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Greening Modern Rice Farming Using Vermicompost and Its Impact on Productivity and Efficiency: An Empirical Analysis from Bangladesh

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Abstract: Greening modern rice farming while improving productivity and reducing chemical use is a desirable goal for sustainable agriculture. This paper analyzes the impact of vermicomposting on productivity and efficiency of modern rice farming using a random sample of 340 farmers from the southwestern region of Bangladesh by applying a stochastic production frontier approach. Results reveal that productivity is significantly higher and the use of chemicals is significantly lower for vermicompost users as expected. However, profitability gain is not significantly different mainly due to the high cost of vermicompost. Use of vermicompost significantly increases productivity along with other conventional inputs and its users are relatively more technically efficient. Policy implications include investments to raise farmers' awareness of the benefits of vermicomposting and support entrepreneurs to expand commercial production of vermicompost, which will synergistically curb the use of chemicals in modern rice farming while improving productivity and efficiency.

Keywords: vermicomposting; rice production; stochastic production frontier; technical efficiency

1. Introduction

Increasing population pressure has forced many countries to use inorganic fertilizers, pesticides and ground water to increase crop productivity in order to meet continuously increasing food demand. The prolonged and excessive use of inorganic fertilizers, pesticides and ground water in crop production exerted severe human and soil health hazards along with environmental pollution [1,2]. Considering these human and soil health hazards, farmers in developed and underdeveloped countries are encouraged to convert their farms into organic farms [3–5].

Bangladesh is characterized by high population growth and density leading to increased demand for food and urbanization thereby placing tremendous pressure on its agricultural land. The per capita availability of agricultural land is becoming scarce and declining over time [6]. Food grain production has increased dramatically over the past decade thereby alleviating the food security crisis that encapsulated the nation since independence. For example, rice production increased by 73.81% from 28.18 million metric ton in 1996 to 48.98 million metric tons in 2017 [7].

Nevertheless, due to excessive application of chemical fertilizers, pesticides and improper soil management, soil quality in rice fields has been degraded over time in Bangladesh. Proper soil management of rice field ensures balance of soil nutrients and reduces toxicity in plants, which helps in improving crop production, environmental sustainability and human health [1,2]. Therefore, appropriate management of soil in rice fields is necessary to increase productivity of modern varieties of rice [8].

Soil degradation is a major problem in intensive agricultural production caused by imbalanced use of chemical fertilizers, limited addition of crop residues and green manure. Soil fertility also declines due to excessive pressure on land by producing the same type of crops and following the same management practices every year [9,10]. Degradation of soil fertility in Bangladesh started since the introduction of a rice-based Green Revolution during the early 1960s [11,12]. Although the introduction of high yield varieties or modern varieties (MV) of rice has increased cropping intensity from 172% in 1991 to 195% in 2017 in Bangladesh, an increase of 13% in intensity of cropping [7,13], such a high level of cropping intensity led to degradation of soil quality because the natural regeneration capacity of the soil is not appropriately replaced [14]. Yu et al. [15] noted that crop rotation practices involving legumes and jute-based cropping systems and application of manure led to depletion of organic matter (OM) in some parts of China [15]. Ali [16] concluded that prolonged cultivation of MV rice using fertilizers, chemicals and machineries during the period 1985–2000 in a village in southwestern Bangladesh led to a reduction of soil quality and degradation of land. Similar conclusions were also drawn by Ali [17]. Saleque et al. [18] noted that increased tillage reduced OM contents of topsoil in MV rice cultivation considerably, whereas OM application is needed to improve soil quality [19].

Organic farming is a production system that avoids excessive use of chemical fertilizers and pesticides in monoculture agriculture. Vermicompost is one such process that is being used in crop production in Bangladesh in recent times. Vermicomposting is a biological process using a variety of worms including earthworms to transform organic waste into natural nutrient-rich compost, which breaks down organic material through the interaction between worms and microorganisms. The final product of vermicomposting is a substance called vermicompost or worm castings [20–22]. Vermicompost is an excellent soil amendment coordinator that enhances porosity, aeration, bulk density, drainage, water-holding capacity and microbial activity of soil [23–25], improves soil fertility in continuous cropping [26], increases nitrogen uptake [27] and dry matter production in plants [28,29]. This nutrient-rich organic substance can be added to the soils to enhance organic matter content and available nutrients, soil fertility and quality [30–35]. Using earthworms to convert organic wastes is an ecologically safe method that leads to an environmentally safe product. In fact, vermicompost can enhance soil fertility physically, chemically and biologically. A number of researchers reported that the application of vermicompost in crop fields increases activity as compared to inorganic agriculture [36,37]. Vermicompost also provides macro elements, such as, nitrogen, phosphorus, potassium, calcium and manganese and microelements, such as, iron, zinc and copper [23,38]. Studies also indicated that vermicompost can retain more soil moisture and thus reduces demand for irrigation by about 30%–40% [39,40].

Sustainable agriculture improves crop production while maintains soil quality, increases soil OM and protects the environment thereby enabling availability of safe chemical-free food for the society. Depletion of soil OM degrades ecosystem services and loses ecosystem resilience. Therefore, there is a need for organic farming that is economically sustainable and a viable crop production method exerting minimum environmental pollution [41–43]. Recently there is a rising interest in using vermicompost for crop production in order to enhance soil fertility and plant growth in degraded soils, reduce negative impacts arising from a lack of soil OM, increase supply of safe food and being friendly to the environment [44–51]. However, such greening of MV rice farming using vermicompost and its impact on productivity and efficiency in rice production in Bangladesh or elsewhere has been nascent. Only recently, Barmon and Tarafder [52] conducted a research on the impact of vermicompost on MV rice cultivation and found that farmers practicing vermicomposting used less quantity of chemical fertilizers and irrigation in MV boro rice (dry winter season) production compared to farmers who did not use vermicompost. The yield and the net profit per hectare of MV boro rice were also significantly higher than farmers who did not use vermicompost. However, Barmon and Tarafder [52] used partial productivity measures (i.e., yield and/or profit per ha) and did not investigate the impact of vermicompost on productivity and efficiency while taking account of the fact that farmers can be inefficient in their production practices and resource use. Their measure of production performance is partial, i.e., yield per ha of MV rice.

Given this background, the main aim of this research is to empirically evaluate benefits of using vermicompost in MV rice production. The specific objectives are to: (a) estimate profitability of using vermicompost; (b) measure the impact of vermicompost on the productivity of MV rice and (c) measure the impact of vermicompost on production efficiency of rice producers. The findings of the present research are expected to provide useful information for the policy makers and other relevant stakeholders involved in future development of MV rice growth in Bangladesh and elsewhere.

2. Methodology

2.1. Data and Variables

Monohorpur is a typical village of Monirampur upazila (sub-district) in Jessore district located at the southwestern region of Bangladesh. The village area is 607 ha with a population of 5792. The literacy rate is relatively high at 63%. Agriculture is the main occupation and the level of adoption of MV rice technology is very high. The study area enjoys relatively good communication facilities via a highway and its socio-economic conditions are better than other nearby villages. It has one of the highest cropping intensity of 260% and is located within the Agro-ecological Zone #14 characterized by clay to loamy soil texture and high and medium high land elevation areas with respect to flooding depth.

Monohorpur village was purposively selected because majority of farmers were using vermicompost in MV rice production. First, a detailed list of vermicompost users and non-users were collected from the upazila (sub-district) agricultural office. Then a total of 155 farmers using vermicompost and another 185 farmers not applying vermicompost to produce MV rice were randomly selected. Selection of both vermicompost users and non-users from the same village has a number of advantages. This is because farmers in a single village are exposed to similar input and output prices, similar information on vermicomposting as well as belong to a similar production environment. As such, differences observed between these two categories of farmers could be confidently attributed to the use of vermicompost. Data were collected by administering a structured and pre-tested questionnaire by the co-author. Information includes details of inputs used and output produced from MV rice production. Detailed socio-economic information of the farmers was collected. The survey was conducted during 2015 by one of the authors (a sample questionnaire administered to conduct the primary survey is available online at Supplementary File S1).

2.2. Analysis of Profitability

Profitability or cost–benefit analysis refers to the calculation of production costs and returns of MV rice production from per ha of land area. The following items are included in this calculation. The total cost (TC) includes total variable costs (TVC) and total fixed costs (TFC). TVC includes costs incurred for using human labor, mechanical power, seed, manure, chemical fertilizers, pesticides and irrigation. The amount of labor used in the production process includes family supplied as well as hired labor. The cost of labor supplied by the family is calculated by imputing market wage for hired labor in the area. TFC includes land rent and interest on operating capital. Cost of the use of owned land was calculated by imputing the market rate of land rent. The gross return (GR) is calculated by multiplying total rice produced by the market price of rice. Profit or gross margin (GM) is defined as GR–TVC. Net return (NR) is defined as GR–TC. Finally, the benefit cost ratio (BCR) is defined as GR/TC.

2.3. Statistical Tests

In order to identify differences with respect a range of socio-economic characteristics and production inputs and outputs, means comparison tests were conducted between vermicompost users and non-users. The standard *t*-test statistic was used to compare the mean difference between these two groups of farmers.

2.4. The Stochastic Production Frontier Model

A farm is said to be technically inefficient if the level of output lies below the frontier or maximum feasible output at a given level of inputs [53]. The use of the stochastic production frontier model to measure technical efficiency is a popular approach [54]. The stochastic production frontier for the *i*th farmer is written as:

$$Y_i = f(X_i) - u_i + v_i, \quad (1)$$

where

Y_i = output produced by farmer i,
X_i = vector of inputs used by farmer i in MV rice production,
v_i = two-sided random error and is assumed to be independently and identically distributed N (0, $\sigma^2 v$) and is independent of the u_i,
u_i = non-negative random variable $(u_i \geq 0)$. u_i is associated with inefficiency in production and is assumed to be independently distributed as truncation at zero of the normal distribution with mean $-Z_i\delta$ and variance $\sigma^2 u$ (|N($-Z_i\delta$,$\sigma^2 u$|)). The Z_i are correlates of inefficiencies on farm i.

We have applied the single stage approach of Battese and Coelli [55] to identify the determinants of technical inefficiency, which is related to a set of farm-specific characteristics subject to statistical error, such that:

$$u_i = Z_i\delta + \zeta_i \geq 0, \quad (2)$$

where,

Z_i = are farm-specific characteristics of *i*th farm households,
ζ_i = double sided random error distributed as $\zeta_i \sim N(0, \sigma_\zeta^2)$.

Since $u_i \geq 0, \zeta_i \geq -Z_i\delta$, the distribution of ζi is truncated from below at the variable truncation point, $-Z_i\delta$.

The technical efficiency of farm *i* is defined as:

$$EFF_i = E[exp(-u_i)|\xi_i] = E[exp(-\delta_0 - \sum Z_i\delta|\xi_i), \quad (3)$$

where

E = expectation operator. The efficiencies were achieved by obtaining the expressions for the conditional expectation u_i upon the observed value of ξ_i, where $\xi_i = v_i - u_i$. Both the stochastic production frontier model and the inefficiency effects models are jointly estimated using the maximum likelihood estimation (MLE) procedure. The likelihood function is presented in terms of the variance parameters, $\sigma^2 = \sigma_v{}^2 + \sigma_u{}^2$ and $\gamma = \sigma_u{}^2/\sigma^2$ [55].

2.5. The Empirical Model

The Cobb–Douglas stochastic production frontier model was used for this study. The translog model was not used because a large number of explanatory variables were included in the model. Kopp and Smith [56] noted that the choice of functional form does not have a major effect on technical efficiency scores. Furthermore, the Cobb–Douglas model is used widely (e.g., [57,58]). The empirical model is given as:

$$lnY_i = \beta_0 + \sum_{j=1}^{8} \beta_j lnX_{ij} + v_i - u_i, \quad (4)$$

and

$$u_i = \delta_0 + \sum_{d=1}^{6} \delta_d Z_{id} + \zeta_i, \quad (5)$$

where

Y_i = rice output (kg),
X_{ij} = jth input for the ith farmer; these are:
X_1 = fertilizer nutrients (kg),
X_2 = seed (kg),
X_3 = pesticides (BDT),
X_4 = irrigation (BDT),
X_5 = labor (person-day),
X_7 = organic manure (kg),
X_8 = vermicompost (kg),
v_i = two-sided random error,
u_i = one-sided half-normal error,
ln = natural logarithm,
Z_{id} = variables representing socio-economic characteristics of the farms to explain inefficiency, these are:
Z_1 = age of the farmer (years),
Z_2 = education of the farmer (completed years of schooling),
Z_3 = subsistence pressure (number of persons per household),
Z_4 = share of female labor (percent),
Z_5 = vermicompost user (1 = if user, 0 = otherwise),
Z_6 = amount of cultivated land (ha),
ζ_i = truncated random variable,
β_0, β_j, δ_0 and δ_i = parameters to be estimated.

We did not specify land under cultivation because of strong collinearity of this variable with all other inputs. Instead, we included the cost of land preparation, which is a monotonically increasing function of land area under cultivation. It is also well-established that land is a major determinant of rice output in Bangladesh (e.g.,). The focus here was to establish influence of other major inputs including vermicompost on rice production although we acknowledged that land area was the most dominant driver of MV rice productivity with or without vermicomposting. Therefore, we refrained from computing returns to scale in MV rice production. The choice of the variables to explain efficiency were based on the existing literature and their justification [53,59].

3. Results and Discussion

3.1. Socio-Economic Characteristics of Sampled Farmers

Table 1 presents selected summary statistics of the sampled farmers classified by vermicompost users and non-users. There was no significant difference in age, education, family size and the use of female labor in MV rice production between vermicompost users and non-users. The average age of the farmers were just under 44 years. The average education level was slightly higher than 8 years of completed schooling, which was at mid-secondary level in Bangladesh. The family size was about four persons per household, which was closely similar to the national level of 4.06 persons in 2016 according to HIES 2016 (Household Income and Expenditure Survey) [60]. However, the amount of land cultivated and the amount of rice produced per farm household were significantly different between vermicompost users and non-users. The average amount of land cultivated by vermicompost users was 0.62 ha as compared to 0.39 ha for non-users. Similarly, the average production of MV rice per household was 3947.01 kg for vermicompost users as compared to 2426.89 kg for non-users. Therefore, although basic socio-economic characteristics of the sampled farmers are the same, the farm operation size and MV rice production was significantly different between the two groups of farmers.

Table 1. Summary statistics of the surveyed farmers by vermicompost users and non-users (mean values).

Items	Vermicompost Users	Vermicompost Non-Users	T-Ratios of Mean Difference
Age of the farmer (years)	43.47	43.85	0.34
Education of the farmer (completed year of schooling)	8.19	8.04	0.31
Family size (persons)	3.98	4.10	0.92
Amount of cultivated land (ha)	0.62	0.39	5.98 ***
MV rice production (kg)	3947.01	2426.89	6.37 ***
Share of female labor (proportion)	0.20	0.19	1.42
Number of observations	155	185	

Note: *** Significant at the 1% level ($p < 0.01$).

3.2. Productivity and Profitability of Vermicompost Use in MV Boro Rice Production

Vermicompost is locally produced by a few for sale to other farmers. The local market price of vermicompost was typically BDT 10 per kg (~£0.10 per kg) in the study area. Farmers usually applied vermicompost 2–3 times in MV rice cultivation. Farmers first apply vermicompost at last ploughing during land preparation stage. The second application was made in the rice field on 15 DAT (days after transplanting) and the final application was during 40–45 DAT as top dressing.

Table 2 presents inputs and yield of MV boro rice per ha classified by vermicompost users and non-users of the surveyed farmers. The average use rates of chemical fertilizers, organic manure and family supplied labor per ha were significantly lower for vermicompost users as compared to non-users as expected. The lower use of family supplied labor might be due to relatively lower requirement of labor for intercultural operations. Hired labor was mainly used for transplanting and harvesting of rice and therefore the use rate of hired labor was similar for both vermicompost users and non-users. In contrast, the mean yield of MV rice per ha was significantly higher for vermicompost users estimated at 6869.8 kg/ha as compared to 6658.8 kg/ha for non-users, thereby establishing the fact that greening MV rice agriculture through vermicomposting could also provide higher output while significantly curb the use of chemicals and other inputs.

Table 2. Productivity and input use rates per ha in modern rice production by vermicompost users and non-users in the study area (mean values).

Items	Vermicompost Users	Vermicompost Non-Users	T-Ratios of Mean Difference
Inputs used in MV rice production			
Seed (kg)	35.0	34.4	0.61
Urea (kg)	258.3	283.8	−4.33 ***
TSP (kg)	133.6	148.7	−4.62 ***
MP (kg)	107.2	107.2	0.00
Gypsum (kg)	104.0	123.8	−6.01 ***
Zinc (kg)	12.60	13.70	−2.18 **
Manure (maund)	92.5	135.3	−9.67 ***
Vermicompost (kg)	262.9	0.0	N/A
Hired male labor (person-day)	142.0	146.0	−1.40
Hired female labor (person-day)	19.0	20.0	−0.12
Family supplied male labor (person-day)	22.0	25.0	2.96 ***
Family supplied female labor (person-day)	23.0	23.0	0.65
Output			
Rice yield (kg)	6869.8	6658.8	4.90 ***
Number of observations	155	185	

Note: *** significant at the 1% level ($p < 0.01$) and ** significant at the 5% level ($p < 0.05$).

Table 3 presents profitability of MV rice production per ha of vermicompost users and non-users. It is clear from Table 2 that the costs of chemicals, organic manure and hired male labor were significantly lower for vermicompost users. However, the total cost of production was not significantly different between vermicompost users and non-users because of high cost incurred in using vermicompost. Although gross return from MV rice production by vermicompost user seemed to be higher than non-users, the difference was not significant. As a result, BCR of MV rice production was not significantly different between vermicompost users and non-users computed at 1.17 and 1.15, respectively.

Table 3. Profitability of boro paddy production by vermicompost users and non-users (BDT per ha) in the study area (mean values).

Items	Vermicompost Users	Vermicompost Non-Users	T-Ratios of Mean Difference
A. Variable costs:			
Seedling cost	1630.8	1610.4	0.46
Irrigation cost	18755.9	18850.3	−0.29
Pesticides cost	3831.7	4034.7	−2.72 ***
Land preparation cost	5041.3	5217.5	−4.12 ***
Urea	4132.9	4540.0	−4.33 ***
TSP	2939.5	3271.9	−4.62 ***
MP	1572.9	1588.0	−0.41
Gypsum	624.0	742.9	−6.01 ***
Zinc	1984.6	2190.1	−2.69 ***
Manure	1598.5	1997.1	−5.34 ***
Vermicompost	4359.2	0.0	N/A
Hired male labor	37267.4	39516.7	−2.22 **
Hired female labor	3337.9	3498.8	−1.03
B. Opportunity cost/Fixed costs:			
Family supplied male labor	6072.9	6060.2	0.05
Family supplied female labor	3988.2	4188.3	−0.80
Opportunity cost of land	26000.0	26000.0	0.00
C. Total costs (A + B)	123138	123307	
Revenue from rice production			
Rice	136063.9	132368.9	−2.79 ***
By-product of rice	8346.4	9855.3	−3.05 ***
D. Total revenue	144410.0	142224.0	1.68 *
E. Net profit (D − C)	21273.0	18917.0	1.40
F. Benefit cost ratio (BCR)	1.17	1.15	0.96
Number of observations	155	185	

Note: *** significant at the 1% level ($p < 0.01$), ** significant at the 5% level ($p < 0.05$) and * significant at the 10% level ($p < 0.10$).

3.3. Productivity Effects of Vermicompost Users

Table 4 presents parameter estimates of the stochastic production frontier and the inefficiency effect model using the MLE procedure in STATA Version 10 software (StataCorp, LLC, College Station, TX, USA) [61]. Eighty percent of the coefficients on the variables were significantly different from zero implying a very good fit of the production frontier function. The value of the coefficient on γ confirmed the presence of a significant level of technical inefficiency.

Coefficients on the input variables had positive signs (i.e., positive marginal products) as expected, except organic manure, which was not significant, and therefore, might not reveal the true relationship. The coefficients could be directly interpreted as elasticities because the Cobb–Douglas model was used. All production inputs except organic manure and pesticides significantly increase MV rice production. The major driver of rice production was irrigation followed by labor and chemical fertilizers as expected. The elasticity value of irrigation was 0.13 indicating that a 1% increase in irrigation would increase MV rice production by 0.13%, which established the importance of irrigation in MV rice agriculture.

The responsiveness of labor and fertilizers to MV rice production was closely similar with irrigation. Table 3 clearly shows that the use of vermicompost significantly increased rice production, which econometrically confirmed the productivity advantage in its use presented in Section 3.2 and Table 2. A 1% increase in the use of vermicompost would increase MV rice production by 0.01%.

Table 4. Joint parameter estimates of the stochastic production frontier with inefficiency effects model.

Variables	Parameters	Coefficients	T-Ratios
Stochastic production frontier			
Constant	β_0	1.1973 ***	7.48
Fertilizer nutrients	β_1	0.1007 ***	2.89
Seed	β_2	0.0297 *	1.93
Pesticides	β_3	0.0211	0.87
Irrigation	β_4	0.1327 ***	4.72
Labor	β_5	0.1175 ***	4.02
Organic manure	β_6	−0.0112	−0.95
Vermicompost	β_7	0.0110 ***	3.05
Land preparation	β_8	0.4720 ***	10.87
Variance Parameters			
$\sigma^2 = \sigma_u{}^2 + \sigma_v{}^2$	σ^2	0.0062 ***	10.96
$\gamma = \sigma_u{}^2/(\sigma_u{}^2 + \sigma_v{}^2)$	γ	0.6932 ***	6.88
Log likelihood		385.90	
Wald χ^2 (8 df and 7 df)	χ^2	1146.90 ***	
Inefficiency effects function			
Constant	δ_0	0.3179 ***	4.35
Age of the farmer	δ_1	0.0002	0.34
Education of the farmer	δ_2	−0.0019 *	−1.65
Subsistence pressure	δ_3	−0.0077 *	−1.82
Share of female labor	δ_4	−0.0881	−0.96
Vermicompost user	δ_5	0.0057	0.21
Amount of land cultivated	δ_6	−0.3679 ***	−4.35
Total number of observations		340	

Note: *** significant at the 1% level ($p < 0.01$) and * significant at the 10% level ($p < 0.10$).

3.4. Determinants of Technical Efficiency in MV Rice Production

The lower panel of Table 4 presents determinants of technical inefficiency. The null hypothesis of no inefficiency effects (H0: $\delta_1 = \delta_2 = \ldots = \delta_6 = 0$) was rejected at the 1% significance level. Education, family size and farm operation size significantly improved technical efficiency, which was consistent with expectation. Asadullah and Rahman [57] and Rahman and Rahman [62] noted a significant influence of education on technical efficiency in rice and maize production in Bangladesh, respectively. Alam et al. [63] noted that farm size and family size significantly improve technical efficiency of rice farming in Bangladesh. Similarly, Rahman [64] also noted a significantly positive influence of family size in crop farming in Bangladesh.

Table 5 presents the distribution of technical efficiency scores. Table 5 reveals that the MV rice farmers were operating at a high level of efficiency. The mean efficiency level was estimated at 90%. The implication is that the output of MV rice could still be increased by 10% by eliminating technical inefficiency. When classified by vermicompost users and non-users, Table 5 clearly shows that technical efficiency levels of vermicompost users were significantly higher by 4 points as compared with non-users. The technical efficiency of vermicompost users was 92% and non-users was 88% ($p < 0.01$). The result clearly demonstrated that vermicompost use in MV rice production improved technical efficiency as well, although such effect could not be confirmed from the econometric model results presented in Table 4.

Table 5. Technical efficiency distribution of the surveyed farmers.

Efficiency Levels	Percentages
up to 80%	1.70
81%–90%	57.40
91% and above	40.90
Mean efficiency by vermicompost users	Proportions
Vermicompost users	0.92
Vermicompost non-users	0.88
Mean efficiency difference (vermicompost user vs. non-user)	0.04
t-statistic of mean efficiency difference	5.68 ***
Overall	
Mean efficiency score	0.90
Standard deviation	0.06
Minimum	0.77
Maximum	0.99

Note: *** significant at the 1% level ($p < 0.01$).

4. Conclusions and Policy Implications

The present study investigated the impact of vermicompost use in MV rice production at the farm-level, because such practice has the potential to reduce chemical use and other inputs. Due to a poor rate of growth of MV rice productivity at 1.4% per annum over the past three decades [65], farmers are looking out for new ways to increase rice production while reducing the use of costly inputs. It seems that Bangladeshi farmers are willing to undertake innovative approaches to increase rice production, e.g., application of vermicompost in addition to conventional production inputs. Results of this study confirmed that the use of vermicompost significantly increased rice productivity and technical efficiency. Savings on chemical inputs and gain in additional output of using vermicompost were also substantial. However, profitability of vermicompost use was not significantly different because of the high cost of vermicomposting.

The following policy implications could be derived from the results. Bangladesh should promote the use of vermicompost so that MV rice farmers could save on the use of scarce inputs while significantly increasing rice production and reducing dependency on chemicals. Although use of vermicompost did not seem to have a significant impact on profitability due to the high cost of vermicomposting at present, the long-term benefit of vermicompost application lies in enhancing soil fertility and a reduction of the use of harmful chemicals. Therefore, measures should be taken to increase awareness of the farmers on the multifaceted benefits of vermicompost use in rice production through various communication mechanisms, such as, agricultural extension services, mass media, non-governmental organizations and other relevant stakeholders involved in agricultural development in Bangladesh. Furthermore, widespread use of vermicompost in rice production will require policy measures offering appropriate incentives to engage entrepreneurs in vermicompost production at a commercial scale in order to lower the cost of vermicomposting, which in turn will improve profitability of MV rice production. This is because use of vermicompost holds promise towards greening MV rice production and improving agricultural sustainability in Bangladesh. Other policy implications include investment in education for the farming population and land/tenancy reform measures to facilitate effective land rental market operations in order to consolidate/increase farm operation size.

Supplementary Materials: The following are available online at http://www.mdpi.com/2077-0472/9/11/239/s1, File S1: An Economic Anylysis of Vermi Compost on MV Paddy Production in Bangladesh: A Case Study of Jessore District.

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