross-section of farmers. Ownership of a tractor plays a lesser role in increasing cropping intensity, although official credit policy has emphasized tractorization over investments in tubewells. Analysis of season-specific cropping intensity also indicates that lack of appropriate varieties for double cropping also constrain cropping intensity. It is estimated that cropping intensity could be increased by at least 30% through policies directed at improving water supplies and by promoting research on earlier varieties of cotton, maize and oilseeds.

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## Introduction

Cropping intensity in irrigated areas of Asia has increased steadily over the past two decades, especially with the introduction of earlier-maturing varieties and improved supplies of irrigation water. With the sharp decline in expansion of irrigated area in Asia in the 1980s (Levine et al., 1988), increasing cropping intensity is expected to play an even larger role in expanding agricultural production in the future. For example, the Food and Agriculture Organization (FAO, 1981) projects cropping intensity in irrigated Asia to increase from 118 in 1975 to 141 in 2000. In the Pakistan Punjab, the overall cropping intensity of 125 also suggests considerable scope for increasing production through higher cropping intensities. Despite this potential, the determinants of cropping intensity have received little attention in recent research in Pakistan.

The aims of this study are to analyze major factors influencing cropping

intensity in the cotton zone of the southern Punjab of Pakistan, and to suggest policy directions that might facilitate further increases in cropping intensity. The potential impacts of tubewell and tractor mechanization on cropping intensity are well recognized, and have been the subject of considerable analysis in both the Indian and Pakistan Punjabs (Kaneda, 1969; McInerney and Donaldson, 1975; Lockwood, 1983; Agarwal, 1984). All of these studies show the expected positive effect of tubewell use. However, the effect of tractor use is more controversial. Binswanger (1978) synthesized data from five studies of tractor mechanization in the Indian and Pakistan Punjabs in the 1970s that suggest that tractor use increased cropping intensity by at most 10%, if at all. More recently, Jayasuriya et al. (1986) concluded from a review of studies in South and Southeast Asia that mechanized land preparation generally has no effect on cropping intensity, although a few studies showed an increase of approximately 10%. They attributed this to the fact that most farmers who mechanize land preparation use rented machinery, losing the potential advantage of more timely operations. These studies underscore the need to disaggregate mechanization between tubewells and tractors, and between ownership and rental of production factors in analyzing determinants of cropping intensity.

Despite the ambiguity of these research findings, official credit policy in Pakistan has favoured lending for tractors instead of tubewells. In the period 1982–85, loans for tubewells counted for less than 2% of official lending of the Agricultural Development Bank of Pakistan, compared to 63% for tractors. This emphasis on tractors has been supported by belief that draught power limits cropping intensity. Likewise, electrification of villages to facilitate use of electric tubewells has lagged far behind the Indian Punjab.

Beyond these questions of mechanization and irrigation, a major factor ignored by analyses of cropping intensity is the availability of suitable cropping patterns. Often there is conflict between the harvesting of one crop and the planting of the next crop, which leads to delayed planting and lower productivity. In this situation, farmers may prefer to leave land fallow rather than attempt double-cropping. Research to develop short-duration varieties that fit into the cropping system, or reduced tillage methods to speed up turn-around time between crops, can potentially alleviate power and, to some extent, water constraints. An important policy question is the role of varietal improvement versus mechanization in increasing cropping intensity. To explore this issue, we depart from the exclusive emphasis in the literature on annual cropping intensity to also analyze season-specific intensities.

### **Data sources**

This paper focuses on a major agro-ecological zone – the cotton-wheat area of the southern Punjab. Cropping intensity in the zone is relatively low at about 130, with substantial areas left fallow in both the ‘rabi’ (winter) and

'kharif' (summer) seasons. This fallow land has been targeted as a major area for the expansion of non-traditional oilseeds, especially sunflowers and soya-beans, in order to reduce Pakistan's chronic dependence on imported vegetable oil. Cropping intensity in the zone has increased rapidly relative to other zones in recent years: the index of cropping intensity rose from 1.12 in the early 1970s to over 1.30 in the early 1980s. Traditionally, two major rotations were practiced, wheat-fallow and fallow-cotton, with wheat as the major subsistence food and cotton the main source of cash. Introduction of semi-dwarf wheat varieties and earlier-maturing varieties of cotton have, however, enabled double-cropping of wheat after cotton (Byerlee et al., 1987). By 1985, about half of the wheat was sown after cotton (Akhtar et al., 1986). Nonetheless, wheat after cotton is generally planted late, increasing the risks of yield losses and decreasing the profitability of this rotation.

In 1986, a sample of 71 farms from Multan District in the heart of the cotton-wheat area was selected to obtain information on cropping patterns and cropping intensity. Fifteen villages were randomly selected, with probability proportional to size as the first-stage sample, and five farmers selected in each village. Additional evidence was obtained by analyzing a larger sample of 150 farmers in the same area interviewed in 1985 during the wheat harvest season. This sample collected data only on cropping intensity in the 'rabi' cycle. However, it provided more detailed information on irrigation sources and management and a larger sample size with which to explore these relationships.

### **Irrigation, power source and cropping intensity**

A range of irrigation and power sources are represented by the sample farmers, whose average farm size was 6.2 ha (Table 1). In general, there is an association between the source of irrigation water and the source of power: farmers who own tractors also own tubewells. Another group of farmers tends to hire both services, while a third group uses only animal power and has no access to tubewell water. As expected, the largest farm size is associated with ownership of tractors and/or tubewells (Table 1).

The canal system of the area was originally designed for a cropping intensity of only 66%, with much of the area served by canal water only during the 'kharif' season. Clearly, the major factor in increasing cropping intensity is the installation of tubewells. In the 1985 survey, 75% of the irrigations to wheat were provided from tubewells, and even in the perennial canal areas, tubewells accounted for about half the water applied. The use of tubewell water is, however, restricted by the quality of groundwater in some villages.

The cropping pattern is almost completely dominated by wheat in the 'rabi' season and cotton in the 'kharif' season. Fodder, the only other significant crop, occupies 13-15% of the cropped area in both seasons. The proportion of area devoted to fodder decreases as farm size decreases (Table 2). Small farm-

TABLE 1

Distribution of farmers and farm size by power source and irrigation source, 1986 survey

	Canal only	Canal + hired tubewell	Canal + tubewell	All
<i>Percent farmers</i>				
<i>Power source</i>				
Animal only	15.5	7.0	0	22.5
Hire tractor <sup>a</sup>	8.5	39.4	4.2	52.1
Own tractor	<u>9.9</u>	<u>4.2</u>	<u>11.3</u>	<u>25.4</u>
All	33.9	50.6	15.5	100.0
<i>Farm size (ha)</i>				
<i>Power source</i>				
Animal only	5.0	3.7	na	4.6
Hire tractor <sup>a</sup>	4.1	4.6	6.6	4.7
Own tractor	<u>9.9</u>	<u>na</u>	<u>12.6</u>	<u>10.7</u>
All	6.2	4.7	11.0	6.2

<sup>a</sup>Includes farms who use *both* hired tractor and own animals.  
n.a., not calculated because cell size less than five observations.

TABLE 2

Cropping pattern and cropping intensity by farm size, 1986 survey

	Farm size			All
	< 2.5 ha	2.5-5.0 ha	> 5.0 ha	
<i>Percent cropped area</i>				
Food crops	42.7	46.3	47.0	45.8
Fodder crops	23.4	17.7	15.6	18.0
Cash crops	<u>33.9</u>	<u>36.0</u>	<u>37.4</u>	<u>36.2</u>
Total	100.0	100.0	100.0	100.0
Cropping intensity index (%) <sup>a</sup>	152	124	134	134

<sup>a</sup>The difference between very small farmers (< 2.5 ha) and other farmers is significant at the 5% level.

ers, who have a larger number of animals per hectare, substitute fodder crops about equally for food crops (mainly wheat) and cash crops (mainly cotton). There is also evidence that the area devoted to fodder crops is reduced by tractor ownership<sup>1</sup>. Over 70% of farmers hiring tractors retained bullocks for some farm operations.

<sup>1</sup>From the 1985 survey, the following regression was fitted:

$$\text{PFOD} = 10.6 - 0.101 \text{ TAREA} - 3.21 \text{ OWNTR}$$

(2.12)\*\*      (2.21)\*\*

$n = 150$ ,  $R^2 = 0.12$ ;  $t$ -value in brackets; \*\*, significant at 5% level; PFOD is percent area fodder; TAREA farm area (ha); and OWNTR a dummy variable (= 1 if the farmer owns a tractor).

TABLE 3

Cropping intensity by irrigation and power source, Southern Punjab, 1986 survey

	Irrigation source			All
	Canal only	Canal + hired tubewell	Canal + tubewell	
<i>Annual cropping intensity</i>				
Power source				
Bullock only	107	156	<sup>b</sup>	123
Hired tractor <sup>a</sup>	121	137	<sup>b</sup>	136
Own tractor	<u>111</u>	<u><sup>b</sup></u>	<u>171</u>	<u>146</u>
All	112	142	158	134

<sup>a</sup>Includes farms who use *both* hired tractor and their own animals.<sup>b</sup>Not calculated because less than five observations in the cell.

The index of cropping intensity, CI, was conventionally measured by the ratio of total cropped area to cultivated area; that is:

$$CI = (\sum CA_i) \times 100 / \text{TAREA}$$

where  $CA_i$  is cropped area in season  $i$  ( $i=1, 2$ ), and TAREA is total cultivated area. In order to analyze the effect of cropping pattern on cropping intensity, we also calculated season-specific cropping intensity for 'rabi' and 'kharif' seasons as:

$$CI_i = CA \times 100 / \text{TAREA}$$

where  $CI_i$  may range from 0 to 100.

Average cropping intensity in the area is 134, but shows surprisingly large variation from 60 to 200 with a coefficient of variation (CV) of 25%. These figures compare with an average cropping intensity for the Indian Punjab of 168 with a CV of 18%, achieved as early as 1971–72 (Agarwal, 1984).

Cropping intensity is closely related to tubewell use, regardless of the type of power source (Table 3). For a given irrigation source there is little effect of power source on cropping intensity. Farmers who own both a tractor and a tubewell have the highest cropping intensity while the lowest occurs on farms having no access to a tubewell and using only bullock power.

### Regression analysis of cropping intensity

The relationship between cropping intensity, and irrigation and power source, was further examined in a regression analysis of annual and season-specific cropping intensity. The following variables were considered to explain variation in cropping intensity.

– *Irrigation variables*

- OWNTW = dummy variable = 1 for ownership of a tubewell,  
zero otherwise
- HIRETW = dummy variable = 1 for hiring of tubewell,  
zero otherwise
- WATQU = dummy variable = 1 for saline groundwater,  
zero otherwise<sup>2</sup>
- CANCLOSE = number of weeks of canal closure in 1986  
(usually 25–30 weeks for seasonal canals but also  
often 4–8 weeks for perennial canals).<sup>2</sup>

- *Farm power variables*. Two variables were used to represent farm power: OWNTR and HIRETR are dummy variables for tractor ownership and tractor hiring analogous to the variables OWNTW and HIRETW defined above for tubewells.

- *Farm size*. Two variables were used to represent farm size:

- TAREA = total farm area (ha)
- LNAREA =  $\log_e$ (TAREA)

LNAREA allows for possible nonlinear effects of farm size. It consistently gave better explanatory power than TAREA and is reported here.

- *Cropping-pattern variables*. Because of conflicts between cotton harvest and wheat planting, and between wheat harvest and preparing land for cotton, some farmers were expected to specialize in one crop at the expense of the other. Hence, the variables PCOTON (percent ‘kharif’ crop area in cotton season) and PWHEAT (percent ‘rabi’ crop area in wheat) were also included in the analysis of *season-specific* cropping intensity.

This list of variables does not pretend to be a complete model of factors influencing cropping intensity. Such a model might include variables reflecting soil type, location, household labour supply and access to credit and other inputs. Our interest was in capturing the policy-relevant influences on cropping intensity associated with access to irrigation water and draught power, which have been extensively treated in the literature, and availability of suitable cropping patterns, which has been ignored in previous studies.<sup>3</sup>

We began with the basic model:

$$CI_i = b_0 + b_1 LNAREA + b_2 OWNTW + b_3 HIRETW + b_4 OWNTR + b_5 HIRETR + e_i$$

results of which are given for annual cropping intensity in equation 1 in Table 4. In this model neither the coefficients for OWNTR or HIRETR were statistically

<sup>2</sup>These variables were available only for the 1985 survey.

<sup>3</sup>We have no reason to expect mis-specification bias due to correlation between variables included in the regression and omitted variables.

TABLE 4

Regression analysis of index of cropping intensity, 1986 survey, Southern Punjab

	Equation 1 <sup>a</sup>	Equation 2 <sup>a</sup>
Independent variable		
LNAREA	-11.5 (2.04)**	-10.4 (1.91)*
OWNTW	44.9 (3.79)***	
HIRETW	34.3 (3.87)***	
USETW		34.1 (4.66)***
OWNTR	15.8 (1.37)	24.8 (2.82)**
HIRETR	-8.1 (0.83)	
USETR		
Constant	128.0	121.7
<i>n</i>	71	71
<i>R</i> <sup>2</sup>	0.32	0.31

<sup>a</sup>Dependent variable is index of cropping intensity (% on annual basis); *t*-values in brackets; \*\*\*, \*\*, \* indicate significance at the 1, 5 and 10% levels, respectively.

TABLE 5

Tests of restrictions on coefficients in the basic regression model

Restriction	<i>F</i> -ratio	Probability
$b_4 = b_5 = 0$	$F_{2,65} = 2.68$	0.076
$b_2 = b_3$	$F_{1,65} = 0.77$	0.380
$b_4 = b_5$	$F_{1,65} = 5.36$	0.024

significant at accepted probability levels. We then tested the restriction that  $b_4 = b_5 = 0$ , which was rejected at the 10% level, using the *F*-ratio (Table 5). Furthermore, equation 1 does not test whether *ownership* of a tubewell or tractor leads to higher cropping intensity than rental of these machines.<sup>4</sup> To analyze this question, we separately tested the restrictions that  $b_2 = b_3$  and  $b_4 = b_5$ . The results given in Table 5 suggest that, although the coefficient of OWNTW

<sup>4</sup>The significant coefficients for OWNTW and HIRETW in equation 1 indicate only that ownership and hiring of a tubewell lead to higher cropping intensity than not having access to tubewell water.

TABLE 6

Comparison of effects of tubewells and tractors on cropping intensity, Indian Punjab, 1971/72, and Southern Punjab, Pakistan, 1986

	Indian Punjab <sup>a</sup>	Pakistan, Southern Punjab
Sample characteristics		
Average farm size (ha)	8.0	6.2
Percent own tractor	22	25
Percent hire tractors	32	52
Percent access to tubewell	82	60
Index of cropping intensity	157 <sup>b</sup>	134
Effect on cropping intensity		
USETW	34.0	37.3
OWNTR	12.1	18.8
HIRETR	4.9	-8.8

<sup>a</sup>Source: Agarwal (1984).

<sup>b</sup>Adjusted to cotton zone only.

is much higher than HIRETW, the difference is not significant. However, ownership of a tractor does lead to significantly higher cropping intensity than tractor rental. These tests led us to the final model in equation 2 (Table 4), where OWNTW and HIRETW are replaced by one variable. USETW – a dummy variable for the use of tubewell, whether owned or hired – and ownership of a tractor is tested against either tractor hire or use of animal power. All coefficients in equation 2 are significant at the 10% level. The use of a tubewell leads to an estimated increase in cropping intensity of 34 points, and ownership of a tractor gives a 25-point increase.

The variable for farm size, LNAREA, has a hypothesized negative sign and is significant at the 10% level. The size of the coefficient of LNAREA in equation 4 indicates that a doubling of farm area decreases the index of cropping intensity by 8 points ( $-10.8 \ln(2)$ ) after standardizing for power source and irrigation type.

For some of these variables, it is possible to make a direct comparison with results of Agarwal (1984) for the adjacent Indian Punjab at a much earlier date, 1971/72 (Table 6).<sup>5</sup> Sample characteristics are quite similar, except that the use of hired tractors in our sample is much higher and bullock use correspondingly lower. The index of cropping intensity for the Indian Punjab is much higher, even when it is adjusted to the cotton zone to make it comparable to our survey area. The effects of power source and irrigation source on cropping intensity are very similar, except for the effect of tractor hiring. However, in neither is the effect of tractor hiring significant.

Using the above coefficients we made a crude calculation of the total increase

<sup>5</sup>Equation (2) above was re-run to include HIRETR to facilitate comparison with the Indian data.

in cropped area,  $\Delta CA$ , due to an increase in one tubewell owner or tractor owner, using the formula:

$$\Delta CA = A_o b_o + r A_h b_h$$

where  $A_o$  and  $A_h$  are the average area farmed by an owner and hirer, respectively,  $r$  is the ratio of hirers to owners, and  $b_o$  and  $b_h$  are the increase in the cropping intensity index due to ownership or hiring of a tubewell or tractor (from equation 4, where  $b_o = b_h = 0.34$  for a tubewell, and  $b_o = 0.25$  and  $b_h = 0$  for each tractor).<sup>6</sup> The ratio  $r$  was calculated from the sample as 3.3 for tubewells (i.e., each tubewell owner rents to an average of 3.3 other farmers) and 2.0 for tractors. Using this method the overall increase in cropped area was 22 ha for a tubewell and only 6.6 ha for a tractor. Since the investment cost of a tubewell and a tractor are roughly equivalent, these results suggest that tubewell investment will have a much larger role in increasing cropping intensity in the area.<sup>7</sup>

We next used the same regression model to analyze season-specific cropping intensities. The correlation between 'rabi' and 'kharif' cropping intensity of 0.48, while highly significant, is not as high as might be expected for farmers whose power source and irrigation sources remain unchanged between seasons. Tubewell use has the expected large and significant effect in both seasons, as does OWNTR, although the effect is somewhat smaller (Table 7).

The variables PCOTON and PWHEAT test the effect of cropping pattern in the opposite season on cropping intensity in the current season. As expected, a higher proportion of area in cotton in 'kharif' season reduces the cropping intensity in 'rabi' season (equation 3b). A similar and even more pronounced result is that farmers who plant more wheat in 'rabi' leave more land fallow in 'kharif' (equation 4b). To a large extent, this reflects the fact that the major alternative crops to cotton and wheat are fodders which are earlier-maturing and grown more easily in double-cropping patterns. In fact, the higher cropping intensity on small farms (Table 2) seems to be due to the fact that small farmers keep a larger proportion of area in fodder (Table 2). Evidence for this is given in Table 6, by comparing equation 3a with 3b and equation 4a with 4b. The inclusion of PCOTON and PWHEAT in the equations reduces the size and the statistical significance of the coefficients for LNAREA.

The larger effect of PWHEAT in relation to PCOTON is somewhat contrary to our a-priori expectations. The turnaround time between cotton and wheat is quite short (on average 7–10 days) (Byerlee et al., 1987) compared to turnaround time from wheat to cotton (average 20–30 days), so that power might be more constraining in preparing land for the 'rabi' cycle. On the other hand,

<sup>6</sup>It is crudely assumed that the average area farmed by each new tubewell or tractor owner is the same as the average area farmed by existing tubewell or tractor owners.

<sup>7</sup>These results, however, do not consider operational costs.

TABLE 7

Regression analysis of index of cropping intensity, rabi and kharif seasons, 1986 survey, Southern Punjab

Independent variable	Cropping intensity 'rabi' season <sup>a</sup>		Cropping intensity 'kharif' season <sup>a</sup>	
	Equation 3a	Equation 3b	Equation 4a	Equation 4b
LNAREA	-3.45 (1.10)	-2.43 (.43)	-6.97 (1.97)**	-3.89 (1.30)
USETW	15.6 (3.72)***	18.5 (4.35)***	18.5 (3.90)***	20.3 (5.15)***
OWNTR	9.68 (1.92)*	11.1 (2.25)**	15.1 (2.64)**	11.0 (2.29)**
PCOTON		-0.374 (2.31)**		
PWHEAT				-1.15 (5.65)***
Constant	61.6	70.6	60.1	104.7
<i>n</i>	71	71	71	71
<i>R</i> <sup>2</sup>	0.20	0.26	0.25	0.50

Note: *t*-values in brackets; \*\*\*, \*\*, \* indicate significance at the 1, 5 and 10% levels, respectively.  
<sup>a</sup>Dependent variable =  $CA_i \times 100 / TAREA$ , where  $CA_i$  is cropped area in season *i*.

land preparation is usually much more intensive for cotton and this seems to outweigh the longer turn-around time available between wheat and cotton.

Finally, an analysis of 'rabi' cropping intensity, RCI, in the 1985 survey supports these results and also enables a test of the effects of variables for ground-water quality and canal closure. The estimated equation was:

$$\begin{aligned}
 RCI = & 90.9 - 11.6 \text{ LNAREA} + (15.3 \text{ USETW} \\
 & (5.95)*** \quad (2.30)*** \\
 & + 4.63 \text{ OWNTR} - 10.6 \text{ WATQU} - 0.627 \text{ CANCELOSE} \\
 & (1.06) \quad (2.73)*** \quad (3.72)***
 \end{aligned}$$

$n = 150$ ,  $R^2 = 0.32$ ; *t*-values in brackets; \*\*\* denotes significance at the 1% level: CANCELOSE is the number of weeks of canal closure, and WATQU is a dummy variable equal to one if the farmer reported poor (saline) groundwater. Both canal closure and poor quality groundwater had the expected negative and significant effects on cropping intensity.

From the above analysis we can make the following general observations:

(1) Irrigation source and quality are the major factors influencing cropping intensity. In addition to tubewell use, year-round canal supplies and good quality groundwater also have important positive effects on cropping intensity.

(2) Farm size has the expected negative impact on cropping intensity, an

effect that has been widely observed in the literature. Nonetheless, much of the effect of farm size seems to be due to the fact that small farmers have a larger proportion of area under fodder crops which are more conducive to double-cropping.

(3) Tractor use has somewhat ambiguous effects on cropping intensity. Tractor owners seem generally to have a significantly higher cropping intensity than tractor hirers or farmers who depend on draught animals. Tractor hirers do not have higher cropping intensity than farmers using animal power. This finding, and the magnitude of the effect of tractor ownership on cropping intensity (about 10–20%), is in line with other studies from South Asia (Binswanger, 1978; Jayasuriya et al., 1986).

### Potential to increase cropping intensity

In light of the above results, we can now estimate the potential for further increases in cropping intensity and consider strategies needed to realize it. Clearly, without substantial change in canal water supplies a significant area of land will always remain fallow because saline groundwater limits use of tubewells. Based on farmers' assessment of groundwater quality, we estimate that 31% of the land was left fallow because of saline groundwater and that there was little potential in these areas to increase cropping intensity. On the other hand, 69% of fallow land could be brought under production with installation of further tubewells and with appropriate cropping patterns. This would provide a potential increase in area of 35%.

The estimated equations of Table 5 suggest that even average-size farmers (6 ha), owing their own tubewells and tractors and located in areas of good groundwater, are only able to achieve a maximum cropping intensity of around 165–170.<sup>8</sup> Our survey indicates that the failure of these farmers with a good resource base to achieve a higher cropping intensity is due to lack of appropriate cropping patterns. In the 1985 survey, the lowest quartile (based on yield) of wheat fields yielded an average of 1.5 t/ha. Two-thirds of these fields were planted after cotton, and their average profitability was negative, largely due to late planting (Akhtar et al., 1986). Farmers are well aware of the risks of late planting of wheat and often prefer to leave land fallow rather than double-crop. Many are seeking alternative crops for the 'rabi' season, especially those with over 2 ha of wheat who, on average, generate a marketable surplus (Byerlee et al., 1987). Most farmer interest centers on spring maize and the non-traditional oilseeds, sunflowers and soybeans. Unfortunately, while these crops are appropriately planted in February after the cotton harvest in November/December, currently available varieties planted at this time mature in late May

<sup>8</sup>Given average size farms and assuming good groundwater and no canal closure, the predicted cropping intensity for  $OWNTR=1$  and  $USETW=1$  is 162 in equation (2).

or early June and delay cotton planting (or at best, reduce the quality of seed-bed preparation for cotton). Hence, while government strategy is to target oilseeds to grow on fallow lands, our own informal interviews indicate that farmers are unlikely to use oilseeds to increase cropping intensity.

Research on spring maize or oilseeds for planting in late January and harvested by mid-May is required before they can be widely double-cropped with cotton. Such research would focus on varieties that mature 7–10 days earlier than current varieties and, in the case of maize, would also screen for cold tolerance in early seedling growth (Eagles, 1986). At present, oilseed breeding seems to focus on yield at the expense of early maturity. Reduced and even zero tillage for these crops, as well as for cotton, also merits consideration as a means of reducing turn-around time and power constraints.

## Conclusions

In a fairly homogeneous cotton-wheat cropping zone of the southern Punjab, we have identified several factors that limit cropping intensity. At a current cropping intensity of 134, an average of one-third of the land is left fallow each season. The potential to utilize this land is constrained roughly equally by three sets of factors:

- (1) In some areas groundwater quality is poor.
- (2) Even where groundwater is good, water shortages occur because of insufficient canal flow and tubewell capacity. To a much lesser degree, draught power shortages may play a role.
- (3) Cropping patterns are inappropriate, and in particular there is a lack of early-maturing and cold-tolerant varieties of maize and oilseeds that could be double-cropped with cotton.

The first of these constraints cannot readily be alleviated without drastic increases in canal water supplies or improved efficiency of irrigation water use; hence nearly one-third of fallow land is unavailable for increasing cropping intensity in the short to medium term.

The second constraint underscores the importance of policy incentives for tubewell investment and suggests some reorientation of current credit programs. The bulk of official bank lending for farmers has been for tractor purchase, in part from the belief that this will increase cropping intensity. Likewise, village electrification will substantially reduce the cost of tubewell use, since electric tubewells can provide water at only half the cost of diesel tubewells (Akhtar et al., 1986). Evidence from this study suggests that the payoff to tubewell investment is higher than tractorization, and that tractor use will have only marginal impact on cropping intensity, except for farmers who purchase their own tractors.

Finally, agricultural research can play a potentially important role in developing early-maturing seed varieties to substitute for draught power con-

straints on increasing cropping intensity. Investment in the development of early-maturing varieties may be a more efficient alternative from the national viewpoint than further investment in mechanization. The coupling of policy incentives to invest in tubewells with carefully focused varietal improvement research offers the potential for rapid increases in cropping intensity in the future.

The results of this study should be regarded as exploratory and a guide to further research on this important topic. An integrated approach that considers the natural resource base, farmers' resources, seasonal crop water budgets, and timing of critical planting and harvesting operations is needed to formulate appropriate policy measures to facilitate increases in cropping intensity.

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