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ABSTRACT

This paper develops a linear programming model of resource use during turnaround time between aus and transplanted aman rice, the two major rice crops in Bangladesh. Research has indicated that shortages of labor and, particularly, of draft power during turnaround have prevented the adoption of modern rice varieties. The model was used to evaluate seven different strategies to reduce these constraints. The results of the model suggest that draft power is a constraint on the area under modern aus varieties, while labor shortages are also evident for aus and transplanted aman varieties. Individually, power tillers and minimum tillage are the most effective ways to reduce the draft power constraint and increase the area under modern aus varieties. But the model also demonstrated the need for new varieties: in particular, a direct-seeded modern aus, a short-duration modern aus, and an IR50-type modern aman. A combination of strategies involving new varieties and power tillers or minimum tillage would give the best results. Together, they increased the area under modern aus varieties in the model from 50% to nearly 100%, and the area under modern aman varieties from 12% to more than 80%.

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A Model of Resource Constraints on Turnaround Time in Bangladesh

The objective of this paper was to develop a linear programming model of labor and draft power constraints on turnaround time between aus and transplanted aman (t. aman) in order to evaluate strategies to reduce these constraints.

Aus and transplanted aman are the two major rainfed rice-growing seasons in Bangladesh. Aus rice is established as a direct-seeded or transplanted crop from April to mid-June and is harvested from July to mid-August. Aman rice is transplanted from late July to mid-September after the aus rice is harvested. The introduction of modern varieties (MVs) for aus and t. aman has increased the pressure on labor and draft power at peak periods. Modern aus varieties have longer field durations than local varieties and are harvested later. Modern t. aman varieties are weakly sensitive or insensitive to photoperiod and must be transplanted early to flower before the advent of cool temperatures, which reduce yields. Thus, the combined effect of introducing MVs has been to extend the aus harvest while increasing the need for timely transplanting in aman.

For the successful adoption of the modern aus - modern t. aman pattern, aman transplanting must be completed by a given date. Under rainfed conditions, the latest date for transplanting modern t. aman varieties is approximately 31 Aug (Magor 1984). Available evidence suggests that turnaround time (the number of days between harvesting and transplanting) averages 15 d (Gill 1981).

Recent work by the Bangladesh Rice Research Institute (BRRI) has provided evidence of shortages of labor and, particularly, draft power during turnaround (Miah et al 1986). Although draft power was not a constraint on the area under modern aman, it was a constraint on the area under modern aus. The draft power shortage was not associated with any particular farm size. Similarly, there was evidence of a labor shortage for transplanting. Medium-sized farms between 1.2 and 2.0 ha grew less modern aus because of problems of obtaining labor for aus transplanting. Farms bigger than 2.0 ha also faced problems of obtaining labor for transplanting aman. Farms smaller than 1.2 ha also faced a labor constraint for aman transplanting because of the cost of labor and the need to supplement income by working for larger farmers.

Several strategies have been proposed to reduce the shortage of animal power. Early work, which focused on mechanization, effectively discredited the view that tractors and power tillers increased output, and the view that they may be used to supplement animal power was rejected on equity grounds (Gill 1981, Jabbar et al 1983). The ensuing debate sparked off a search for alternative strategies, ranging from improved animal nutrition to zero or minimum tillage to new plows and yokes. The potential benefits from these strategies remain largely unknown, however. Meanwhile, agricultural engineers have continued to press for mechanization.

A linear programming model was developed to test seven strategies to reduce resource constraints on turnaround: an improved plow, power tillers, minimum tillage, extending transplanting of BR11 to 31 Aug, short-duration modern aus varieties, direct-seeded modern aus varieties, and short-duration, photoperiod-insensitive modern aman varieties.

The specific objectives were to

- identify and measure resource constraints on turnaround time,
- compare the impact of different strategies on increasing the area under MVs, and
- target the most appropriate strategy.

The database for the model was provided by a simple random sample of 98 farms growing rainfed aus - t. aman rice in 6 villages in the BRRI project area. This clearly limits the generalizations that can be made from the model. The survey site was representative of only one rice environment: the shallow flooded, rainfed system of eastern Bangladesh. The site was atypical because its proximity to Dhaka offered greater scope for off-farm employment and consequently a greater need for migrant labor on the farm during peak seasons. Nevertheless, the model may provide insights into future developments as technological change spreads to other parts of the country. Other limitations of the model will be made explicit.

The modern aus variety most widely grown in the BRRI project area was called "China" by farmers. Scientists refer to Purbachi as "China." When samples from the village sites were examined by the BRRI Plant Breeding Division, they were identified as BR1 (Chandina). Thus, farmers use China as a generic term for BR1 or Purbachi. Both varieties have similar yields and field durations. In this paper, we employ the name farmers use, and China refers to BR1 and Purbachi.

The paper is divided into four parts. The first describes the methods used to build the model. The next validates the basic model, while the third compares the impact of alternative strategies. The results are summarized in the last section.

METHODS

Linear programming has been widely used to model the impact of new technology on small farms (e.g., Barlow et al 1979, 1983). A linear programming model has three components: an objective function, a set of activities, and a series of constraints. In this section, we describe how we defined each of these three components in our linear programming model of turnaround time.

The objective function of the programming model maximized rice output. Output was defined not in money terms, as revenue, but in real terms, as gross yield. Yields were preferred to revenues to emphasize the importance of transplanting date in the farmer's choice of aman varieties. The small area under high-quality, higher priced local varieties was <5% of the total and was therefore not considered in the model. The main factors affecting aman yields are transplanting date and rainfall. Yield equations that consider both factors were developed by Magor (1982). From these equations, estimates of yields were made for a three-in-four-year probability of a given rainfall and for a given land type. The yield estimates were made for northeast Bangladesh, where the onset of cool nights is slightly earlier than in Joydebpur, where BRRI is located. Nevertheless, these estimates have been used since they reflect the effects of both water stress and transplanting date on the yields of different varieties. The yield-forecasting equations developed for Dhaka District by Ahmad (1984) were not used because yields and transplanting dates were based on farmer recall and were therefore considered less reliable.

Table 1 shows the aman yields used in the model. Yields were estimated for a land type where water stands for 10-12 d after heavy rain. Yields of Pajam and BR11 were high, with a rapid decline beginning in the later part of August and September, respectively. The yield decline for the locally improved variety, Nizersail, which is highly photoperiod sensitive, was far less rapid than for Pajam or BR11. By the first week of September, Nizersail outyielded Pajam and BR11. For late transplanting, a short-duration, photoperiod-insensitive variety like IR50, which can be transplanted until 12 Sep, provides an alternative to Nizersail. (A photoperiod-sensitive modern aman variety was not considered here because there is at present insufficient information on the performance of advanced lines under rainfed conditions.) The yields of each aman variety are at about two-thirds the recommended fertilizer dose. The water stress level is for a 75% probability, and so, for 3 yr in 4, yield would be expected to be higher because of a more favorable rainfall pattern.

Table 1. Yield (t/ha) of aman varieties by transplanting date and with a 75% probability of water stress in September and October.[a]

Week code	Transplanting date	Local (Nizersail)	Pajam	Modern (BR11)	IR50 type
Week 5	10 Jul	–	4.1	4.6	–
Week 6	17 Jul	–	4.1	4.6	–
Week 7	24 Jul	–	4.1	4.6	–
Week 8	1 Aug	–	3.9	4.4	–
Week 9	8 Aug	–	3.5	4.0	–
Week 10	15 Aug	–	3.5	4.0	–
Week 11	22 Aug	2.9	3.3	3.6	–
Week 12	29 Aug	2.8	2.7	3.2	–
Week 13	5 Sep	2.6	–	2.4	3.1
Week 14	12 Sep	2.4	–	1.4	2.7
Week 15					

[a]Nizersail, Pajam, and BR11 are estimates from Magor (1984); IR50 type is from BRRI (1986).

Table 2. Aus yields and field durations for the programming model.[a]

Variety and description	Yield (t/ha)	Field duration (d)
Pukhi (direct-seeded) local	2.0	90
Pukhi (transplanted) local	2.0	70
China (BR1 or Purbachi)	4.4	90-95
Biplab (BR3)	5.0	110
Short-duration China	4.0	80-85
Direct-seeded modern variety	3.4	100

[a]Estimates for Pukhi from Hoque and Hobbs (1981), for short-duration China and direct-seeded modern aus from BRRI (1986), and for China and Biplab from Magor (1984) and Elahi et al (1985).

Field duration is very important for aus varieties, because it determines the earliest date aman can be transplanted. Table 2 shows the aus yields and field durations used in the model. Field durations for transplanted crops ranged from 70 to 110 d, and yields from 2 to 5 t/ha. Table 2 also shows two new varieties of aus that were introduced into the model. The first is a short-duration transplanted aus with a field duration of 80-85 d, examples being the advanced lines IR8608-298-3-1-1-2 and IR9729-67-3, with yields of about 4 t/ha (BRRI 1986). The second new variety is a direct-seeded modern aus, an example being BR21, recently released by the National Seed Board as one of the first direct-seeded modern aus varieties, with a duration of 100 d seed to seed (Orr et al 1987).

Since our aim was to model existing reality, the activities represented the 8 major cropping patterns, covering 91% of the area cultivated during aus and aman. Average dates of harvesting and transplanting were defined for each pattern. Aus harvest dates for the major patterns and aman transplanting dates are shown in Tables 3 and 4. Most patterns showed considerable variation. For each week (from 8 Jul to 14 Sep) the dominant cropping pattern being transplanted was selected for the model. This generally coincided with the mean transplanting date for a particular pattern. An exception was made for the pattern China

Table 3. Aus harvest dates for major cropping patterns, Joydebpur, 1985.[a]

Pattern	Median	Mean[b]	Variance[c] (d)	SD (d)	Plots (no.)
China - modern	6 Aug	7 Aug a	60.3083 a	7.7659	17
China - Pajam	9 Aug	11 Aug a	67.6334 ab	8.2239	58
China - local	22 Aug	22 Aug	110.5574 a	10.5146	245
Biplab - local	24 Aug	26 Aug	61.9252 abc	7.8693	59
Pukhi - modern	19 Jul	20 Jul	69.5560 abc	8.3400	44
Pukhi - Pajam	22 Jul	27 Jul	203.2983 a d	14.2583	127
Pukhi - local	7 Aug	6 Aug a	253.0261 a d	15.9068	88

[a]Turnaround time survey, BRRI, 1985. [b]Means followed by a common letter are not significantly different at the 5% level by t-test. [c]Variances followed by a common letter are not significantly different at the 5% level by F-test.

Table 4. Aman transplanting dates for major cropping patterns, Joydebpur, 1985.[a]

Pattern	Median	Mean[b]	Variance[c] (d)	SD (d)	Plots (no.)
China - modern	13 Aug	14 Aug a	70.8676 a	8.4183	17
China - Pajam	17 Aug	20 Aug	70.6948 ab	8.4080	58
China - local	3 Sep	1 Sep	82.3805 abc	9.0764	245
Biplab - local	2 Sep	3 Sep	52.1882 ab d	7.2241	59
Pukhi - modern	3 Aug	4 Aug b	68.2029 abcd	8.2585	44
Pukhi - Pajam	15 Aug	16 Aug	160.8596 e	12.6830	127
Pukhi - local	29 Aug	25 Aug a	145.0970 e	12.0456	88
Fallow - modern	15 Jul	21 Jul	348.45716 f	18.6670	108
Fallow - Pajam	27 Jul	4 Aug b	463.4596 f	21.5281	81

[a]Turnaround time survey, BRRI, 1985. [b]Means followed by a common letter are not significantly different at the 5% level by t-test. [c]Variances followed by a common letter are not significantly different at the 5% level by F-test.

- local, where two vectors were used to cover the range of transplanting dates. Transplanting for each pattern was assumed to be completed in 1 wk, and similarly for land preparation and harvesting.

Labor requirements for each operation were taken from coefficients developed from work at the Bhogra research site by the BRRI Rice Farming Systems Division (Hoque and Hobbs 1981). The coefficient for harvesting was 165 h/ha, including time for cutting, threshing, carrying, and cleaning, all of which are frequently part of the same contract. The labor coefficient for aman transplanting was 274 h/ha, including 85 h for uprooting seedlings — usually part of the contract. The labor coefficient for plowing (180 h) included 19 h for trimming or repairing plot boundaries. Finally, the animal labor coefficient for plowing was obtained by adding the human hours for plowing and harrowing for aman (149 + 14 = 161) and multiplying by 2. Labor coefficients for establishing local aus varied according to the proportions transplanted and direct seeded. Direct seeding required only 4 h/ha.

The third component of the model is resource constraints: land, labor, and draft power. The land constraint is simply the existing area under the eight major cropping patterns. To model animal and human labor use, the turnaround period between aus and t. aman was divided into 16 wk (3 Jun-22 Sep) between the start and end of fieldwork (for week codes, see Appendix). The basic linear programming model covers 10 wk, namely weeks 5-14 (8 Jul-15 Sep), to coincide with the range of aus harvesting and aman transplanting dates of the major cropping patterns. Because our aim was to model the existing reality, the quantity of labor and draft power used in each week in the model was the quantity actually recorded by the survey. The labor hours represent the hours actually spent for harvesting, threshing, plowing, repairing boundaries, uprooting, and transplanting in any given week. Similarly, the animal hours represent the hours spent for land preparation, omitting hours for threshing. The weekly distribution of human and animal labor shows a drop in week 12 (26 Aug-1 Sep), caused by the Islamic holiday of Id-ul-Azha, which fell on 26 Aug.

Some fine-tuning was required to obtain consistent results. It was necessary to adjust the area of land used by the model. While the activities in the model included only the eight major cropping patterns, the weekly amounts of labor and draft power covered all the cropping patterns, including those omitted from the model. Consequently, labor availability was overestimated. To correct for this, the land area was revised upward to 78 ha. Secondly, labor and draft power levels in weeks 5 and 6 had to be increased. Data collection in the turnaround time survey began with the start of the aus harvest. Preliminary labor in plowing fallow, etc., was omitted and had to be estimated for the basic model. Finally, the cropping patterns were sensitive to labor available for transplanting aus. Labor availability had to be estimated for this period based on data on time of transplanting during the survey year collected from one of the survey villages by the BRRI Rice Farming Systems Division.

All three components of the model are brought together in the data matrix (Table 5). The basic model consists of 8 activities and 23 constraints. The top row shows the net revenue, here defined in terms of yield. The columns represent the different activities, with each activity named after the corresponding aus - aman cropping pattern. The vectors for each activity show the average week in which aus was transplanted and harvested, and in which land was prepared and aman transplanted, together with the labor required for these operations. Constraints appear in the rows on the left, with separate rows for labor and draft power. The level of the constraint shows the hours actually recorded by the turnaround time survey. New technology vectors are shown in Table 6 and described individually in the third section of this paper.

THE BASIC MODEL

The results of this basic model are shown in Tables 7, 8, and 9. Table 7 compares the actual area under five major

Table 5. Data matrix for the basic model.[a]

Parameter	Net revenue	FALLMOD (kg) 4600	FALLPAJ (kg) 4100	CHPAJAM (kg) 7845	CHLOCAL1 (kg) 7025	CHLOCAL2 (kg) 6780	BIPLOCAL (kg) 7625	LOCMOD (kg) 6400	LOCPAJAM (kg) 5445	LOCLOC (kg) 4795
Land (ha)	78 >	1	1	1	1	1	1	1	1	1
Aus1 (h)	4000 >	0	0	0	0	0	274	11	25	4
Aus2 (h)	6000 >	0	0	274	0	0	0	0	0	0
Aus3 (h)	7800 >	0	0	0	274	274	0	0	0	0
Aus4 (h)	5500 >	0	0	0	0	0	0	0	0	130
LWK5 (h)	4000 >	180	0	0	0	0	0	0	0	0
LWK6 (h)	3650 >	274	180	0	0	0	0	165	0	0
LWK7 (h)	3400 >	0	274	0	0	0	0	180	165	0
LWK8 (h)	5000 >	0	0	0	0	0	0	274	0	0
LWK9 (h)	7500 >	0	0	165	0	0	0	0	180	165
LWK10 (h)	10000 >	0	0	454	0	0	0	0	274	0
LWK11 (h)	11000 >	0	0	0	165	0	0	0	0	254
LWK12 (h)	9500 >	0	0	0	180	165	345	0	0	200
LWK13 (h)	11000 >	0	0	0	274	180	274	0	0	0
LWK14 (h)	3556 >	0	0	0	0	274	0	0	0	0
DWK5 (h)	3000 >	322	0	0	0	0	0	0	0	0
DWK6 (h)	1375 >	0	322	0	0	0	0	0	0	0
DWK7 (h)	1946 >	0	0	0	0	0	0	322	0	0
DWK8 (h)	2560 >	0	0	0	0	0	0	0	0	0
DWK9 (h)	3556 >	0	0	0	0	0	0	0	322	0
DWK10 (h)	4597 >	0	0	322	0	0	0	0	0	0
DWK11 (h)	6108 >	0	0	0	0	0	0	0	0	322
DWK12 (h)	5662 >	0	0	0	322	0	322	0	0	0
DWK13 (h)	5384 >	0	0	0	0	322	0	0	0	0
Spare (h)	5 >	0	0	0	0	0	0	0	0	0

[a]FALLMOD = fallow - modern aman, FALLPAJ = fallow - Pajam, CHPAJAM = China - Pajam, CHLOCAL1 = China - local aman, CHLOCAL2 = China - local aman, BIPLOCAL = Biplab - local aman, LOCMOD = local aus - modern aman, LOCPAJAM = local aus - Pajam, LOCLOC = local aus - local aman.

Table 6. New technology vectors.[a]

Parameter	DSRCHMOD (kg) 7800	SDCHMOD (kg) 8000	CHMOD1 (kg) 8040	CHMOD2 (kg) 7570	LOCMOD2 (kg) 5170	CHINIR50 (kg) 7900	CHINIR50WK14 (kg) 7100
Land (ha)	1	1	1	1	1	1	1
AUS1 (h)	0	0	274	0	4	0	0
AUS2 (h)	0	274	0	274	0	0	0
AUS3 (h)	4	0	0	0	0	274	274
AUS4 (h)	0	0	0	0	130	0	0
LWK5 (h)	0	0	0	0	0	0	0
LWK6 (h)	0	0	0	0	0	0	0
LWK7 (h)	345	0	0	0	0	0	0
LWK8 (h)	274	165	0	0	0	0	0
LWK9 (h)	0	454	0	0	165	0	0
LWK10 (h)	0	0	165	0	0	0	0
LWK11 (h)	0	0	454	165	254	165	0
LWK12 (h)	0	0	0	454	200	180	165
LWK13 (h)	0	0	0	0	0	274	180
LWK14 (h)	0	0	0	0	0	0	274
DWK5 (h)	0	0	0	0	0	0	0
DWK6 (h)	0	0	0	0	0	0	0
DWK7 (h)	322	0	4	0	0	0	0
DWK8 (h)	0	0	0	0	0	0	0
DWK9 (h)	0	322	0	0	0	0	0
DWK10 (h)	0	0	322	0	0	0	
DWK11 (h)	0	0	0	0	322	0	0
DWK12 (h)	0	0	0	322	0	322	0
DWK13 (h)	0	0	0	0	0	0	322
Spare (h)	0	0	0	0	0	0	0

[a]DSRCHMOD = direct-seeded modern aus - modern aman, SDCHMOD = short-duration modern aus - modern aman, CHMOD1 = modern aus - modern aman, CHMOD2 = modern aus - modern aman, LOCMOD2 = local aus - modern aman (transplanted in week 12), CHINIR50 = modern aus - IR50-type modern aman, CHINIR50WK14 = modern aus - IR50-type modern aman, transplanted up to mid-September.

cropping patterns with the areas given by the model. The model clearly captured the dominant modern aus - local aman pattern. This pattern covered 41% of the aus - aman area in reality, and 39% in the basic model. The only serious discrepancy arose with the pattern modern aus - Pajam. The area under this pattern in the model was twice the actual area. This may be because the objective function of the model maximized output, and China - Pajam was the highest yielding pattern in the basic model. At the aggregate level, however, the estimated yield for the actual situation was 6.2 t/ha compared with 6.5 t/ha for the basic model. The closeness of fit of the model indicates that total yield was a reasonable objective function for the rice - rice system.

The model was much less successful in capturing the specific varieties adopted within these five major patterns. Table 8 compares the actual area under eight cropping patterns with the areas given by the model. The model failed to capture the pattern fallow - Pajam. Instead, the fallow - Pajam area has been replaced by fallow - modern. This may reflect a knowledge gap, since fallow - modern outyields fallow - Pajam. Alternatively, farmers may prefer Pajam, which yields well at low fertility levels and is harvested earlier than BR11. Other discrepancies occurred with the modern aus patterns. The model overestimated the areas under the higher-yielding patterns China - Pajam and Biplab - local, while underestimating the area under the lower-yielding China - local pattern, which farmers preferred. These differences are to be expected, given the limitations of the model.

The second test of the model is whether it correctly identifies resource constraints. Linear programming sorts constraints into those that limit or "bind" the optimal plan, and those that remain in surplus. The binding constraints in the basic model are shown in Table 9. The column "marginal product" shows the impact on net output of increasing the supply of the constraint by one unit. If, for example, the supply of land was increased from 78 to 79 ha, total output would increase by 4.6 t. The table also shows the range of resource supply over which the marginal product remains constant. Thus, land provides an increase of 4.6 t per additional ha up to 81 ha, beyond which the marginal product will be lower.

Table 9 clearly brings out the importance of the draft power constraint after the harvest of modern aus. The draft power constraint was greatest in week 12. The model shows that each additional hour of animal labor in this week would add about 7 kg to output. The marginal product of draft power remained constant up to 9,200 h, about 3,600 h above the level actually used. The model thus reinforced our earlier conclusion of a draft power constraint on the area under modern aus.

Draft power constraints also appeared in weeks 7, 9, and 10. Week 7 coincided with land preparation for the cropping pattern local - modern, week 9 with land preparation for local - Pajam, and week 10 with land preparation for China - Pajam. Each of the higher yielding aus - aman patterns, therefore, was limited by draft power. In fact, this did not represent an absolute shortage. The maximum number of animal hours used for land preparation in any one week was 6,108 in week 11. Table 9 shows that the upper limit to the draft power constraint did not exceed this potential supply. Only in week 12 was there an absolute shortage of draft power.

Labor constraints also appeared in weeks 12 and 14. Week 12 coincided with harvesting, plowing, and transplanting for the cropping patterns China - local, Biplab - local, and local - local. Week 14 coincided with transplanting

Table 7. Area under 5 patterns in the basic model.[a]

Pattern	Actual		Model	
	Hectares	%	Hectares	%
Fallow - aman	10.960	14.44	6.009	7.70
Local - local	9.38	12.36	10.190	13.07
Local - modern	16.73	22.05	17.086	21.91
Modern - Pajam	7.13	9.40	14.276	18.30
Modern - local	31.68	41.75	30.438	39.02
All patterns	75.88	100.00	78.000	100.00

[a]Turnaround time survey, BRRI, 1985. Figures may not add to totals because of rounding error.

Table 8. Area under major cropping patterns in the basic model.[a]

Pattern	Actual		Model	
	Hectares	%	Hectares	%
Fallow - modern	5.22	6.88	6.009	7.71
Fallow - Pajam	5.74	7.56	–	–
Local - modern	4.33	5.71	6.043	7.75
Local - Pajam	12.40	16.34	11.043	14.16
Local - local	9.38	12.36	10.190	13.06
China - Pajam	7.13	9.40	14.276	18.30
China - local	25.74	33.92	17.238	22.10
Biplab - local	5.94	7.83	13.200	16.92
All patterns	75.88	100.00	78.000	100.00

[a]Turnaround time survey, BRRI, 1985. Figures may not add to totals because of rounding error.

Table 9. Binding constraints in the basic model.[a]

Binding constraint	Marginal product (t/unit)	Range over which marginal product stays constant		
		Lower limit	Present level	Upper limit
Land (ha)	4.6	71.991	78.000	81.308
DWK7 (h)	5.5	915.490	1946.000	2822.556
DWK9 (h)	2.5	2566.343	3556.000	4134.898
DWK10 (h)	10.1	3531.940	4597.000	4946.379
DWK12 (h)	7.0	4231.770	5622.000	9223.770
LWK12 (h)	0.9	8846.440	9500.000	10687.350
LWK14 (h)	7.4	675.380	3556.000	4581.420
AUS1 (h)	1.6	2028.280	4000.000	5085.310

[a]Turnaround time survey, BRRI, 1985.

for China - local. Thus, labor constraints were associated with modern aus - local aman patterns, which is in accordance with the turnaround time survey. Farmers during this period relied heavily on migrant labor for both harvesting and transplanting. A labor constraint also appeared at the time of aus transplanting. Aus week 1 coincided with the transplanting of Biplab and the direct seeding of local aus. A labor shortage for early transplanting seems plausible. Our earlier analysis of labor constraints showed that more migrant labor was used to transplant Biplab (74%) than China (65%). We argued that this was because Biplab has a longer field duration than China, and farmers used more hired labor to ensure timely transplanting (Orr et al 1987). The model reinforced this suggestion of a labor shortage for early transplanting.

STRATEGIES

The objective of this section is to analyze different strategies to reduce resource constraints on turnaround and increase the area under MVs. Linear programming allows us to model the effect of introducing these strategies and thus to measure their relative impact on output. The method takes no account of differences in the social cost of each innovation. What the method allows, however, is a rough idea of the expected benefits (in terms of higher paddy output) provided by each innovation.

One strategy is to increase the supply of draft power by improving the efficiency of existing resources. Improved animal nutrition has been suggested as one solution. For example, crop residues can be treated with urea to increase the supply of nutrients (Saadullah et al 1981). This option may be uneconomic for small farmers, however, since the urea required to treat residues could equally well be used to increase rice yields (Magor 1986). Even if the practice is economic for larger farmers, the strategy will work only over the long term. This strategy has thus not been considered here. Similarly, the introduction of a threshing machine was not modeled, since earlier evidence suggested that the use of animals for threshing did not delay land preparation for t. aman.

Improved plow

In the short run, it is possible to increase the efficiency of draft power by intermediate technology such as improved plows or a neck harness for cattle (Farouk and Sarkar 1983, Haq 1984, Hussein et al 1980). Field research by the Bangladesh Agricultural University has shown that efficiency gains are possible by introducing a moldboard plow. The major advantage of the moldboard plow is that it cuts the soil more quickly and reduces the number of tilling operations.

Animal hours required with the new plow were estimated using labor coefficients for the BRRI project area. On the average, land preparation for t. aman requires 147 h/ha for plowing and 14 h/ha for harrowing. Farmers normally do six plowings and seven harrowings, regardless of the aman variety used (Hoque et al 1976). This gives labor coefficients of 24.5 h/plowing and 2 h/harrowing. We assumed the moldboard plow reduces the number of plowings to 4 but increases the number of harrowings to 10. This gives a labor requirement of 118 h/ha. Multiplying by 2 to obtain animal hours gives a coefficient of 236 h/ha. Time was added for trimming or repairing plot boundaries (19 h), making the total human hours required 139 h/ha. These new coefficients were then entered in the data matrix for the modern aus patterns China - local and Biplab - local. The results are summarized:

- The new plow increased the area under modern aus from 45 ha in the basic model to 51 ha, or 65% of the total aus area. The area under modern aman fell, however, because of the reduction in the pattern fallow - modern aman. Aggregate yields rose to 6.7 t/ha (Table 10).
- The only major change that occurred in cropping pattern was a large reduction in the area under fallow - modern aman, suggesting that fallow - aman patterns reflect a shortage of draft power at the peak period. To reduce pressure on draft power, farmers may opt for single cropping (Table 11).
- The new plow did not reduce the marginal product of draft power in week 12. One additional hour at the peak period added 10 kg to the aggregate yield (Table 12). The range over which the marginal product remained constant was reduced, however, from more than 3,000 to only 397 additional h (Table 13).

Power tillers

Previous research has suggested there is a potential demand for power tillers on farms with three or four draft animals. The model allows us to estimate the expected benefits from this strategy.

Table 10. Area under modern varieties in each programming model.[a]

Model number	Model description	Modern aus		Modern aman		Output (t/ha)
		Hectares	%	Hectares	%	
1	Actual	38.81	51.12	9.55	12.59	6.2
2	Basic	44.71	57.32	12.05	15.45	6.5
3	Plow	51.08	65.48	6.45	8.40	6.7
4	Tiller	54.72	70.15	11.16	14.31	6.8
5	Minimum tillage	56.02	71.82	6.04	7.75	6.9
6	Direct-seeded MV aus	51.42	65.92	22.06	28.28	6.6
7	Short MV aus	52.33	67.09	22.98	29.46	6.7
8	BR1 - BR11	44.84	57.49	37.57	48.16	6.5
9	IR50-type	44.84	57.48	34.41	44.24	6.7
10	Models 6, 7, 8, 9	61.83	79.27	77.89	99.87	7.2
11	Model 10 + tiller	70.86	90.85	56.02	71.82	7.5
12	Model 10 + minimum tillage	76.84	98.52	65.05	83.34	7.9

[a]Turnaround time survey, BRRI, 1985. Actual yields are hypothetical estimates based on recommended management practices and a normal year.

Table 11. Area (ha) under each pattern by programming model.[a]

Pattern	2 Basic model	3 New plow	4 Power tiller	5 Minimum tillage	6 DSR BR1	7 Short BR1	8 BR1 - BR11	9 BR1 - IR50	10 Combined varieties	11 Models 10 + 4	12 Models 10 + 5
Fallow - Pajam	–	–	–	–	–	0.408	–	–	–	–	–
Fallow - modern	6.009	0.500	5.119	–	9.317	9.317	–	–	1.006	3.460	–
Local - modern	6.043	6.043	6.043	6.043	6.043	6.043	6.043	6.043	–	–	–
Local - Pajam	11.043	11.043	11.043	11.043	–	3.422	11.043	11.043	–	–	1.157
Local - local	10.190	9.337	1.080	4.893	11.224	–	–	16.075	–	–	–
China - Pajam	14.276	14.276	14.276	14.276	14.276	14.276	7.094	14.276	–	10.854	11.792
China - local	17.238	23.588	27.105	17.238	18.491	16.488	24.631	–	–	–	–
Biplab - local	13.200	13.212	13.333	13.200	11.946	13.949	5.931	2.095	0.102	11.123	–
Direct-seeded BR1					6.072			–	6.043	6.043	12.162
Short BR1	–				–	7.621		–	11.043	11.043	10.106
BR1 - BR11				–	–		7.183	–	16.357	3.422	14.493
Local - modern 2			–		–		16.075	–	15.068	3.675	–
BR1 - IR50		–	–	–	–	–	–	28.467	28.379	28.379	28.290
Total	78.00	78.00	78.00	78.00	78.00	78.00	78.00	78.00	78.00	78.00	78.00

[a]Turnaround time survey, BRRI, 1985.

Table 12. Marginal products (kg per unit) by programming model.[a]

Constraint	2 Basic model	3 New plow	4 Power tiller	5 Minimum tillage	6 DSR BR1	7 Short BR1	8 BR1 - BR11	9 BR1 - IR50	10 Combined varieties	11 Models 10 + 4	12 Models 10 + 5
Land (ha)	4,600	4,600	4,600	4,765	4,067	4,100	4,676	4,795	4,600	4,600	5,184
DWK5 (h)	–	–	–	–	1.653	1.553	3.329	–	–	–	–
DWK7 (h)	5.535	5.535	5.535	4.776	1.196	7.068	–	4.984	9.923	9.845	14.491
DWK9 (h)	2.498	2.498	2.498	1.394	–	1.682	2.332	2.019	–	7.077	–
DWK10 (h)	10.078	10.078	10.078	9.591	11.731	4.934	9.841	9.472	5.695	6.596	–
DWK12 (h)	7.004	9.720	7.004	1.531	7.151	9.048	5.922	8.789	9.224	2.356	–
LWK7 (h)	–	–	–	–	10.818	–	–	–	–	–	–
LWK9 (h)	–	–	–	–	–	4.159	–	–	3.450	–	–
LWK12 (h)	0.943	0.943	0.943	–	3.636	–	2.455	–	–	2.754	–
LWK14 (h)	7.389	7.389	7.389	–	7.709	9.781	6.200	7.438	7.920	–	–
AUS1 (h)	1.622	1.622	1.622	9.574	–	2.190	0.712	–	0.201	4.804	10.422
AUS2 (h)	–	–	–	–	–	5.366	–	–	–	4.092	9.710
AUS3 (h)	–	–	–	7.384	–	–	–	1.004	1.204	7.466	9.911

[a]Turnaround time survey, BRRI, 1985.

Table 14 shows coefficients for power tillers and draft power. The field capacity of a power tiller, assuming it works 5.5 h/d, 7 d/wk, was estimated at 39 h/wk. In 39 h, 1 tiller can give only 1 tillage to 15.8 ha. One tillage with a power tiller is equivalent to two plowings and two harrowings with ordinary draft animals (Gill 1981). Farmers in the BRRI project area typically do an average of six plowings and seven harrowings for t. aman (Hoque et al 1976). One power tiller must therefore perform three tillings to prepare land to the normal standard for aman transplanting. One tiller may thus cover about 5 ha/wk. The animal labor required for 5 ha is 1,610 h. One power tiller, therefore, is equivalent to 1,610 h/wk of animal power.

The BRRI Agricultural Engineering Division has the resources to supply two power tillers on a trial basis in the project area. To evaluate their impact, therefore, we assumed that two tillers were available for hire at the peak period. This increased the total number of animal hours in week 12 to 8,842 h. The results are summarized:

- The introduction of 2 power tillers to supplement draft power in week 12 increased the area under modern aus from 45 ha in the basic model to 55 ha, or 70% of the total aus area. The area under modern aman remained the same at 14% of the total aman area. Aggregate yields increased to 6.8 t/ha (Table 10).
- Power tillers changed the cropping pattern, with a big reduction in the local - local pattern. Interestingly, the area under the pattern fallow - modern did not change. The area under China - local expanded to fill the gap left by local - local (Table 11).
- Power tillers reduced the number of hours over which the marginal product of draft power remained constant in week 12 from 3,000 to 381 h (Table 13). The marginal product of 1 h of draft power remained positive, however, at 7 kg. Labor constraints increased during aus transplanting (Table 12). Thus, the model suggests that, by easing the constraint on draft power, power tillers will increase the demand for labor to transplant modern aus.

Table 13. Level of resource constraints (additional h at constant MP) by programming model.[a]

Constraint	2 Basic model	3 New plow	4 Power tiller	5 Minimum tillage	6 DSR BR1	7 Short BR1	8 BR1 - BR11	9 BR1 - IR50	10 Combined varieties	11 Models 10 + 4	12 Models 10 + 5
Land (ha)	3.308	8.617	4.198	12.374	7.745	0.148	2.894	2.894	8.31	5.857	1.263
DWK5 (h)	–	–	–	–	117.555	91.341	–	–	–	–	–
DWK7 (h)	876.556	6155.667	876.556	876.556	876.556	195.212	876.564	876.556	324.075	1116.72	170.74
DWK9 (h)	578.898	149.495	578.898	578.898	–	524.711	956.253	578.898	1527.78	50.385	–
DWK10 (h)	349.379	160.886	349.379	349.379	603.647	79.036	702.66	349.379	32.898	102.582	–
DWK12 (h)	3601.77	397.00	381.767	655.92	3614.02	131.247	1405.55	1405.56	324.075	3881.92	–
LWK7 (h)					646.979		–	–	–	–	–
LWK9 (h)	–				–	67.254		–	166.06	–	–
LWK12 (h)	1187.35	98.725	1011.44		370.543	–	1185.18	–	–	105.13	–
LWK14 (h)	1025.42	830.006	354.391	–	1025.42	111.682	1025.42	1025.42	275.766	–	–
AUS1 (h)	1085.31	2872.14	354.391	1321.01		961.866	1943.63	–	570.155	250.281	288.12
AUS2 (h)	–	–		–	–	24.443	–	–	–	–	288.13
AUS3 (h)	–			1321.01	–	–	–	573.975	570.155	253.333	288.13

[a]Turnaround time survey, BRRI, 1985.

Table 14. Labor requirement for power tillers.[a]

Item	Bullock team		Power tiller
	Plowing	Harrowing	
Working day (h)	5.5	5.5	5.5
Area (ha/d)	0.27	0.81	5.5
Time (h/ha)	20.37	6.79	2.5

[a]From Gill 1981, p. 58, Table 4.11.

Minimum or zero tillage

Previous research suggested that zero tillage would increase the area transplanted before 31 Aug by 25%. Zero tillage may be an unrealistic strategy, however. Interviews with farmers in the BRRI project area revealed that they strongly believed land preparation and time to decompose aus straw increased t. aman yields. A more realistic target, therefore, is minimum tillage to reduce the number of plowings and harrowings required. At present, farmers in the project area do six plowings and seven harrowings for t. aman. This was reduced to 3 plowings and 4 harrowings, giving coefficients of 80 h/ha and 160 animal h/ha for land preparation. To model the impact of minimum tillage, these coefficients were used in the modern aus - aman patterns. The results are summarized:

- Minimum tillage increased the area under modern aus, which rose from 45 ha in the basic model to 56 ha, or 72% of the total aus area. The area under modern aman declined, however, since the pattern fallow - modern was reduced. Aggregate yields rose to 6.8 t/ha (Table 10).
- Cropping patterns also changed. The pattern fallow - modern dropped out of the optimal plan, and the area under the local - local pattern was reduced. The pattern China - local expanded, reflecting the easing of the draft power constraint on modern aus (Table 11).
- Minimum tillage reduced the number of hours over which the marginal product of draft power remained constant in week 12 (Table 12). The marginal product remained positive, at 1.5 kg/h (Table 13).

Extending modern aus - modern aman

Our previous research showed that, whereas 64% of the aman area was transplanted by 31 Aug (the cut-off date for BR11), only 12% of the t. aman area was under MVs. The mean transplanting date for modern aman was 2 Aug. To measure the impact of an extended transplanting date, the pattern BR1 - BR11 was introduced into the model. This pattern occupied only 1.6 ha among the sample and may thus be regarded as a new technology. The vector for the new pattern is shown in Table 6. Two patterns were modeled. In the first, China was transplanted early (1-7 May) and harvested in week 10, followed by land preparation and transplanting of modern aman in week 11. In the second pattern, China was transplanted later (8-14 May) and harvested in week 11, followed by land preparation and transplanting in week 12. Yields from the first pattern (8.4 t/ha) are higher than from the second (7.6 t/ha) because of the difference in transplanting date. As a result of the later transplanting of BR11, a second local - modern vector with aman transplanted in week 12 was also introduced into the model. The results of these changes are summarized:

- The area under modern aus did not change, but remained at 45 ha or 57% of the total aus area, the same as in the basic model. Although negative, this is a significant result, confirming our earlier finding of a draft power constraint on the area under modern aus. Extending the transplanting date of BR11 increased the area under modern aman dramatically, however. It rose to 38 ha, or 48% of the total aman area. Aggregate yields increased to 6.5 t/ha (Table 10).
- Several changes occurred in cropping pattern, reflecting the shift to modern aman. Patterns fallow - modern and local - local dropped out of the optimal plan, while the area under China - Pajam was reduced. The

increase in modern aman occurred in the local - modern pattern, and not in modern - modern. The reduction in China - Pajam and Biplab - local, both high-yielding patterns, helps explain the low aggregate yields in the model (Table 11).

- Extending the transplanting date for modern aman actually reduced the draft power constraint in week 12, perhaps because of the reduction in the Biplab - local pattern (Table 13). The marginal product of draft power remained positive, however, at 6 kg/h (Table 12).

Direct-seeded modern aus

A tall, modern aus variety with vigorous seedlings that could shade out weeds quickly would enable the crop to be direct seeded. This would allow aus to be sown directly after the first rain rather than delaying until rainfall provides sufficient water for transplanting. Direct seeding would thus allow establishment of the aus crop 3-8 wk earlier than transplanted aus, which would bring forward the harvest date and allow more time for t. aman land preparation (Hoque and Hobbs 1981). But direct seeding also has disadvantages. Direct-seeded aus rice would be drought-prone because of the erratic timing of the premonsoon rains; it would be harvested in the middle of the monsoon; and extra labor would be required for weeding (H. Brammer, pers. comm.). Our research showed that the target group for this variety was farms between 1.2 and 2.4 ha, which faced a labor constraint on transplanting aus.

Mechanization was not considered a viable strategy for this labor constraint. A comparison of manual and machine transplanting showed that, to break even, a transplanting machine had to cover 26 ha/yr. The maximum area a machine could cover was estimated at 14 ha (Baqui 1981). With existing production practices and wage rates, therefore, machine transplanting is uneconomic.

The vector for direct-seeded modern aus is shown in Table 6. The variety is direct seeded early in the season (1-8 May), allowing an early harvest and land preparation in week 7 before transplanting of modern aman in week 8. The combined yield of this aus - aman pattern was 7.8 t/ha. The results are summarized:

- Direct-seeded modern aus increased the area under modern aus from 43 ha in the basic model to 51 ha. Aggregate yields rose slightly from 6.5 to 6.6 t/ha (Table 10).
- The new variety replaced the low-yielding pattern local - Pajam, which was excluded from the optimal plan. Surprisingly, the area under fallow - modern aman increased. The area under the new variety was small (7 ha) (Table 11).
- Direct seeding did not change the draft power constraint in week 12. The marginal product of draft power remained at 7 kg/h (Table 12). Similarly, the range over which the marginal product stayed constant remained at 3,600 h (Table 13), because the new pattern substituted for local - Pajam, which was harvested early in the season. More draft power will be required in week 5, however, because of the increase in the area under fallow - modern.

Short-duration modern aus

A shorter-duration transplanted modern aus would have two advantages. It would enable aus to be transplanted later to escape uncertain rainfall conditions, and it would enable farmers to harvest aus earlier, thus extending the time available for land preparation for t. aman and reducing the pressure on draft power. This would benefit all farmers, but particularly large farmers with 3-4 draft animals who work them intensively for long periods. Moreover, a shorter-duration aus variety would reduce the labor constraint on transplanting. Again, this would benefit primarily large farmers, who rely mostly on hired labor for transplanting aman.

The vector for short-duration modern aus is shown in Table 6. The new variety can be transplanted between 7 and 14 May to compete with the pattern China - Pajam. This allows the aus to be harvested in week 8, followed by land preparation and aman transplanting in week 9. The yield from this pattern was 8 t/ha. The results are summarized:

- The area under modern aus increased from 43 ha in the basic model to 52 ha, or 67% of the total aus area. Similarly, the area under modern aman increased from 15 ha to 29 ha, or 29% of the total aman area. Aggregate yields rose accordingly from 6.5 to 6.7 t/ha (Table 10).
- All patterns were included in the optimal plan, but the areas under the patterns local - local and local - Pajam were reduced. The area under the new pattern was again low, at only 8 ha (Table 11).
- Short-duration modern aus effectively reduced the draft power constraint. Table 13 shows that the marginal product of draft power in week 12 remained constant only for an additional 130 h above the existing level. The marginal product of an hour of draft power remained high at 9 kg/h (Table 12).

IR50-type t. aman

In the previous models, the area under modern aman was constrained by the need to transplant it before 31 Aug. To increase the area of modern aman above 60% of the total aman area, it is necessary to introduce a variety of t. aman that either is photoperiod sensitive or has a shorter field duration. An IR50-type variety, which has a shorter field duration, can be transplanted up to mid-September and outyields BR11 when transplanted late. The vectors for the new technology are shown in Table 6. Since the pattern modern aus - IR50 was designed to replace the pattern

China - local, two vectors were required. These vectors corresponded to transplanting IR50 over 2 wk in September. At each stage — from aus transplanting through harvesting, land preparation, and aman transplanting — the new technology competes directly with China - local. Yields from the new pattern are well above those from the prevailing China - local pattern. The results are summarized:

- The area under modern aus remained the same as in the basic model, namely 45 ha, or 57% of the total aus area. The area under modern aman increased to 35 ha, or 44% of the total aman area. Aggregate yields rose to 6.6 t/ha (Table 10).
- Cropping patterns also changed, and BR1 - IR50 replaced China - local as the dominant pattern. Interestingly, fallow - aman dropped out of the optimal plan, reflecting higher returns after the peak period of draft power use. The area under Biplab - local was greatly reduced, but the area under local - local increased (Table 11).
- The new pattern did not significantly change the draft power constraint in week 12. The marginal product of draft power remained constant over an additional 1,400 h (Table 13). Each animal hour in the peak week adds an extra 9 kg to total output (Table 12).

Direct-seeded aus, short-duration modern aus, China - modern, and IR50-type t. aman

In the previous models, we measured the effects of new varieties individually. Finally, we introduced all the varietal changes into the same model to assess their combined effect. The model incorporates direct-seeded modern aus, short-duration aus, and the pattern China - modern. In addition, the model includes a photoperiod-insensitive t. aman variety, IR50, which can be transplanted up to 14 Sep. The results are summarized:

- The area under modern aus increased to 62 ha, or 79% of the total aus area, while the area under modern aman increased to 78 ha, or 100% of the aman area. Aggregate yields rose to 7.2 t/ha (Table 10).
- Several patterns were excluded from the optimal plan. Local - modern, local - local, China - Pajam, and China - local all dropped out. The Biplab - local and fallow - aman patterns were greatly reduced (Table 11).
- Constraints remained much the same. This time, the introduction of short-duration modern aus did not reduce the draft power constraint in week 12, because it was counterbalanced by extending the pattern China - modern. Draft power thus continued to constrain output after the harvest of modern aus. The marginal product of draft power in week 12 remained high at 9 kg/h (Table 12). The range over which the marginal product remained constant — 324 h — was less than in the basic model, however (Table 13). Labor constraints increased during aus transplanting, reflecting the change to transplanted MVs.

Direct-seeded modern aus, short-duration modern aus, extended BR1 - BR11, IR50-type t. aman, and power tiller

To evaluate the potential impact of mechanization, two power tillers were introduced into the model along with the new varieties and extended BR1 - BR11. The results are summarized:

- The introduction of 2 power tillers to supplement draft power in week 12 increased the area under modern aus to 71 ha, or 91% of the total aus area. This reflects the easing of the draft power constraint in week 12. The area under modern aman fell, compared with the previous model, to 71% of the total aman area. Because of the greater area under modern aus, aggregate yields rose to 7.5 t/ha (Table 10).
- Several changes occurred in cropping patterns over the previous model. The area under the modern - modern and local - modern patterns fell, reducing the total area under modern aman. Local - modern and China - Pajam dropped out of the optimal plan, while the area under Biplab - local increased (Table 11).
- Power tillers reduced the marginal product of draft power in the peak week from 12 to 2 kg/h (Table 12). The constraint remained, however, with the marginal product staying constant for an additional 3,800 h of animal power (Table 13).

Direct-seeded modern aus, short-duration modern aus, extended BR1 - BR11, IR50-type t. aman, and minimum tillage

To evaluate the potential impact of minimum tillage combined with new varieties, the hours required for land preparation in the modern aus - t. aman patterns were reduced to 80 manhours and 160 animal hours per ha. The results are summarized:

- The introduction of minimum tillage into the modern aus patterns increased the area under modern aus to 77 ha, or 99% of the total aus area, while the area under modern aman rose to 65 ha, or 83% of the total aman area. Thus, the effect is similar to that of introducing power tillers. Aggregate yields were higher — 7.8 t/ha because of the greater proportion under modern aus (Table 10).
- Changes in cropping pattern show that the increase in area under modern aus resulted from decreases in the fallow - modern and local - modern patterns, both of which dropped out of the optimal plan. There was also a significant change from IR50 transplanted in week 14 to IR50 transplanted in week 13. Because aman yields are sensitive to transplanting date, earlier transplanting increased the yield from the BR1 - IR50 pattern (Table 11). The area under direct-seeded modern aus increased, reflecting the labor constraint on aus transplanting.
- Minimum tillage eliminated the draft power constraint in week 12 (Tables 12, 13), but there was a significant

increase in the labor constraint on aus transplanting. Increasing the area under transplanted modern aus will increase the seasonal demand for labor at this period.

CONCLUSIONS

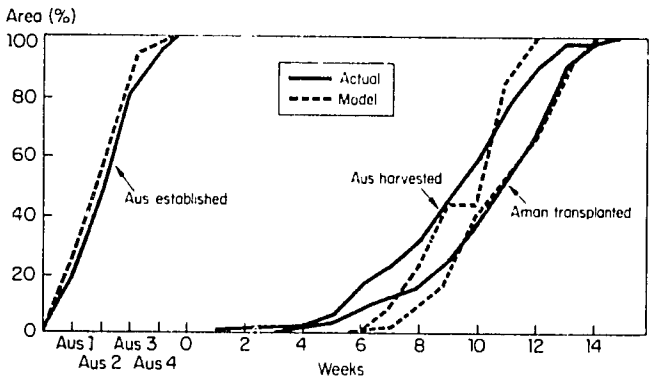
These increases can all be achieved with the existing resources of labor and draft power. Figure 1 compares the present situation with the projections in Model 10 after introducing new varieties. The graph shows the mean percentage area of aus established, aman transplanted, and aus harvested during 1985 aus and aman in Joydebpur. Both the aus establishment and aman transplanting dates — the key parameters of the system — produced by the model correspond closely to the actual dates, which, of course, reflect current labor and draft power resources.

The objective of this paper was to construct a linear programming model of labor and draft power use during the turnaround time between aus and t. aman. Because the model is a simplified version of reality, the results must be treated with caution. The numbers represent only rough orders of magnitude that allow us to estimate the direction of change between different strategies. We emphasize the qualitative rather than the quantitative aspect of our conclusions.

Constraints

The model clearly demonstrates the existence of a draft power constraint. Draft power was a binding constraint in the later half of Aug after the harvest of modern aus. This result confirmed our earlier conclusion that supply and demand for draft power were in equilibrium after the harvest of modern aus and that there was no surplus draft power at the aggregate level. The model indicated a large constraint of about 3,600 h during the peak week.

Labor was also a constraint during harvesting and transplanting of the modern aus - local aman pattern. This result confirmed our earlier analysis of labor constraints, which showed that farms bigger than 2.0 ha experienced a shortage of labor for transplanting after the harvest of modern aus. The model indicated a peak shortage of 1,000 h.



1. Mean cumulative percentage area of aus established, aus harvested, and aman transplanted, Joydebpur, 1985, and in linear programming model.

Finally, labor was a constraint during aus transplanting. Again, this result is supported by our earlier study, which demonstrated that farms between 1.2 and 2.0 ha were unable to hire enough labor for transplanting and consequently grew less modern aus. The model indicated a shortage of about 1,000 h. As the area under modern aus expands with the reduction of resource constraints on turnaround, labor constraints on aus transplanting will become more acute.

Impact of different strategies

The results of the different strategies are summarized in Table 15, which shows that the area under modern aus increased whichever strategy was applied, with the significant exception of extending BR1 - BR11. This confirms our earlier conclusion of a draft power constraint on the area under modern aus.

The model suggests that the biggest increase under modern aus resulted from minimum tillage or power tillers. The introduction of two power tillers during the peak week (26 Aug-1 Sep) — and halving the tillage required for the modern aus - aman pattern — gave similar results. Power tillers and minimum tillage are thus viable alternatives, but the model suggests that they are unlikely to increase the area under modern aus to much above 70%.

Another strategy that promised high returns was extending BR1 - BR11. At present, most BR11 is transplanted between 12 and 18 Aug or even earlier, after fallow. The model suggests that extending BR1 - BR11 up to 31 Aug would increase the area under modern aman from the current level of 15% to almost 50%. Aggregate yields did not greatly increase, however, because of the draft power constraint, which prevented any expansion of the area under modern aus. Extending cannot overcome this problem, but its promotion is urgently needed to encourage farmers to transplant modern aman up to 31 Aug, the cutoff date for BR11 under rainfed conditions.

Targeting the best strategy

The model suggests that there is no single solution to the problem of reducing resource constraints on turnaround

Table 15. Results of individual strategies.

Model	Modern aus (%)	Modern aman (%)	Aus+aman yield (t/ha)
Actual situation	51	13	6.2
Basic model	57	15	6.5
Extended BR1 - BR11	57	48	6.5
Moldboard plow	65	8	6.6
Direct-seeded MV aus	66	28	6.6
Short-duration MV aus	67	29	6.7
Power tiller	70	14	6.8
Minimum tillage	72	8	6.8

Table 16. Results of combined strategies.

Model	Modern aus (%)	Modern aman (%)	Aus+aman yield (t/ha)
Variety change (direct-seeded MV aus + short-duration MV aus + IR50-type t. aman) + extended BR1 - BR11	79	100	7.2
Variety change + extended BR1 - BR11 + power tillers	91	72	7.5
Variety change + extended BR1 - BR11 + minimum tillage	99	83	7.9

time. A combination of strategies involving plant breeders, engineers, and agricultural extension workers gave the best results. Three such combinations were modeled. The first involves only new varieties, without the mechanization strategy. The second involves new varieties but also includes power tillers. The third involves new varieties without power tillers, but includes minimum tillage. The results are summarized in Table 16.

In combination, the varietal strategies offer high returns. The model suggests that the introduction of direct-seeded aus, short-duration aus, an extended BR1 - BR11 pattern, and an IR50-type t. aman would increase the area of modern aus to 79% of the total aus area. Aggregate yields would increase to 7.2 t/ha. The second model shows the change when power tillers are included. The model indicates that the introduction of power tillers during the peak week for land preparation would further increase the area under modern aus to 91% of the total aus area. Aggregate yields would increase to 7.5 t/ha. The introduction of minimum tillage would increase the area under modern aus to 99% of the total aus area, and aggregate yields to 7.9 t/ha.

Three major conclusions emerge from this analysis. First, farmers have chosen a combination of varieties for aus and t. aman that enables harvesting, land preparation, and transplanting to be spread over time. The model suggests that this spreading of operations has maximized total yields in the face of labor and draft power constraints. Second, new varieties are essential, and the model shows that their introduction will increase the areas of modern aus and aman far above present levels. The model clearly illustrates the need for a range of varietal types for the shallow flooded, rainfed rice environment. To increase the area under modern aus, a direct-seeded variety and a short-duration variety are urgently needed. Similarly, to maximize the area under modern aman, a high-yielding BR11 plant type that yields well even when transplanted at the end of August and a photoperiod-insensitive, short-duration aman like IR50 are required. As part of this effort, agricultural extension workers should encourage wider adoption of BR11. Third, to further increase the area under modern aus, it is necessary to reduce the constraint on draft power, either by introducing minimum tillage or by supplementing animal power with power tillers.

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Appendix. Week codes for LP model.

Week code	Actual dates
AUS1	6-12 May
AUS2	13-19 May
AUS3	20-26 May
AUS4	27 May-2 Jun
WK0	3-9 Jun
WK1	10-16 Jun
WK2	17-23 Jun
WK3	24-31 Jun
WK4	1-7 Jul
WK5	8-14 Jul
WK6	15-21 Jul
WK7	22-28 Jul
WK8	29 Jul-4 Aug
WK9	5-11 Aug
WK10	12-18 Aug
WK11	19-25 Aug
WK12	26 Aug-1 Sep
WK13	2-8 Sep
WK14	9-15 Sep
WK15	16-22 Sep

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