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AN OPTIMAL CROPPING PLAN FOR FARMERS IN A SHALLOW TUBEWELL IRRIGATED AREA IN BANGLADESH

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ABSTRACT

This study was undertaken in an area of Bangladesh to assess the impact of minor irrigation on different farm sizes and determines the optimum allocation of resources of large and small farmers among different crops in a shallow tubewell (STW) irrigation system. Farm survey method was used to collect data in order to develop linear programming representative farm models. The analysis takes into account crop activities, inputs used, farm size and soil types. Optimal plans show mis-allocation of existing resources and indicated considerable scope for increasing farm income by reallocation of existing resources. The mis-allocation of resources on large farms was greater than on small farms. The analysis suggests that, by reallocating existing resources, large farms can increase farm income and employment more significantly than small farms. The research supports the view that the government should maintain a policy that favours private sector investment and operation of STW irrigation and the extension workers may direct farmers to allocate their resources in better way.

I. INTRODUCTION

Agriculture is the major component of the GDP of Bangladesh though its share is decreasing. The crop sub-sector (especially food crops) contributes 73% of total agricultural output. Agriculture is dominated by traditional farming with small, fragmented, scattered holdings and low productivity. Since the mid-sixties the government has promoted the introduction of 'green revolution technologies' (seed-fertiliser-irrigation) to increase yields. Irrigation is considered the 'leading input' in the green revolution technology and is the prime mover of growth for Bangladesh agriculture. The rapid growth in irrigation, especially minor irrigation, made it possible for Bangladesh to make a progressive shift from a high-risk monsoon dependent agriculture and increase crop yields, farm income and employment.

Minor irrigation technologies in Bangladesh comprise low lift pumps (LLPs), deep tubewells (DTWs), shallow tubewells (STWs) and manually operated pumps (MOPs) (IIMI, 1995). Since 1973 the area under irrigation has expanded from 0.5 million hectares to 3.7 million hectares in 1997. Over 90% of this area is irrigated by various modes of minor irrigation and about 10% by major surface water canal schemes (FAO, 1997). Almost 60% of the area under minor irrigation is irrigated by STWs with 32% divided more or less equally between LLPs and DTWs, and the remaining 8% irrigated by manually operated pumps. Most

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of the growth in the irrigated area can be attributed to STWs and the area irrigated by STWs has increased over five times since 1982 compared to around two times for LLP, DTW and canal irrigation and a decline in the area irrigated manually.

One of the government's main objectives for irrigation development is "to ensure equitable distribution of benefits and poverty alleviation" (GOB, 1998). The effects of irrigation development on different farm sizes are one important consideration. With rapid expansion of minor irrigation, there has been concern as to who gained access to the benefits of this technology. Empirical studies show that irrigation technologies have increased agricultural productivity and employment, but the benefits have accrued disproportionately and more rapidly to the relatively rich. The study will examine the effects of minor irrigation (STWs) on farm sizes and their cropping patterns, agricultural productivity, farm income and employment.

It is felt that under the existing technology, sufficient potential exists for improving agricultural production and augmenting farm returns by reallocation of the existing resources. An optimum combination of crop enterprises will lead to efficient use of land and other resources, and thereby increase the income of farmers. This study makes an attempt to examine the land use pattern for farmers in STW area and develop optimal plans considering their available resources. The study will provide information to planners, government, extension workers and farmers regarding the optimal cropping plans of large and small farmers.

The main objective of the study is to develop efficient farm plans for an average large and small farm in the STW irrigated system in Shibganj Upazila of Bogra district. The objectives are:

i) To develop representative farm level models to assess the optimum allocation of the available resources of small and large farmers among different crops in a STW irrigation system; and

ii) To provide planning guidelines for better utilisation of available farm resources.

II. METHODOLOGY

(a) Sampling Technique: A group of farmers from 10 shallow tubewells (2 from each block) from 5 agricultural blocks of Shibganj Upazila of Bogra district were chosen randomly. The area is situated about 20 kilometers north of Bogra town on the Bogra - Rangpur highway. All farms in the study area were listed according to their land holdings to identify farm size. Selection of sample farms in each of the block by land distribution is shown in Table 1.

Table 1. Farm classification and sample size in STW area of Bogra District

Block	No. of STWs	Selected farmers	No. of farmers selected according to farm size (ha)			
			0.01-1.0 Small	1.01-2.0 Medium	2.01-above Large	All
Chackpara	2	21	17	4	-	21
Shibganj	2	24	22	-	2	24
Deuli	2	23	20	3	-	23
Shankarpur	2	24	15	7	2	24
Gugia	2	22	15	6	1	22
Total	**10**	**114**	**89 (78)**	**20 (18)**	**5 (4)**	**114 (100)**

Figures in parentheses show the percentage of the total.
Source: Sarker, 2000

Both primary and secondary data were used. Primary data were collected by carrying out a field survey from April to June 1999. Secondary data of agro-climatic, infrastructure and other information were collected from the Bangladesh Meteorological office, Directorate of Agricultural Extension (DAE), Upazila Agriculture Office and other government publications. The survey covered three agricultural crop seasons (Kharif I: 16 March to 30 June; Kharif II: 01 July to 15 October and Rabi: 16 October to 15 March), beginning with the sowing time of aus crop in March-April 1998, then aman crop during July- August to November-December 1998 and ending with the boro crop harvest in April- May 1999.

To record the information, a well-structured and pre-tested survey schedule was used to interview the farmers and tubewell owners directly. The questionnaire had sections for obtaining general information on the farm and data on the costs and returns of different crops grown in each season and information relating to investment and operating capital requirements and technical aspects of the irrigation system.

(b) Analytical Technique: Linear programming (LP) was used to determine the optimal cropping plan for average small and large farms. LP is the simplest form of mathematical technique used at the farm level to find the profit maximising combination of activities, subject to constraints imposed by fixed resources (Hazell and Norton, 1986). The assumed objective function in this study is to maximise gross margins for an annual cycle. Gross margins were calculated by deducting the variable production costs (except labour, bullocks, power tillers and irrigation cost) from the gross return. Labour, bullocks, power tillers and irrigation water hiring for respective periods were treated as separate activities and the cost of these activities have not been included in the gross margins of individual crops.
The objective function was to:

$$\text{Maximise: } Z_0 = \sum_{j} C_j x_j - \sum_{t=1}^{12} W_h L_t - \sum_{t=1}^{8} W_b K_t - \sum_{t=1}^{6} W_d P_t - \sum_{t=1}^{5} W_c I_t$$

Where, Z_0 = total gross margin in taka

C_j = net return (taka) per hectare of the j^{th} crop activity

X_j = the area (ha) of the j^{th} crop activity

W_h = wage rate (taka) per unit of human labour

L_t = number of hired human labour (man-days) in t^{th} period

W_b = wage rate (taka) per unit of bullock labour

K_t = number of hired bullock labour (pair-days) in t^{th} period

W_d = hire charge (taka) per unit of power tiller

P_t = power tiller hours hired in t^{th} period

W_c = water charge (taka) per unit (m^3) of irrigation water

I_t = amount of irrigation water (m^3) purchased in t^{th} period

f_k = cereal production in kgs of k^{th} crop

x_k = the area of the k^{th} cereal crop

C_t = working capital available in t^{th} period in taka

$F^{(min)}$ = minimum cereal requirement of the farm family

The non-negativity restrictions were,

$$X_j \geq 0, L_t \geq 0, K_t \geq 0, P_t \geq 0, I_t \geq 0$$

Subject to land, labour, bullocks, power tillers, irrigation water, working capital and minimum cereal requirements constraints as discussed below:

(i) Land Constraints: Average large and small farm size in the study area were 2.55 and 0.57 hectares. This area was classified into five categories based on elevation and the cropping season. These were high non-rice land (HNRL), medium high rice land (MHRL), medium aman land (MAL), medium non-rice land (MNRL) and medium boro land (MBL). The cultivated farm sizes range from 0.1 to 0.94 hectares for small farms and 2.01 to 4.01 hectares for large farms. The land constraint used was as follows:

$$\sum_j l_{js} x_j \leq L_s \qquad (s = 1, 2, 3, 4 \text{ and } 5)$$

Where, l_{js} = land coefficient for j^{th} crop on s^{th} type of land for hectare

x_j = j^{th} crop activity on s^{th} type of land

L_s = available s^{th} type of land in hectares.

(ii) Family Labour Constraints: The agricultural labour force includes every person who worked part-time or full-time on the land. It includes those who employed in agriculture and excludes the rural work force employed in non-agricultural activities within rural areas. We assume 12 months availability of family labour and some casual labour is often hired to accomplish farm operations on time. The labour constraint was incorporated in the model as follows:

$$\sum_j h_{jt}x_j - L_t \le H_t \qquad (t = 1 \text{ to } 12)$$

Where, h_{jt} = labour requirement for j^{th} crop activity in t^{th} period in man-days

x_j = the level of the j^{th} crop activity

L_t = labour hired in t^{th} period in man-days

H_t = labour (man-days) available in t^{th} period.

(iii) Bullock Constraints: For setting up bullock restrictive periods, the seasonal operational requirements for bullocks for different crops were examined in consultation with the farmers. The periods of very high bullock requirements during which farmers had to hire in bullocks were then identified. On the basis of this information, 8 restrictive periods for bullock labour were incorporated in the model as below:

$$\sum_j b_{jt}x_j - K_t \le B_t \qquad (t = 1 \text{ to } 8)$$

Where, b_{jt} = bullock labour requirement for j^{th} crop activity in t^{th} period in pair days

K_t = bullock labour hired in t^{th} period in pair days

B_t = bullock pair days available in t^{th} period.

(iv) Power Tiller Constraint: The availability of power tillers was considered restrictive during, January, February, July, August, November and December. Power tiller hiring is a common practice and is considered an activity in the matrix. The power tiller constraint was formulated and incorporated in the model as below:

$$\sum_j d_{jt}x_j - P_t \le D_t \qquad (t = 1 \text{ to } 6)$$

Where, d_{jt} = power tiller requirement for j^{th} crop activity in t^{th} period in hours

P_t = power tiller hired in t^{th} period in hours

D_t = power tiller available in t^{th} period.

(v) Irrigation Water Constraints: Irrigation water availability depends on tubewell water supplies, whether owned tubewell water or purchased tubewell water. As farmers irrigate their crops roughly 3 to 4 times in a month, the month is selected to specify water constraints. Tubewell water use is computed at the farm level and aggregated for each crop. On the basis of water requirement (mm during growth period) of crops amount of irrigation water was calculated. Irrigation starts in December and ends in April. The following monthly inequalities are included in the models:

$$\sum_j w_{jt}x_j - I_t \le W_t \qquad (t = 1 \text{ to } 5)$$

Where, w_{jt} = irrigation water requirement (m^3) for j^{th} crop activity in t^{th} period in (m^3)

I_t = irrigation water supply (m^3) in t^{th} period in (m^3)
W_t = irrigation water available (m^3) in t^{th} period.

(vi) Cash Constraints: Farmers need cash for both production and consumption expenses. Consequently, its scarcity not only limits agricultural production but also leads farmers to adopt subsistence oriented production patterns. The cash needed for production of the different crops should be less than or equal to the total availability of cash for an average farm. In this study, cash has been defined as the working capital required for meeting day-to-day farm production expenses both in cash and kind. Cash availability was considered on an annual basis taken as 20% of the total income (agricultural income and non-agricultural income) (Rahman, 1984; and Baksh and Ahmed, 1985). It was assumed as Taka 43,550 for large farms and Taka 5,560 for small farms based on farm budget data. The working capital constraint was treated as follows:

$$\sum_j c_{jt} x_j \leq C_t \qquad (t = 1 \text{ to } 12)$$

Where, c_{jt} = capital requirement in taka for j^{th} crop activity in t^{th} period
C_t = capital available in taka in t^{th} period.

(vii) Minimum Cereal Requirement Constraints: Family food supply was also incorporated in the model. Most farmers in the area wanted to plant cereal crops to fulfill their home consumption requirements. Many researchers (Alam, 1994, Jaim, 1982, Singh, 1970 and Sinha, 1967) have incorporated this constraint in their models. Different approaches were used for calculating the minimum food grain requirements for family consumption. Alam (1994) calculated the minimum requirement for food grain on the basis of information received from individual farm families. Due to lack of consumption data for the entire year, the procedure used in this study was satisfaction of subsistence food grain requirements as estimated by Institute of Nutrition and Food Science (INFS) (INFS, 1977). The INFS recommended that 419 grams of rice and 45 grams of wheat were required for average consumption (per head / per day). The consumption constraints specified for the different food grain crops (rice) was set equal to or greater than the minimum cereal requirement. It was assumed to be 2,309 kg and 1,370 kg for large and small farms. The cereal requirement between farm sizes varies due to family sizes. Minimum cereal requirement was specified as:

$$\sum_j f_k x_k \geq F^{(min)}$$

Where, f_k = cereal production in kgs of k^{th} crop activity
x_k = the level of the k^{th} cereal crop activity
$F^{(min)}$ = minimum cereal requirement in kg of the farm family.

III. RESULTS AND DISCUSSION

A. Resource Utilisation

(a) Land Utilisation: Optimisation and reallocation of available resources bring significant changes to the existing land use pattern (Table 2). The crop HYV boro found prime place on the medium land on the large and small farms, which accounted for 38% and 39% of the total cropped areas respectively. The next dominant crop was Transplanted (T) aman on the medium land, which occupied about 37% and 39% on both types of farms. The optimum plan increased medium aman land (2% on large and 4% on small farms) than the existing plans and full utilisation of other types of land. Banana was the dominant crop on high non-rice land, which accounted for 4% and 3% of the total cropped area on large and small farms. Model results show that the area under banana increased approximately twice over the existing land allocation on the high non-rice land. In the medium non-rice land the area under potato increased by about 3% and 4% over the existing land allocation on large and small farms. About 78% and 80% land was under cereal production on large and small farms. Due to optimisation, the cropping intensity increased for both groups of farms compared to their existing plans. The cropping intensity increased to 222% and 218% in the optimal plans on large and small farms, compared to 205% and 212% in their existing plans (Table 2). This finding is similar to Alam (1994) who concluded that optimal plans can increase cropping intensity by 16% compare to the existing plan. Commercial crops such as banana and potato were important for all farms.

(b) Labour Utilisation: The optimum plans indicate a transfer of land from low valued crops to high valued cash crops. The utilisation of human labour on different farms for the existing and optimal production plans in different months is presented in Tables 3 which reveals that total employment of labour increased 24% and 2% on large and small farms respectively compared to the existing situation. This was due to transfer of a land to banana, aus and T. aman (Table 2), which utilised more labour. Therefore, during January to March and June to December greater utilisation of labour was observed in the optimal plans. The optimum plan shows that on small farms, the availability of family labour was sufficient to meet all farming needs. However, large farmers hired greater numbers of labour (369 man-days) on daily wages to perform farming operations on time. Human labour hiring was observed in the months of February to May, July and November on large farms (Table 3). Family labour supply is scarce in these periods. February to May are months for HYV boro and rabi crops cultivation, which demand more labour for planting, intercultural operations like weeding and irrigating, and post harvest operations like cutting, threshing, cleaning and storing. February and November are peak labour demand months due to HYV boro transplanting and T. aman harvesting. The increase in the employment of labour in the optimal plans (24% for large farms and 2% for small farms) is very important finding in the context of the labour surplus economy of Bangladesh, where one government objective is to alleviate poverty and create new employment opportunities. Results of the analysis show that the increase of labour employment on irrigated farms was mostly derived from the changes in land use patterns and increased T. aman area (Table 2).

Table 2. Existing and optimal land utilisation (ha) by crops between large and small farms

Items	High Non Rice Land				Medium High Rice Land		Medium Aman Land	Medium Non Rice Land		Medium Boro Land	Total Cropped Area(ha)	Cropping Intensity (%)
	Banana	Kh-I Veg.	Wheat	Rabi Veg.	Aus Rice	Jute	T. Aman	Potato	Mustard	HYV Boro		
Large Farm (2.55ha)												
Existing Plan*	0.10 (2)	0.04 (1)	0.05 (1)	0.04 (1)	0.09 (2)	0.07 (1)	1.65 (32)	0.81 (16)	0.22 (4)	2.16 (41)	5.23 (100)	205
Optimal Plan	0.23 (4)	-	-	-	0.16 (3)	-	2.06 (37)	1.03 (18)	-	2.16 (38)	5.64 (100)	221
Small Farm (0.57 ha)												
Existing Plan*	0.02 (2)	0.01 (1)	0	0.01 (1)	0.02 (2)	0.01 (1)	0.46 (38)	0.12 (10)	0.06 (5)	0.50 (41)	1.21 (100)	212
Optimal Plan	0.04 (3)	-	-	-	0.03 (2)	-	0.49 (39)	0.18 (14)	-	0.50 (39)	1.27 (100)	218

Figures in parentheses are the percentages of total cropped land
Source: Sarker, 2000

Table 3. Labour utilization (man-days) by large and small farms

Months	Available	Existing Plan	Optimal Plan	Increase or Decrease Over Existing Plan	
				Man-days	Percentage
Large Farm					
January	88	67.6	68.4	0.8	1.2
February	88	164.0	170.7	6.7	4.0
March	88	106.2	106.2	0	0
April	88	94.0	98.8	4.8	5.0
May	88	139.8	139.9	0.1	0
June	61.6	6.2	34.2	28.0	452.0
July	61.6	94.7	144.1	49.4	52.2
August	88	50.3	60.7	10.4	20.6
September	61.6	26.8	61.0	34.2	128.0
October	61.6	22.8	58.1	35.3	155.0
November	88	192.0	237.7	45.7	23.8
December	61.6	33.5	59.8	26.3	78.7
Total	**924.0**	**998.0**	**1239.5**	**24L6**	**24.2**
Small Farm					
January	34.3	14.2	14.4	0.20	1.4
February	34.3	29.7	31.6	1.9	6.4
March	34.3	23.3	25.3	2.0	8.6
April	34.3	26.0	16.4	-9.6	-37.0
May	34.3	37.0	36.7	-0.3	0
June	34.3	1.3	1.4	0.1	6.9
July	34.3	24.3	25.8	1.5	6.2
August	34.3	14.9	15.7	0.8	5.2
September	34.3	7.4	8.0	0.6	8.4
October	34.3	6.1	7.0	0.9	15.0
November	34.3	45.8	51.7	5.9	12.9
December	34.3	6.1	**5.5**	-0.6	-10.5
Total	**411.6**	**236.2**	**239.7**	**3.5**	**1.5**

Source: Sarker, 2000

(c) Bullock Utilisation: The utilisation of bullock time on different farm groups in different months is presented in Table 4. The optimal plans indicate that total bullock utilisation increased by 8% on large farms and 3% on small farms compared to their existing situation. This was due to increased area under T, aman which utilised more bullock time (Table 2). Therefore, during July greater utilisation of bullock time was noticed for land preparation in the optimal plans (Table 4). The optimum plans predict that for small farms, the availability of bullock time was sufficient to meet all farming needs. However, large farmers hired bullock time during January, July and November to perform land preparation operation for HYV boro, T. aman and potato on time (Table 4).

Table 4. Bullock utilization (animal-days) by large and small farms

Months	Available	Existing Plan	Optimal Plan	Increase or Decrease over Existing Plan	
				Animal-days	Percentage
Large Farm					
January	14	34.6	34.6	0	0
February	14	5.8	5.8	0	0
April	14	4.6	6.0	1.4	31.0
May	14	1.2	1.6	0.4	26.6
July	14	28.0	35.0	7.0	25.0
August	14	4.4	5.5	1.1	25.1
November	14	14.4	15.5	1.1	7.1
December	14	5.7	2.7	-3.0	-52.0
Total	**112**	**98.8**	**106.7**	**8.0**	**8.1**
Small Farm					
January	7	8.0	8.0	0	0
February	7	1.3	1.3	0	0
April	7	0.9	1.1	0.2	17.4
May	7	0.2	0.3	0.1	20.8
July	7	7.8	8.3	0.5	5.9
August	7	1.2	1.3	0.1	6.5
November	7	2.0	2.7	0.7	36.4
December	7	1.2	0.5	-0.7	-61.3
Total	**56**	**22.8**	**23.5**	**0.7**	**3.1**

Source: Sarker, 2000

(d) Power Tillers Utilisation: The utilisation of power tillers on different farm groups in different months is presented in Table 5. Both bullocks and power tillers were used for land preparation. The optimum plans show that about 84 and 18 hours of power tiller were used by large and small farms respectively to perform land preparation operations on time which was 14% and 10% higher than existing plans. This was due to the transfer of land under T. aman and potato (Table 2). During July and November greater utilisation of power tiller was observed for land preparation in the optimal plans (Table 5). For T. aman, potato and boro land preparation, power tiller is popular in the study area because farmers are cultivating larger areas under these crops and require a shorter turn around time.

(e) Irrigation Water: The application of irrigation water on different farm groups in different months is presented in Table 6. The plan used 29,383 and 6,543 cubic metres (m) of irrigation water on large and small farms respectively compared to 28,434 and 6,339 m^3 in the existing situation although aus rice, kharif-I vegetables and T. aman did not require any irrigation water. This was due to the transfer of greater land area under banana, which utilised more water. HYV boro rice and potato required more water than other crops. Larger amounts of irrigation water were needed in the months of March and April due to very dry weather.

Table 5. Power Tiller utilization (hours) by large and small farms

Months	Available	Existing Plan	Optimal Plan	Increase or Decrease over Existing Plan	
				Hours	Percentage
Large Farm					
January	0	25.9	25.9	0	0
February	0	6.4	6.4	0	0
July	0	19.8	24.7	4.9	25.0
August	0	4.9	6.1	1.2	25.0
November	0	14.6	18.5	3.9	27.2
December	0	2.0	2.5	0.5	27.0
Total	**0**	**73.5**	**84.1**	**10.6**	**14.5**
Small Farm					
January	0	6.0	6.0	0	0
February	0	1.5	1.5	0	0
July	0	5.5	5.8	0.3	5.8
August	0	1.4	1.4	0.1	5.9
November	0	2.2	3.2	1.1	50.0
December	0	0.3	0.4	0.2	51.7
Total	**0**	**16.8**	**18.4**	**1.6**	**9.7**

Source: Sarker, 2000

Table 6. Irrigation Water utilization (m^3) by large and small farms

Months	Available	Existing Plan	Optimal Plan	Increase or Decrease over Existing Plan	
				m^3	Percentage
Large Farm					
January	0	4538	4686	148	3.3
February	0	6823	7140	317	4.7
March	0	8042	8280	238	3.0
April	0	7949	8108	159	2.0
December	0	1082	1169	87	8.0
Total	**0**	**28434**	**29383**	**949**	**3.4**
Small Farm					
January	0	962	995	33	3.4
February	0	1540	1600	60	3.9
March	0	1806	1887	81	4.5
April	0	1836	1857	21	1.1
December	0	195	204	9	4.6
Total	**0**	**6339**	**6543**	**204**	**3.2**

Source: Sarker, 2000

(f) Cereal Production: The annual cereal production on different farm groups is presented in Table 7. Rice is the major cereal crop, its production on both large and small farm groups was significantly greater than home consumption needs in both the existing and optimal plans. The optimum plans show that about 15,621 and 2,806 kg of cereal was surplus on large and small farms respectively, which was 11% and 4% higher than existing plans. This was due to the increased area under T. aman and aus (Table 2).

Table 7. Existing and optimal cereal production (kg) on large and small farms

Farm Size	Minimum Cereal Required	Existing Plan		Optimal Plan		Increase of Surplus Over Existing Plan	
		Production	Surplus	Production	Surplus	Kilogram	Percentage
Large Farm	2361	16469	14108	17982	15621	1513	10.7
Small Farm	1422	4113	2691	4228	2806	115	4.3

(g) Farm Total Gross Margins (GM)/Farm Income: Total farm gross margin is limited by the availability of land, labour and water resources. The analysis of crop area in Table 2 indicates major shifts in the existing cropping patterns. Highly remunerative cash crops like banana and potato entered into the optimal plans. An examination of Table 8 reveals that optimal plans increased farm income by 27% and 3% on large and small farms.

Table 8. Existing and optimal farm income/total gross margin (Tk/ha) on large and small farms

Farm Size	Existing Plan*	Optimal Plan	Increase or Decrease over Existing Plan	
			Taka	Percentage
Large Farm	11408	13925	2517	26.5
Small Farm	11755	12095	340	2.9

Source: Sarker, 2000

This shows a mis-allocation of existing resources on both farm types and considerable scope for increasing farm income by reallocation of the existing resources. Alam (1994) support this finding. The results suggest that by reallocating existing resources large farms can . increase farm income more significantly than small farms.

B. Marginal Value Product (MVP) of Resources

The marginal value products (MVP) of the land, human labor, bullock time, power tillers, irrigation water and cash capital derived from the 'duals' of the optimum solutions of the respective models are presented in Table 9. The MVP of a resource is the increase in total revenue that will occur as a result of increasing the level of that resource by one unit (i.e. to increase the land availability by one hectare). The MVP of a limiting resource will also indicate how much the farmer can be prepared to pay in order to purchase that extra unit of a resource (e.g. the price a farmer will be prepared to pay in order to purchase or rent an additional hectare of land or additional man-day of labour etc.). Hence the opportunity cost (or shadow price) of a limiting resource will be equal to its MVP, whilst for a slack resource it will be zero.

(a) MVP of Land: The MVP of land varied considerably. Table 9 reveals that the MVP of land for small farms was higher than large farms. The shadow values (in Taka per hectare) of Taka 40,958 and 51,891 for high non-rice land; Taka 1,021 and Taka 3,502 for medium high rice land; Taka 19,710 and Taka 31,841 for medium non-rice land; and Taka 1,051 and Taka

616 medium boro land for large and small farms respectively are high, which means that the value of the objective function would be increased by this amount if one additional hectare of land of this category is included in the plan. Zero shadow value of medium aman land indicates some land is fallow, which is similar to the existing situation. In the case of large farms, the average land shadow value per year was Taka 12,548 which was less than the existing land rent (Taka 14,925/ha per year) as compared to Taka 17,570 on small farms which was greater than the existing land rent (Taka 14,925/ha per year) prevalent in the study area in 1999.

(b) MVP of Labour: The MVP of human labour for different months is shown in Table 9. In the case of small farms, the MVP of human labour for different months in the optimum plan was zero (except May and November). This indicates that available human labour was surplus in terms of requirement in the optimum plan on small farms. For large farms, different results were observed. A positive MVP of human labour was observed during the months of February to May, July and November on large farms, which indicates that labour is scarce in these periods. February to May are months for HYV boro and rabi crops cultivation time, which demand more labour for planting, intercultural operations like weeding, irrigating, and post harvest operation like cutting, threshing, cleaning and storing. February and November are the peak labour demand months due to HYV boro transplanting and T. aman harvesting.

(c) MVP of Bullock Time: Table 9 reveals that the MVP of bullock time was zero in most periods (except January, July and November). This shows the excess availability of bullock power on the farms and the extent of their under-employment, which prevailed. The MVP of bullock time in the months of January, July and November were Taka 80.16 on large farms and Taka 82.04 on small farms, which was greater than prevailing market hiring rates of Taka 67.50.

(d) MVP of Power Tillers: In addition to bullock time, all types of farms hired power tillers to perform land preparation operations on time. The positive MVP of power tillers throughout the period indicates that, irrespective of farm size, all farms used power tillers. The MVPs of power tillers were Taka 65.31 and 66.85 on large and small farms respectively (Table 9) which was greater than prevailing market rates of Taka 55.00.

(e) MVP of Irrigation Water: An examination of Table 9 reveals that the MVPs of irrigation water were Taka 0.58 and Taka 0.60 per cubic metre (m^3) on large and small farms respectively. In other words, the large farmer would be prepared to pay Taka 0.58 for an extra cubic metre of irrigation water and the small farmer Taka 0.60. With reference to the existing market price (Taka 0.49) these MVPs are 18% and 22% higher on large and small farms situations.

(f) MVP of Cash Capital: It is evident from the Table 9 that MVPs of cash capital were Taka 0.19 and Taka 0.22 for large and small farms, which indicate urgent need to provide credit facilities for introducing irrigation and high value cash crops as well as for optimal utilization of available resources. The MVP for a small farm was higher than large farm. For economic efficiency the use of capital should be invested to the point where the MVP equals the interest or borrowing rate.

Table 9. Marginal Value Products (MVP) for binding constraints

Items	Large Farms	Small Farms
Land (Tk./ha)		
High Non Rice Land (HNRL)	40958	51891
Medium High Rice Land (MHRL)	1021	3502
Medium Aman Land (MAL)	-	-
Medium Non Rice Land (MNRL)	19710	31841
Medium Boro Land (MBL)	1051	616
Labour (Tk./Man-day)		
January	-	-
February	71.25	-
March	71.25	-
April	71.25	-
May	65.31	66.85
June	-	-
July	65.31	-
August	-	-
September	-	-
October	-	-
November	71.25	72.93
December	-	-
Bullock (Tk./Animal-day)		
January	80.16	82.05
February	-	-
April	-	-
May	-	-
July	80.16	82.05
August	-	-
November	85.56	-
December	-	-
Power Tiller (Tk./Hour)		
January	65.31	66.85
February	65.31	66.85
July	65.31	66.85
August	65.31	66.85
November	65.31	66.85
December	65.31	66.85
Irrigation Water (Tk./m^3)		
January	0.58	0.60
February	0.58	0.60
March	0.58	0.60
April	0.58	0.60
December	0.58	0.60
Cash Capital	**0.19**	**0.22**

IV. CONCLUSIONS

The study provides farm resource optimization and cropping plan for farmers in a STW irrigation area of Bangladesh. The optimal plans increased the cropped areas and thus increased the cropping intensities on large and small farms. Cereal based cropping patterns maintained dominance in both existing and optimal plans. The optimal plans revealed considerable scope for transfer of land from low valued crops to high valued cash crops. The MVP of land varied considerably according to land type. The MVP of land on small farms was higher than on large farms.

Labour employment increased in the optimal plans. Large farmers faced scarcity of family labour in the months of February to May, July and November. On the other hand, for small farms availability of family labour was surplus to crop demands and sufficient to meet all farming activities. In optimal plans, the availability of bullock time was also sufficient to meet all farming needs for small farms but the large farmers hired bullocks on daily rates to perform farming operations on time. In addition to bullock time, both small and large f arms hired in power tillers to perform land preparation operations on time. The MVP of power tiller is greater on large farms than small farms.

The plans used 29,383 and 6,543 m^3 of irrigation water on large and small farms respectively. The respective MVPs of irrigation water were Taka 0.58 and Taka 0.60 and MVPs were greater than the prevailing market price for irrigation water. Regarding capital, the plans indicate that MVPs of capital were Taka 0.19 and 0.22 for large and small farms which imply that there is a need to provide credit facilities to introduce irrigation and high valued cash crops as well as for optimal utilisation of resources. The optimal plans indicate major shifts in existing cropping patterns for both large and small farms. Highly remunerative cash crops like banana and potato entered into the optimum plans. Optimal plans increased farm income by 27% and 3% on large and small farms. This shows that there is a mis-allocation of existing resources for both types of farms and considerable scope for increasing farm income by reallocation of existing resources.

V. PLANNING IMPLICATIONS

Results of the study suggest a number of planning options for developing agriculture in Bogra district.

(a) STWs irrigation had a positive effect on farm sizes by changing cropping patterns, increasing cropping intensity, agricultural productivity, farm income and employment. Therefore, the government should continue to maintain a policy environment that favours private sector investment and operation of minor irrigation equipment.

(b) The study indicated that labour employment increased in the STWs irrigation areas, but surplus labour was higher on small farms than large farms. Redistribution of land is a precondition for fair distribution of irrigation benefits. However, in view of current sociopolitical circumstances, land redistribution does not appear realistic. A better idea might be to insist on full utilisation of all cultivable lands - a measure that could be implemented by introducing a fallow land tax or under-utilisation tax. Another incentive to full utilisation would be permitting the acquisition of land that has remained fallow for several years. All 'khas land' (land belonging to the government) must be identified and distributed among landless and poor farmers and cooperative use of this land should be encouraged.

(c) Optimal plans increased the area under highly remunerative cash crops like banana and potato and also increased income of both large and small farms. Thus, there is a considerable scope for increasing farm income by reallocation of existing resources and extension workers may provide guidelines to farmers for better allocation of resources.

Further Research

The present investigation on farm resource optimisation and optimal cropping plans in STWs irrigation area is useful for planning. However, because of time and resource constraints, the study is confined to one selected area representing a particular agro-ecological region. Therefore, findings of this study may not be generalised for the whole country. Further research may be conducted on the following lines:

(a) Results of the model drawn from a large survey covering different agro-ecological region of Bangladesh, and comparison of the results across various zones, can further improve the conclusions emerging from the study.

(b) A comparative study on optimum resource use considering other irrigation technologies, such as DTW, LLPs and major surface canal irrigation, is another important direction for future research.

(c) Other enterprises like livestock and fisheries may be included in the household models for greater coverage of livelihoods, income and employment.

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