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Impacts of the Alternate Wetting and Drying Irrigation System on Modern Varieties of Paddy Production in Bangladesh: A Case Study of Jessore District

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This paper attempts to estimate the impacts of Alternate Wetting and Drying (AWD) irrigation system on modern varieties (MV) of paddy production in Bangladesh. This study was conducted using primary data. A total of 140 MV *boro* producers were randomly selected from Manoharpur village of Monirampur Upazila in the district of Jessore, of which 70 farmers used the advanced AWD irrigation technique and the remaining used traditional irrigation techniques in cultivating MV *boro* paddy. Information on inputs and output of MV *boro* paddy cultivation was collected through a structured questionnaire. The study findings indicate that AWD farmers used less chemical fertilisers (with the exception of TSP) such as urea, MP, Gypsum and Zinc compared to farmers using traditional irrigation. Moreover, the amount of chemical fertiliser used also varied significantly within the same farming system. The farmers used almost similar proportions of temporary hired and family (male and female) labour for MV *boro* paddy cultivation under both irrigation systems. However, per hectare yield of MV *boro* paddy, revenue and profit were significantly higher in farms that used the AWD irrigation technique. In addition, farmers using the AWD irrigation technique used excessive irrigation and urea per hectare compared to their traditional counterparts. AWD results in approximately 10 per cent increase in productivity. Another 4 per cent increase was due to differences in quantities of inputs used in the study area.

Keywords: Alternate Wetting and Drying, Irrigation System, MV Paddy, Technological Change, Bangladesh
JEL Classification: O13, O33, Q15, Q16

I. INTRODUCTION

Water is the basic resource for agricultural production. The development of groundwater resources is a vital driving force for agricultural intensification and it has significant impacts on high yielding varieties (HYV) of paddy and wheat in

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South Asia, especially in India, Pakistan, Bangladesh, Nepal and Sri Lanka. Groundwater irrigation has significant impacts on HYV paddy and wheat production, rural household income, poverty alleviation and income distribution in Asia. The irrigation system has increased rural household income significantly and reduced poverty and inequality of income distribution through HYV paddy and wheat in Asia (Huang *et al.* 2005, Rosegrant and Evenson 1992, Hossain, Gascon and Marciano 2000, Datta, Tewari and Joshi 2004, Saleth 1991, Selvarajan and Subramanian 1981). The irrigation system has also increased employment throughout South Asia by encouraging HYV paddy and wheat production (Patel 1981).

The productivity of groundwater irrigation depends on the amount of application and its quality (Tyagi *et al.* 2004, Panda 1986). Intensive use of groundwater irrigation with poor drainage and management systems lead to rise in salinity in semi-arid and arid zones (Pingali and Shah 2001, Chambers 1988, Abrol 1987, Dogra 1986). Moreover, poor quality water in the absence of proper crop management also raises salinity and introduces adverse environmental outcomes (Dinar and Vaux 1985, Bajwa and Jason 1989, Sharma and Rao 1998, Sarwar, Bastiaanssen and Feedes 2001, Datta and Dayal 2000). The disproportionate supply of canal water with marginal quality enhances large variations in cropping patterns, irrigation applications and water productivity of irrigation system (Tyagi *et al.* 2004). Datta, Tewari and Joshi (2004) concluded that subsurface drainage system has improved the crop production through cropping intensification and diversification, increasing farm income and employment in Northwest India.

Over the past few decades, several economic journals have published articles or research notes on groundwater resources, irrigation systems, irrigation models, efficient use of water under different irrigation methods/systems and merits and demerits of irrigation water for HYV paddy and wheat production in terms of soil fertility in developed and developing countries. In contrast, a large number of studies report contradictory results of irrigation systems for HYV paddy and wheat production dating back to the green revolution in South Asia. Some researchers also conducted research on performance of irrigation system, and institutional reforms of irrigation systems in Pakistan. Yield per unit of water and yield per unit area are the most popular measures for evaluating technical efficiency and agricultural technological progress respectively. Similarly, net income per unit of water and net income per unit of area are the most significant measures of economic efficiency and financial utility of irrigation systems respectively. Farmers are able to pay water and other service charges if they acquire financial utility from irrigation systems (Bhatti, Schulze and Levine 1991). Chaudhry and Ali (1989) argued that consumers and producers gained substantial benefits investing in irrigation canal operation and maintenance (O&M).

Water is one of the main inputs for modern varieties (MV) of boro paddy cultivation along with seeds, pesticides and chemical fertilisers. Ground water is the main source of irrigating MV paddy cultivation in Bangladesh. Due to the extensive use of irrigation water during the boro season, ground water tables are declining gradually in Bangladesh and thus the water scarcity is increasing day by day.

The adoption of new or improved methods of production can shift the production function, suggesting technological progress. Production can be increased with new technology by using the same amount of inputs that were normally used in older technology. In other words, the production level in old technology can be attained with new technology by using fewer amounts of inputs. Alternate Wetting and Drying (AWD), also known as a disembodied new technology (Basavaraja, Mahajanshetti and Sivanagaraju 2008), generates new technical change, mainly due to improved management methods (Sankhayan 1988). The Alternate Wetting and Drying (AWD) is a modern water-saving technology that the farmers normally apply to reduce their water use in MV boro paddy cultivation. The application of AWD irrigation technique in MV paddy cultivation is a newly introduced technology in Bangladesh. The farmers are gradually applying the AWD irrigation technique in MV paddy cultivation and its use depends on the efficiency of extension workers in providing their services. Recently, studies have been conducted on the adoption, effects and efficiency of AWD irrigation for rice production in the northern part of Bangladesh (Rahman and Bulbul, 2014a, 2014b, 2015) and India (Kulkarni 2011, Singh *et al.* 2013). However, the economic impacts of AWD irrigation technique on MV boro paddy production in Bangladesh have been paid less attention. Therefore, the present study (i) compares and contrasts the cost and returns of MV boro paddy cultivation in AWD irrigation technique and traditional irrigation technique and (ii) decomposes the contribution of resources to the productivity differences between the two methods of irrigation. Moreover, the study also determines the resource use efficiency of AWD irrigation technique and traditional irrigation technique in MV boro paddy cultivation. The findings of the present study are expected to contribute towards providing benchmark information for economists, researchers, as well as policy makers and will provide useful information for the further development of MV paddy farming in Bangladesh.

II. METHODOLOGY OF THE STUDY

2.1 Sources of Data

The impacts of technologically modified AWD irrigation technique/system on MV boro paddy production were examined in Manoharpur Village of Monirampur Upazila in the district of Jessore. Manoharpur Village was purposively selected because a large number of farmers in this village adopted the use of AWD irrigation technique along with the existing traditional irrigation system for MV paddy production. Initially, a detailed list of farmers who implemented AWD irrigation technique and traditional irrigation in MV paddy production was collected from the upazila agriculture office. Primary data were used in order to conduct this study. The information (covering the calendar year 2015) on various inputs and output of MV paddy production under these two existing irrigation systems and the socio-economic information of farmers were collected through a structured questionnaire. A total of 140 farmers were randomly selected from this study village, of which 70 farmers used AWD irrigation, while the remaining 70 farmers used the traditional irrigation system in their MV boro paddy cultivation.

2.2 Analytical Techniques

2.2.1 Profitability Analysis

The estimation of profit of MV paddy cultivation under the method of the AWD irrigation and traditional irrigation techniques is as follows:

$$\pi = \sum P_1.Q_1 + \sum P_2.Q_2 - \sum P_{xi}.X_i - TFC$$

where,

π = Profit for the advanced technology (AWD) /traditional irrigation technique under study;

P_1=Price of the crop (paddy) grown;

Q_1=Quantity of output (paddy) obtained;

P_2=Price of by-product (straw);

Q_2=Quantity of by-product obtained (straw);

Px_i= Price of the *i*th (variable) input,

X_i= Quantity of the *i*th input used for the crop, and

TFC = Total fixed cost.

2.2 Resource Use Efficiency

Neo-classical theory states that the resources would be efficiently used in agricultural production farming where marginal value product (MVP) is equal to their marginal factor cost (MFC) in markets under conditions of perfect competition. In general, the producers would choose the input levels that maximise the economic profit [Total Revenue (TR) – Total Cost (TC)]. The marginal value product (MVP) of an input would be estimated by multiplying the coefficient of production elasticity with the output-input ratio at the geometric mean level. This can be shown in the following formula:

$$MVP = \frac{\overline{Y}_i}{\overline{X}_i}.\beta_i$$

where, β_i = regression coefficient of input X_i in the underlying production function

$\overline{X}_i$ = mean value (geometric mean) of variable input X_i

$\overline{Y}_i$ = mean value (geometric mean) of gross output of boro paddy

Marginal value products (MVPs) of various inputs are expressed in terms of relevant prices; this is also referred to as marginal revenue product (MRP). If MVP is higher than the MFC (market price of that input), then an increase of that input in the production system raises output; this increases profits.If the input resources are efficiently used then profit will be maximised in MV boro paddy where the ratio of MVP to MFC will tend to be 1 (one) or, in other words, MVP will equal MFC for each input.

In order to test the resource use, efficiency in MV boro paddy production, the ratio of MVP to the MFC for each input is compared and tested for its equality to 1 (i.e., $\frac{MVP}{MFC} = 1$) (Gujarati 1965).

2.3 Decomposition Analysis

Solow (1957) developed a decomposition analysis to evaluate the effects of technological change on output growth in US agriculture. Bisaliah (1977) extended the framework of decomposition analysis to examine the impact of technological change in Indian agriculture. Recently the farmers in India are practicing a new technologically advanced MV rice cultivation system which is known as System of Rice Intensification (SRI). Basavaraja, Mahajanshetti and Sivanagaraju (2008) used this decomposition analysis to examine the impact of technological change in rice cultivation, in India. In this study, the output decomposition analysis model, as developed by Bisaliah (1977), is used to measure the contributions of technology and resource use differentials to the total productivity differences between the AWD irrigation technique and the traditional irrigation technique in MV paddy cultivation. It was observed from various studies that introduction of technology has significantly enhanced land productivity (Balakrishna 2012, Kiresur and Manjunath 2011). It is expected that the AWD irrigation technique in MV paddy cultivation will result in changes in input-use pattern, which, in turn, will affect land productivity. Hence, increase in land productivity in MV paddy is not only due to adoption of the AWD irrigation technique, but also attributable to the changes in use of factors in production. The following output decomposition model was used in this study. The Cobb-Douglas production function in logarithmic form for MV boro paddy production is:

$$\ln Y = A + b_1 \ln X_1 + b_2 \ln X_2 + b_3 \ln X_3 + b_4 \ln X_4 + b_5 \ln X_5 + b_6 \ln X_6 + b_7 \ln X_7 + b_8 \ln X_8 + u_i \tag{1}$$

where,

Y = Output in kg/ha,

X_1 = Seeds (kg/ha)

X_2 = Land preparation cost (taka/ha)

X_3 = Irrigation cost (taka/ha)

X_4 = Cost of pesticides (taka/ha)

X_5 = Urea (kg/ha)

X_6 = Cost of other fertilisers (taka/ha)

X7= Manure (mound/ha)

X_8 = Human labour (man-day/ha)

U = Error term

The difference in the natural logarithms of MV paddy output between the methods AWD irrigation technique and traditional irrigation technique may be written as:

$$[\ln Y_{AWD} - \ln Y_{TIS} = [\ln A_{AWD} - \ln A_{TIS}] + \sum_{i=1}^{7}[b_{AWD} \ln X_{AWD} - b_{TIS} \ln X_{TIS}] \quad (2)$$

where "AWD" and "TIS" represent the production functions of MV paddy under the methods of AWD irrigation technique and traditional irrigation technique in MV paddy production respectively.

Adding and subtracting $\sum_{i=1}^{7} b_{AWD_i} \ln X_{TIS_i}$ in the above equation and rearranging the terms yields the following decomposition model:

$$[\ln Y_{AWD} - \ln Y_{TIS}] = [\ln A_{AWD} - \ln A_{TIS}] + \sum_{i=1}^{7}[b_{AWD} - b_{TIS}] \ln X_{TIS} +$$

$$\sum_{i=1}^{7} b_{AWD}[\ln X_{AWD} - \ln X_{TIS}] \quad (3)$$

The above model involved in decomposing the logarithmic ratio of per hectare productivity of MV paddy under the methods of AWD irrigation (new irrigation system) and traditional irrigation techniques (previous irrigation practice). This is approximately a measure of percentage change in per hectare output between the two methods – AWD and the traditional irrigation technique. The left hand side of equation (3) indicates the difference in the per hectare productivity of MV paddy production in the method of the application of AWD irrigation technique and traditional irrigation technique, while the right hand side decomposes the difference in productivity into changes due to technology as well as input use.

The first bracketed expression on the right hand side is a measure of percentage change in output due to a shift in the scale parameter of the production function (neutral technology). The second bracketed expression is the difference between output elasticities each weighted by natural logarithms of the volume of that input used under the traditional irrigation technique; which is a measure of change in output due to shift in slope parameters (output elasticities) of the production function (non-neutral technology). The third bracketed expression is the natural logarithms of the ratio of each input of AWD irrigation technique to traditional irrigation system, each weighted by output elasticity of that input. This expression is a measure of change in output due to differences in the per hectare quantities of inputs used and the given output elasticity of these inputs under the method of the application of AWD irrigation technology in MV paddy cultivation.

To examine whether the parameters of the production function defining the two techniques of MV paddy production are different, which is an essential component of decomposition analysis, intercept and slope dummies will be introduced into the log linear production function. This is illustrated as follows:

$$\ln Y = \ln A + b_1 \ln X_1 + b_2 \ln X_2 + b_3 \ln X_3 + b_4 \ln X_4 + b_5 \ln X_5 + b_6 \ln X_6 + cD + d_1[D_1 \ln X_1] + d_2[D_2 \ln X_2] + d_3[D_3 \ln X_3] + d_4[D_4 \ln X_4] + d_5[D_5 \ln X_5] + d_6[D_6 \ln X_6] + d_7[D_7 \ln X_7] + u_i$$

=Intercept dummy which takes value '1' if it is the method of AWD irrigation technique in MV paddy cultivation and value '0' otherwise.

$D_1 \ln X_1$, $D_2 \ln X_2$, $D_3 \ln X_3$, $D_4 \ln X_4$, $D_5 \ln X_5$, $D_6 \ln X_6$ and $D_7 \ln X_7$ are slope dummies of X_1, X_2, X_3, X_4, X_5, X_6 and X_7 respectively taking value '1' if it is the method of AWD irrigation technique in MV paddy cultivation and value '0' otherwise.

2.4 Conceptual Framework of the Study

AWD and traditional irrigation systems are commonly used in MV paddy production in South western Bangladesh. The present study considers the impacts of agricultural technological change on ground water irrigation input use in MV paddy production as well as land productivity. The new AWD irrigation technology improves crop yield using less inputs, especially for irrigation that has direct impact on fertilisers. The present study considers only the application of irrigation for MV paddy production between two farming systems. The hypothetical yield curves of two existed MV paddy production under AWD and traditional irrigation in MV paddy farming system in Bangladesh are depicted in Figure 1.

Figure 1: Hypothetical Yield Curves of Modern Variety (MV) of Paddy under AWD Irrigation Technique and Traditional Irrigation Technique in MV Paddy Farming Systems in Bangladesh

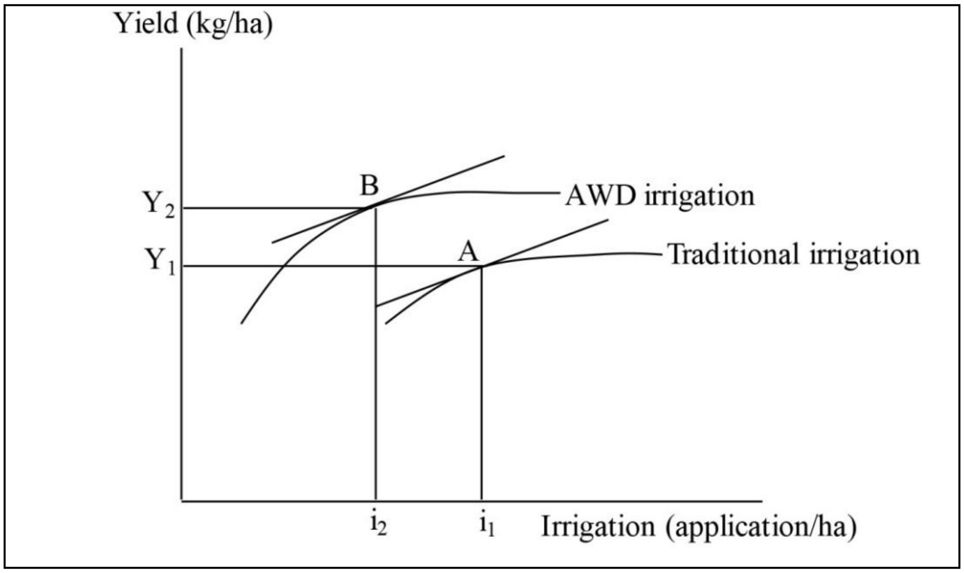

Figure 1 shows that MV paddy farming yield curve under AWD farming system shifts upward from traditional irrigation system for MV paddy farming mainly because of technological progress. Due to the advent of new technically progressed AWD farming system, farmers could be able to produce more paddy grain from per unit of farm land compared to traditional irrigation of paddy farming using the same amount of ground water irrigation. The main reason is that the paddy plants are able to receive optimal water from 15-20 cm depth of the top soils for survival. The farmers usually overflow the paddy field during irrigation period and this water is not fully absorbed by the paddy plants. A large portion of irrigated water to paddy field is vaporized and/or sometimes the farmers irrigate the paddy field even though there is sufficient water in topsoils. In other words, sometimes the farmers use excess or misuse ground water for MV paddy cultivation. Therefore, it can be assumed that AWD irrigation technique reduce the application of irrigation in MV paddy production. As a result, less ground water irrigation as well as chemical fertilisers is required for MV paddy production under AWD irrigation technique. Under the traditional irrigation farming system, Y1 amount of paddy could be produced using i1 amount of irrigation, whereas Y2 amount of paddy can be produced using i2 amount of irrigation under AWD irrigation technique. Now one of the most popular MV varieties of paddy named BR28 is being produced in the study villages. Along with BR28 paddy, some other varieties are also being produced in the study village and yield is almost the same like BR28 MV paddy. Thus it is assumed that the yield of the variety is almost same at the best production environments in the study villages.

III. BRIEF PROFILES OF THE STUDY VILLAGES/AREAS

3.1 Characteristics of Sampled Farmers

Application of AWD irrigation technique in MV paddy cultivation is a newly adopted technology in Bangladesh. This method is only applicable in MV paddy cultivation for farmers who transplant seedling in line by line in paddy fields. At an early stage, most of the farmers in the study villages are not aware about the application of AWD irrigation technique in MV paddy cultivation. Since the farmers lacked the basic knowledge about this particular method in MV paddy cultivation, they experimented initially on the basis of trial and error on a part of their total cultivable land. However, the farmers were satisfied with the improvement in their yield.

3.2 MV Paddy Production Systems in Bangladesh

Currently, three different types of paddy are being produced in Bangladesh in three distinct seasons: aus (April to August), transplanting aman (T. aman) (August to December), and boro (January to April). Among them, aus and T. aman paddy are produced in rain-drenched water and MV boro paddy is produced in irrigated water (ground water or surface water from rivers and canals). Modern varieties of paddy were introduced in Bangladesh for the boro and aus season in 1967 and aman season in 1970 (Hossain, Gascon and Marciano 2000). In 2011, only 46 per cent of the area was irrigated under MV paddy production in Bangladesh (BBS 2011). Irrigation and chemical fertilisers are not used for local aus and T. aman paddy production because the paddy fields are flooded under water. Farmers plant MV boro paddy from mid-January to mid-February and harvest from mid-April to mid-May. Furthermore, farmers usually use chemical fertilisers, pesticides and irrigation for boro paddy production. Along with paddy crops, farmers also cultivate oil seeds, potatoes and other vegetables in comparatively higher elevated land during the winter season.

3.3 Awareness of the Concept of AWD Irrigation Techniques

The Alternate Wetting and Drying (AWD) is a modern, water-saving technology that farmers normally apply to reduce water usage in irrigated paddy fields in modern varieties (MV) of boro paddy cultivation. This water saving method was developed by International Rice Research Institute (IRRI) and adopted by Bangladesh Rice Research Institute (BRRI). From its inception, this water-saving technology has been widely adopted in China. After the successful results of AWD method in MV and HYV paddy cultivation in China, it has been highly recommended for practice in MV paddy cultivation in Northern India and Philippines.

AWD is a single device that has been used to observe the water level in paddy field for deciding the frequency and time of irrigation. The field water tube can be made up of 30 cm long plastic pipe or bamboo and have a diameter of 10 cm or more so that the water table is easily visible. Additionally, the tube is perforated with many holes on all sides, so that water can flow easily in and out of the tube. AWD can be started a few weeks (normally 1-2 weeks) after transplanting of seedling of paddy in rice field. In AWD, irrigation water is applied a few days after the disappearance of the ponded water. As a result, the field is alternatively flooded and non-flooded. After the irrigation, the water depth will gradually decrease. When the water level has dropped to about 15 cm below surface level of soil, irrigation should be applied to re-flood the field to a depth of about 5 cm. The paddy field should be kept flooded, topping up to a depth of 5 cm as it is a pre-requisite prior to one week required for flowering. After flowering, during grain filling and ripening, water levels can be allowed to drop again to 15 cm below the soil surface before re-irrigation. The number of days of non-flooded soil between irrigations can fluctuate from 1 to more than 10 days depending on a number of factors such as soil type, weather and crop growth stage.

IV. RESULTS AND DISCUSSIONS

4.1 Inputs used in MV Paddy Production

Ever since the Green Revolution, seeds, irrigation, chemical fertiliser, pesticides, manure and land preparation equipment are the main inputs of MV paddy production. As most of the agricultural cultivable land has already been used for crop cultivation, mainly in MV paddy production, farmers are trying to increase the maximum level of output through trial and error experimenting with available scarce inputs and technologies already adopted in MV paddy cultivation in Bangladesh. Recently the farmers are using AWD as one of the major inputs instead of the traditional irrigation technique, for MV paddy production in some parts of Bangladesh. As the present study attempts to estimate the impacts of AWD irrigation technique in MV boro paddy production, the comparison between main inputs used in MV boro paddy production under the two production practices that used AWD and traditional irrigation techniques in Bangladesh is made in this section.

4.1.1 Chemical Fertiliser and Manure

Farmers use various types of chemical fertilisers and manure to enhance the soil fertility that assists in producing maximum rice yield. The farmers' practice of inorganic fertiliser management varied widely across and within the villages. So did the cropping patterns and soil textures across seasons and geographical areas. Chemical fertilisers such as urea, triple super phosphate (TSP), murate of potash (MP), gypsum and zinc sulfate are commonly used in MV paddy production in Bangladesh. The main inputs used in MV boro paddy production under both practices (AWD irrigation technique and traditional irrigation technique) are presented in Table I.

Table I shows that on an average, the farmers used about 323.1 kg and 341.5 kg of urea in MV boro paddy cultivation per hectare under AWD irrigation and traditional irrigation techniques respectively. In other words, the farmers used slightly less urea per hectare in AWD irrigation technique in comparison to traditional irrigation practice in MV boro paddy cultivation. The sampled farmers also used a comparatively less amount of Murate of Potash (MP) (106.2 kg/ha) and Gypsum (111.3 kg/ha) per hectare in MV boro paddy production under AWD irrigation technique compared to traditional irrigation technique (120.8 kg of MP and 137.3 kg of Gypsum). However, the sampled farmers used other chemical fertilisers such as Triple Super Phosphate (TSP) and manure in similar proportions. The amount of chemical fertiliser and manure used in paddy production per hectare also varied significantly within the same farming system.

TABLE I

INPUTS USED IN PER HECTARE MV BORO PADDY PRODUCTION UNDER TWO PRACTICES

Particulars	AWD irrigation (a)	Traditional irrigation (b)	Ratio (a/b)
A. Inputs used in MV paddy production			
(i) Seed (kg)	33.7	31.0	1.09
Chemical fertiliser			
(ii) Urea (kg)	323.1	341.5	0.95
(iii) TSP (kg)	157.1	156.3	1.00
(iv) MP (kg)	106.2	120.8	0.88

(Contd. Table I)

Particulars	AWD irrigation (a)	Traditional irrigation (b)	Ratio (a/b)
(v) Gypsum (kg)	111.3	137.3	0.81
(vi) Zinc (kg)	10.0	11.2	0.90
Organic fertilser			
(vii) Manure (mound)	188.6	191.9	0.98
Hired labour			
(viii) Hired male labour (man-day)	159.0	156.0	1.02
(ix) Hired female labour (man-day)	20.0	18.0	1.11
Family labour			
(xi) Family male labour (man-day)	20.0	20.0	1.00
(xi) Family female labour (man-day)	25.0	29.0	0.86
B. Boro paddy production (kg)	7031.5	6577.9	1.07

Source: Field Survey, 2015.

Notes: (i) Average farm size was 0.37 ha and 0.78 ha for AWD and traditional irrigation users of MV paddy production respectively.
(ii) 1US$=80.60 Taka, May, 2016.

4.1.2 Labour Input

The utilisation of labour in agricultural sectors depends on many factors, such as cropping patterns, cropping intensity, irrigation, and other intensive agricultural activities (Suryawanshi and Kapase 1985). The Green Revolution has changed agricultural land and labour productivity, and considerably impacted labour demand and/or employment in developing countries. Moreover, the adoption of new technology has substantially increased total agricultural employment and has significantly contributed to household income by increasing labour demand in developing countries (Estudillo and Otsuka 1999). The diffusion of modern technology has increased the size of the labour market by increasing the demand for hired labour in Bangladesh (Hossain, Quasem, Akash and Jabber 1990). However, Alauddin and Tisdell (1995) argued that modern agricultural technology increased labour demand four-fold from the 1960s to the 1980s in the dry season, but the labour demand was stagnant in the wet season. The employment-generating effects of modern agricultural technology have slowed down in recent years in Bangladesh. The Green Revolution has increased labour absorption at its early stage, but this factor later decreased in most developing countries after the adoption of the new labour-saving chemical and mechanical innovations (Jayasuriya and Chand 1986).

The temporarily hired and family (male and female) labour used in MV boro paddy cultivation is also presented in Table I. The table shows that the sampled farmers in this study used temporarily hired and family male labour in similar proportions for MV boro paddy cultivation per hectare.

4.2 Yield of MV Paddy Production

The yield in the production of MV boro paddy under the irrigation tecniques is also shown in Table I. It appears from the table that per hectare yield of MV boro paddy production under AWD irrigation technique (about 7.0 ton/ha) was significantly higher than the technique of traditional irrigation (about 6.6 ton/ha). It is interesting to note that yield production per hectare varied significantly within and between the two practicing methods in the study village.

4.3 Cost and Return of MV Boro Paddy Production

The cost of and returns from MV boro paddy production using the technically advanced AWD irrigation technique and traditional irrigation technique are discussed below.

4.3.1 Per Hectare Cost of MV Boro Paddy

The cost of items associated with the MV paddy cultivation includes the cost of seeds, irrigation, pesticides, land preparation (bullock and power tiller), hired labour, chemical fertilisers and manure. The gross return from MV paddy farming includes revenue from paddy and by-product straw. The total cost includes associated variable costs and fixed costs. The opportunity costs of home supplied seeds, family supplied labours (both male and female) and self-owned land was calculated based on the current market price in the locality.

The per hectare costs, gross revenue and profit of MV boro paddy farming are presented in Table II. The table shows that per hectare production cost of MV boro paddy cultivation was almost the same in both practices but the cost of irrigation, pesticides, urea, MP, Gypsum, hired male labour and opportunity cost of family labour were different. The main reason for this was that comparatively less number of applications of irrigation is required in MV boro paddy cultivation using AWD irrigation technique compared to the traditional irrigation technique in the study village. So, the cost of irrigation was less by applying AWD irrigation. The table shows that the cost of irrigation per hectare of MV boro paddy production was about 30 per cent less in AWD than the traditional irrigation technique. Another reason may be that in AWD irrigation technique of

MV boro paddy cultivation, the soils of paddy field become relatively dry than the clay paddy field. As a result, the applied chemical fertilisers comparatively stay for a prolonged period in the paddy fields under AWD irrigation techniques than the traditional irrigation practices. In general, insects prefer water-full or clay-soiled paddy fields for survival. Therefore, it is assumed that based on this hypothetical concept, farmers used comparatively less amount of chemical fertilisers and pesticides in MV boro paddy production using the modern method of AWD irrigation technique than its traditional counterpart. Table II shows that the costs of pesticides, urea, MP and Zinc were about 12 per cent, 5 per cent, 12 per cent, and 18 per cent less in per hectare MV boro cultivation under the AWD technique in the study village respectively. With exception to hired female labour, the sampled farmers used slightly more temporary hired and family male labour in per hectare MV boro paddy production under AWD irrigation technique than under traditional irrigation technique.

TABLE II
COSTS AND RETURNS OF PER HECTARE BORO PADDY PRODUCTION UNDER TWO PRACTICES

Particulars	AWD irrigation (Taka)	Traditional irrigation (Taka)	Ratio
A. Variable costs of MV paddy production			
(i) Seedling cost	1581.7	1550.4	1.02
(ii) Irrigation cost	15888.6	22579.6	0.70
(iii) Pesticides cost	4229.0	4810.6	0.88
(iv) Land preparation cost	5267.2	5175.2	1.02
Chemical fertiliser			
(v) Urea	5168.4	5464.4	0.95
(vi) TSP	3455.7	3439.2	1.00
(vii) MP	1380.3	1570.7	0.88
(viii) Gypsum	674.9	823.8	0.82
(ix) Zinc	1820.7	1951.7	0.93
Organic fertiliser			
(x) Manure	2322.8	2256.7	1.03

(Contd. Table II)

Particulars	AWD irrigation (Taka)	Traditional irrigation (Taka)	Ratio
Labours			
(xi) Hired male labor	44716.6	39293.9	1.14
(xii) Hired female labor	3835.1	3948.8	0.97
B. Opportunity cost/Fixed cost			
(xiii) Family male labor	5966.5	4943.2	1.21
(xiv) Family female labor	4811.7	4716.0	1.02
(xv) Opportunity cost of land	25,000.0	25,000.0	1.00
C. Total costs (variable and fixed costs) (A+B)	126,119	127,524	0.99
Revenue from paddy production			
(i) Paddy	137595.3	119531.9	1.15
(ii) By-product of paddy	13667.9	13780.1	0.99
D. Total revenue (i)+(ii)	151,1263	133,312	1.13
E. Net profit (D-C)	25,144	5,788	4.34
F. Benefit cost ratio (BCR)	1.20	1.05	1.15

Source: Field Survey, 2015.
Notes: (i) Average farm size was 0.37 ha and 0.78 ha for AWD and traditional irrigation producers of MV paddy production.
(ii) 1US$=80.60 Taka, May, 2016.

4.3.2 Per Hectare Return of MV Boro Paddy

Gross revenue is calculated by multiplying the total volume of production of enterprises with the farm-gate price. Net profit is calculated by subtracting total production cost (fixed and variable costs) from gross revenue. As mentioned earlier that, on average, per hectare production and revenue of MV boro paddy was higher applying the AWD irrigation compared to the traditional irrigation method (Table III). As average total cost of per hectare boro paddy production was almost the same for the two adopted practices, net profit of per hectare MV boro paddy was also higher (4.34 times) in the method of application of AWD irrigation compared to the traditional irrigation technique. As a result, benefit cost ratio (BCR) of per hectare MV boro paddy production was about 1.15 times higher in AWD irrigation technique than in traditional irrigation. Therefore, it may be concluded that MV boro paddy cultivation is more profitable under technologically advanced AWD irrigation technique. Moreover, AWD irrigation is a water-saving irrigation technique in comparison to traditional irrigation technique for MV paddy cultivation in the study village.

4.4 Efficiency Measure and Resource Use Efficiency of MV Boro Paddy Production

The estimation of the efficiency measures and resource use efficiency of MV boro production under the method of application of AWD irrigation technique and the traditional irrigation technique in the Cobb-Douglas production function is briefly discussed in this section.

4.4.1 Summary Statistics of Inputs and Output of Cobb-Douglas Model

The descriptive statistics of value of the key variables (in the Cobb-Douglas production function are presented in Table III. The inputs and outputs of MV paddy production under the practices of AWD irrigation technique and traditional irrigation technique were calculated in terms of monetary units instead of physical units mainly because the present study estimates the resource use efficiency based on the coefficients of Cobb-Douglas production function.

TABLE III

SUMMARY STATISTICS OF THE SAMPLED VARIABLES IN PER HECTARE MV BORO PRODUCTION UNDER TWO PRACTICES IN JESSORE DISTRICT

Name of variables	AWD Irrigation method				Traditional irrigation method			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Paddy grain (kg) (Y)	7337.30***	246.4	6886.1	7784.2	6422.86***	258.5	5987.9	7035.8
Seed (kg)(X_1)	36.68***	5.3	26.2	48.7	35.73***	4.0	29.9	44.9
Land preparation (taka) (X_2)	5267.20***	417.3	4528.3	5950.5	5175.23***	421.4	4490.9	6062.7
Irrigation cost (taka) (X_3)	15044.45***	1463.4	10250.1	18562.4	22579.64***	20602.0	17140.3	191986.4
Pesticide cost (taka) (X_4)	4228.95***	563.5	2245.5	5987.9	4810.62***	572.1	3742.4	5838.2
Urea (Kg) (X_5)	323.02***	50.3	224.5	449.1	341.52***	30.1	284.4	411.7
Other fertiliser (taka) (X_6)	7324.48***	832.4	5054.1	10104.6	7785.36***	1177.9	5445.1	10213.1
Manure (mound) (X_7)	188.58***	21.4	149.7	232.0	191.94***	31.2	89.8	247.0
Labour (man-day) (X_8)	201.04***	34.4	142.5	286.0	210.09***	27.0	149.5	266.3

Source: Author’s calculation.

Notes: (i) The figures in parentheses indicate the information of MV boro paddy production.

(ii) Sample size of both MV boro paddy productions was 70.

(iii) *** denotes significant at 1% level.

The table reveals that considerable variation exists among the farmers in terms of production practices. The input and output data were obtained on per hectare basis in the farm survey. The average per hectare production (Y) of MV boro paddy under the technique of AWD and traditional irrigation technique was about 7,337 kg and 6,423 kg respectively, and it significantly varied among the farms.

The average use of paddy seed (X_1) per hectare for boro paddy cultivation was almost the same in both techniques and widely varied among the farms. The mean land preparation cost (X_2) of MV boro paddy cultivation was also almost the same in both techniques even though a wide variation exists among the farms; it was statistically significant at 1% level. The main reason was that the farmers almost used the same modes of cultivator (power tiller) for plowing the paddy fields.

Irrigation and pesticides are the main inputs for MV boro paddy cultivation. Cost of pesticides is an important input for MV boro paddy production. The mean irrigation cost (X_3) per hectare for MV boro paddy cultivation under the technique of AWD irrigation was significantly smaller than that under the technique of traditional irrigation and it widely varied among the farms (statistically significant at 1% level). The mean pesticide cost (X_4) per hectare for MV boro paddy production under the technique of AWD irrigation was also significantly less than that under the method of application of traditional irrigation and it significantly varied among the farms. The causes of comparatively less pesticide cost in the method of AWD irrigation have been discussed earlier.

Chemical fertilisers such as urea, TSP, MP, Gypsum and Zinc Sulfate are also important inputs of MV boro paddy production. As the present study estimates the impact of AWD irrigation technique on MV boro paddy cultivation, we have separated the cost of urea from the costs of other chemical fertilizers such as TSP, MP, Gypsum, and Zinc Sulphate because urea is the main chemical fertiliser for MV boro paddy cultivation. The mean usage of urea (X_5) was significantly smaller in MV boro paddy cultivation under the technique of AWD irrigation than that under traditional irrigation and a wide variation exists among the farms. The main reason was that a comparatively small amount of urea is required to produce MV boro paddy cultivation under the technique of AWD irrigation. The mean cost of other fertilisers (X_6) was also smaller in MV boro paddy cultivation under the method of AWD irrigation technique than that under traditional irrigation technique and widely varied among the farms in both irrigation techniques, which was statistically significant at 1% level.

The mean manure cost (X_7) of MV boro paddy cultivation was almost the same under both techniques even though a wide variation exists among the farms; this was statistically significant at 1% level. The average number of human labour (X_8) per hectare for MV boro paddy production under the practice of AWD irrigation technique was also relatively smaller and was statistically significant at 1% level.

4.5 Productivity and Decomposition Analysis

In order to test the difference in the structural relationship in the parameters defining the production functions for the two methods, the log-linear Cobb-Douglas production with both intercept and slope dummies was estimated using the ordinary least square (OLS) method. The empirical results of the Cobb-Douglas production function of MV boro paddy cultivation under the application of AWD and traditional irrigation techniques are presented in Table IV. The estimated production function explained about 84 per cent of the variation in MV boro paddy output due to variation in all the resources put together and reflected a good fit of the model. The intercept dummy and slope dummies of pesticides, irrigation and urea were significantly different from zero, indicating that the production parameters of pesticides, irrigation and fertiliser urea in AWD irrigation technique and traditional irrigation technique in MV boro paddy production were not the same. However, although all other parameters were also not the same in the two production functions, they were not statistically significant. The positive estimate of intercept dummy implied that the output of the method of the application of AWD irrigation technique was significantly higher than that in the traditional irrigation technique for a given level of resources. Table IV also shows that the elasticity coefficients of the production with respect to each input under the method of AWD irrigation technique were comparatively higher than those of the traditional irrigation technique for a given level of resources in MV boro paddy production.

For decomposing the productivity difference between the method of the application of AWD irrigation technique and traditional irrigation technique in MV boro paddy cultivation, the parameters of the per hectare production functions and the mean levels of input use for the two methods were also estimated separately. The estimates provided in Table IV shows that 76 and 74 percent of variation in paddy output, respectively in the AWD irrigation technique and traditional irrigation technique, were explained by the independent variables. The intercept term in the case of AWD irrigation technique was significantly higher than that for the traditional irrigation technique in MV boro paddy cultivation. This virtually signified that there was an upward shift in the production function due to technological advancement and this change was associated with AWD irrigation technique in MV boro paddy cultivation. The production elasticity coefficient of irrigation was negative (-0.041) for MV boro paddy production under the AWD irrigation technique and was statistically significant at 1% level. On the other hand, it was positive (0.053) and was also statistically significant at 1% level for MV boro paddy cultivation in the latter technique. This indicates that farmers used excess irrigation in per hectare MV boro paddy production under AWD irrigation technique, whereas the farmers had an opportunity to use more irrigation under traditional irrigation technique. In other words, the farmers have an opportunity to produce the same amount of MV boro paddy using less irrigation under AWD irrigation technique compared to the traditional irrigation technique in the study area.

TABLE IV

ESTIMATED PRODUCTION FUNCTIONS OF MV BORO PADDY WITH INTERCEPT AND SLOPE DUMMIES

Particulars	Production elasticity		
	Pooled	AWD irrigation	Traditional irrigation
Intercept	8.237***	9.755***	8.231***
	(0.868)	(0.804)	(0.959)
Seeds (taka)	0.114**	0.151**	0.123**
	(0.093)	(0.081)	(0.033)
Land preparation (taka)	-0.028**	0.034	0.033
	(0.016)	(0.068)	(0.040)
Irrigation (taka)	-0.0305***	-0.041***	0.031**
	(0.0145)	(0.016)	(0.022)
Pesticides (taka)	-0.075**	0.098*	0.077**
	(0.037)	(0.0114)	(0.012)
Urea (kg)	0.068*	-0.62***	0.083***
	(0.039)	(0.124)	(0.013)
Other fertiliser cost (taka)	0.142	0.115	0.105
	(0.029)	(0.095)	(0.912)
Manure (maund)	0.045	0.058*	0.047
	(0.035)	(0.031)	(0.041)
Labour (man-day)	-0.0367	-0.025	-0.034
	(0.0337)	(0.0342)	(0.051)

(Contd. Table IV)

Particulars	Production elasticity		
	Pooled	AWD irrigation	Traditional irrigation
Dummy			
Intercept	1.424***		
	(0.410)		
Seeds (taka)	0.0232		
	(0.056)		
Land Preparation (taka)	-0.011		
	(0.048**)		
Pesticides (taka)	0.048**		
	(0.023)		
Irrigation (taka)	0.053***		
	(0.024)		
Urea (kg)	0.046**		
	(0.023)		
Other fertiliser cost (taka)	-0.042		
	(0.038)		
Manure (maund)	0.038		
	(0.025)		
Labour (man-day)	0.120		
	(0.057)		
R^2	0.84	0.76	0.74
F-value	71.16***	38.56***	34.16***

Notes : (i) Figures in parentheses are standard errors.
(ii) ***, ** and * indicate significant at 1%, 5% and 10% respectively.

The production elasticity coefficients of seed were positive and statistically significant at 5% level for both in AWD irrigation technique and traditional irrigation technique in MV paddy production. On the other hand, the production elasticity coefficient of urea was negative (-0.62) (statistically significant at 1% level) in AWD irrigation technique, whereas it was positive (0.083) (statistically significant at 1% level) in traditional irrigation technique in MV boro paddy cultivation. This implied that the farmers used excess urea in per hectare MV boro paddy production in AWD irrigation cultivation, whereas the farmers could produce more MV paddy using more urea under traditional irrigation technique. The production coefficient of manure was positive (0.058) and was statistically significant at 10% level, indicating that the farmers could produce/ more MV boro paddy using more manure in AWD irrigation technique. The production coefficients of labour were negative and were not statistically significant for MV paddy production under both irrigation techniques, indicating that the sampled farmers used slightly higher labour in per hectare MV paddy production in the study village. The major contribution to output came from the combined effects of urea and irrigation for AWD irrigation technique in MV boro paddy production.

4.6 Intensification of Resource Use Efficiency of MV Paddy Production

The marginal value products (MVPs) of various inputs were estimated at the geometric mean (GM) levels for AWD and traditional irrigation techniques in MV boro paddy cultivation with comparison to their respective prices. Marginal factor cost (MFC) of all inputs is expressed in terms of an additional Bangladeshi taka (BDT) spent for providing individual inputs using a Cobb-Douglas production. The MVP and the ratio of MVP to MFC of MV boro paddy cultivation under the method of application of AWD irrigation and the traditional irrigation are presented in Table V. The figures in Table V show that none of the ratio of MVPs of inputs to MFC was equal to one, indicating that the sampled farmers in the study area failed to show their efficiency in using the resources under both the AWD and traditional irrigation techniques for cultivating MV boro paddy.

The MVP and MFC ratio of seed costs of MV boro paddy production were 30.205 and 22.110 in AWD irrigation technique and traditional irrigation technique respectively, which was positive and greater than unity (significant at 5% level), indicating that the farmers did not utilise efficiently the inputs in MV boro paddy cultivation under both the irrigation techniques in the study area. So, there was an opportunity for the farmers to increase production by using seed input. The MVP and MFC ratio for urea (-14.083) (significant at 1% level) were negative and greater than one, which indicates that the farmer who used AWD irrigation technique applied significantly excessive urea for MV boro paddy cultivation in the short-run, keeping the use of other resources at a constant level. In the case of farmers who used the traditional irrigation technique, the ratio of MVP to MFC for urea (1.561) was positive and greater than unity which indicates that the farmers did not utilise the opportunity of fully optimising the inputs in MV boro paddy cultivation. So, there was an opportunity for the farmers to increase production by using more urea. Nevertheless, MVP-MFC ratios for land preparation cost, pesticide cost and other fertilisers' cost were positive and less than one, indicating that profit could have been maximised in the short-run by using less quantity of these resources for MV boro paddy cultivation by those farmers who used AWD irrigation technique. Similar conclusions could also be made in MV boro cultivation for those who used the traditional irrigation technique.

The MVP to MFC ratios of irrigation (-0.019) and labour cost (-0.912) were negative, but less than unity for the farmers who used AWD irrigation technique for MV boro paddy cultivation. This implied that the farmers had no opportunity to reduce these inputs to maintain the same level of MV boro paddy production. On the other hand, the ratios for irrigation (0.020) were positive and less than one, while the ratios for labour (-1.039) were negative and greater than unity for those adopting the traditional irrigation technique. Interestingly, this indicates that farmers who used the traditional irrigation technique used excessive labour per hectare for MV boro paddy cultivation, however, had no opportunity to reduce irrigation to maintain the same level of MV paddy. Therefore, it may be concluded that the farmers did not efficiently use the input resources in both the AWD and traditional irrigation techniques in MV boro paddy cultivation. This hindered the achievement of maximum level of output of paddy in the study area.

TABLE V

RESOURCE USE EFFICIENCY IN COBB-DOUGLAS PRODUCTION FOR BOTH AWD AND TRADITIONAL IRRIGATION TECHNIQUES USED IN BORO PADDY CULTIVATION

Name of variables	AWD Irrigation Method			Traditional Irrigation Method		
	Coefficients	MPV	MVP/MFC	Coefficients	MPV	MVP/MFC
Seed (X_1)	0.151**	30.205	30.205	0.123**	22.110	22.110
Land preparation cost (X_2)	0.034	0.047	0.047	0.033	0.041	0.041
Irrigation cost (X_3)	-0.041***	-0.019	-0.019	0.070**	0.020	0.020
Pesticide cost (X_4)	0.097*	0.168	0.168	0.077**	0.103	0.103
Urea (X_5)	-0.62***	-14.083	-14.083	0.083***	1.561	1.561
Other fertiliser cost (X_6)	0.115	0.115	0.115	0.105	0.087	0.087
Mathure (X_7)	0.058*	2.256	2.256	0.047	1.572	1.572
Labour (X_8)	-0.025	-0.912	-0.912	-0.034	-1.039	-1.039

Source: Author’s calculation.
Notes: (i) MVP=Marginal value product, MFC=Marginal factor cost.
(ii) ***, ** and * indicate statistically significant at 1%, 5% and 10% respectively

4.7 Productivity Difference Analysis

Using the decomposition model, the productivity difference between the AWD irrigation technique and the traditional irrigation technique was decomposed into its constituent sources and the results are presented in Table VI. The results of the decomposition analysis revealed that there was not much discrepancy between the observed difference and the estimated difference for MV boro (14.14% and 13.33%) both under the AWD irrigation and traditional irrigation methods respectively. It can further be inferred that technological and input use differentials together contributed to the total productivity difference of the order of 14.14 per cent and 10.12 per cent for MV boro paddy. This implied that MV boro paddy productivity could be increased by 10.12 per cent if the farmers could use technologically advanced irrigation technique instead of traditional irrigation technique along with the same level of resource use in MV boro paddy cultivation. An increase in productivity exclusively from technological improvement is brought about through a shift in the scale and/or slope parameters of the production function.

The contributions of differences in inputs use between the method of the AWD irrigation and traditional irrigation in MV boro paddy cultivation to the productivity difference were estimated to be only 5.56 per cent. The larger quantity of irrigation, pesticides and urea used in MV boro paddy under the method of the AWD irrigation has helped to increased yield of paddy by 4.26 per cent, 1.21 per cent and 8.34 per cent; this was realised by not applying the traditional irrigation method for MV boro paddy cultivation. This implied that the farmers who used the technologically advanced AWD irrigation technique instead of traditional irrigation technique in MV boro paddy cultivation obtained higher output by spending slightly more on these inputs under the same production environment in the particular study area.

TABLE VI

DECOMPOSITION OF OUTPUT DIFFERENCE BETWEEN THE METHOD OF AWD AND TRADITIONAL IRRIGATION METHODS IN MV PADDY CULTIVATION

Source of difference	Boro paddy cultivation (Per cent contribution)
Observed difference in output [$\ln Y_{AWD}$-$\ln Y_{TIS}$	14.14
Source of contribution	
Due to difference in technology	10.12
Due to difference in input use	
Seed (X_1)	2.15
Land preparation cost (X_2)	0.65
Irrigation cost (X_3)	-4.26
Pesticide cost (X_4)	-1.21
Urea (X_5)	-8.34
Other fertiliser cost (X_6)	1.76
Mathure (X_7)	1.35
Labour (X_8)	2.16
Due to all inputs	5.56
Estimated difference in output	13.33

Source: Author’s calculation.

V. CONCLUSIONS

Rice is the main staple food in Bangladesh. The government of Bangladesh has been trying to achieve food self-sufficiency by utilising the scarce input resources efficiently and optimally within production processes from our limited land resources to match the growing food demand which results from population growth. In an effort to devise feasible solutions, farmers are experimenting with different combinations of inputs through extensive trial and error to find an optimal threshold to achieve input efficiency in paddy cultivation. As a result, the AWD irrigation technique is one such method that is recently being used for MV paddy cultivation in Bangladesh.

The findings of the study indicated that the farmers used fewer amounts of chemical fertilisers per hectare MV paddy cultivation (with the exception of TSP) such as urea (about 5 per cent), MP (about 12 per cent), Gypsum (about 19 per cent) and Zinc (about 10 per cent) in AWD irrigation technique in comparison to the traditional irrigation technique, which are the main inputs for MV boro paddy cultivation. However, Triple Super Phosphate (TSP) was used in almost similar proportions. The amount of chemical fertilisers used in per hectare of MV boro paddy cultivation also varied significantly within the same farming system. The farmers that adopted the AWD irrigation instead of the traditional irrigation technique used comparatively more temporarily hired female and fewer family-supplied female labours per hectare of MV boro paddy cultivation. However, the farmers used similar proportions of hired male and female labour per hectare for MV boro paddy cultivation under both irrigation techniques.

Per hectare production costs of MV boro paddy cultivation were almost similar in both irrigation techniques. In addition, the realised yield of MV boro paddy was significantly higher in farms that used AWD irrigation technique instead of traditional irrigation technique. This confirms the fact that revenue as well as net profit was also higher for the farmers who used the technologically-advanced AWD irrigation technique instead of traditional irrigation technique in the study area.

The results of the Cobb-Douglas production function show that irrigation and urea in AWD irrigation technique had a significant negative impact on MV boro paddy, while the traditional irrigation method posed a positive significant impact. These results indicated that the farmers could produce the same level of output from MV boro paddy cultivation using comparatively fewer applications of AWD irrigation and urea, which is unattainable using the traditional irrigation technique in the study area.

The results of the ratios of MVP to MFC showed that none of the marginal value products (MVPs) of inputs were equal marginal factor costs (MFC), indicating that the farmers did not optimally use the input resources in both methods of AWD irrigation and the traditional irrigation techniques in MV boro paddy cultivation. This hindered the maximum level of output of paddy grain in the study area from being attained. The technological changes in MV boro paddy have brought about 14.14 per cent productivity differences between the AWD irrigation technique and the traditional irrigation technique. The major component of this productivity difference was due to the AWD irrigation technique in MV boro paddy cultivation, which contributed to 10.12%. The remaining 4.02 per cent difference in output for MV boro paddy was due to difference in quantities of inputs used in the study area. Therefore, it may be concluded that the AWD irrigation technique has significant impact on MV paddy production in the study area.

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