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Co-Composted Fecal Sludge Based Integrated Nutrient Management for Sustainable *Aman* Rice Production

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Abstract

This study was undertaken to judge the efficacy and economic feasibility of co-composted fecal sludge (CCFS) in increasing growth and productivity of transplant Aman (T. *Aman*) rice and to optimize CCFS dose for integration with chemical fertilizers to maximize T. *Aman* rice yield and economic return. This study was consisted of two factors included two T. *Aman* rice varieties namely, BRRI dhan 49 and Dhanigold; and 10 chemical fertilizer+CCFS combinations such as, recommended dose of synthetic fertilizer (RDF), CCFS @ 5 t ha^{-1}, RDF+CCFS @ 2 t ha^{-1}, RDF+CCFS @ 1.5 t ha^{-1}, RDF+CCFS @ 1 t ha^{-1}, RDF+CCFS @ 0.5 t ha^{-1}, 75% RDF+CCFS @ 2 t ha^{-1}, 75% RDF+CCFS @ 1.5 t ha^{-1}, 75% RDF+CCFS @ 1 t ha^{-1} and 75% RDF+CCFS @ 0.5 t ha^{-1}. A clear advantage of integrating CCFS with chemical fertilizers to increase rice growth and yield was evident in this study. The highest grain yield was recorded when CCFS @ 2 t ha^{-1} was integrated with recommended chemical fertilizers, and that was >7% higher than that obtained from the application of only recommended chemical fertilizers. But application of only CCFS @ 5 t ha^{-1} reduced grain yield by as much as 47%. The highest benefit:cost ratio for BRRI dhan49 and Dhanigold (1.66 and 1.61, respectively) were calculated from recommended chemical fertilizers application closely followed by application of recommended chemical fertilizers+CCFS @ 2 t ha^{-1} (1.55 and 1.49, respectively). In case of both the varieties, application of only CCFS @ 5 t ha^{-1} resulted in negative net return and <1 benefit:cost ratio (0.75 and 0.73, respectively for BRRI dhan 49 and Dhanigold) due to poorer yield and higher cost for CCFS. Encouraging findings of this study confirm that CCFS obtained from faecal sludge can be integrated with chemical fertilizers to increase the productivity of T. *Aman* rice. In terms of grain yield, recommended chemical fertilizers+CCFS @ 2 t ha^{-1} appeared as the best option, but application of only recommended chemical fertilizers was found a bit more economic than integration. Application of only CCFS without chemical fertilizers was found neither productive nor economic. To conclude, co-compost can be used to supplement chemical fertilizers for in rice cultivation, and thus will contribute to green agriculture by improving soil health and minimizing environmental pollution. It is therefore necessary to conduct multi-location trials for consecutive years on other crops as well to confirm the potentiality of co-compost as a manure to increase crop productivity, and as a soil conditioner for soil health improvement.

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Introduction

The geographical and climatic conditions of Bangladesh are highly conducive to rice (*Oryza sativa* L.) cultivation, making it one of the leading rice-producing countries in the world. Bangladesh has ranked third globally (FAO, 2022) in rice cultivation. Rice is the staple food of around 170 million people in Bangladesh, accounting for approximately 78% of total arable land (BBS, 2023). Rice is farmed in three distinct seasons in Bangladesh*: Aus*, *Aman*, and *Boro*, with total *Aman*rice production of 14958.39 thousand metric tons (MT) from 5720.13 hectares (ha) of cultivable land in 2021–2022 cropping season (BBS, 2023). Despite having year-round ideal soil and climate for rice farming, Bangladesh's unit area output is much lower than that of other rice-growing nations across the world. Inadequate and improper management procedures in rice growing are the main source of production differences. Among the various agronomic management techniques, good soil management, particularly prudent nutrient usage, shows a significant impact on preserving soil health and increasing rice productivity (Iqbal *et al.*, 2020; Luo *et al.*, 2018). The repeated use of inorganic fertilizer alone or the continuous application of chemical fertilizers at higher doses both fail to sustain the desired yield, degrade the physical state of the soils, reduce the organic matter content of the soils, and have a negative impact on the environment (Chakraborty *et al.,* 2020; Zhang *et al*., 2024).

The most efficient way to meet the demand for food in this situation and improve soil and environmental conditions is to cultivate improved varieties and practice good nutrient management, such as integrated use of organic manure and chemical fertilizers (Aktar *et al*., 2018; Sultana *et al.*, 2021). Cowdung, compost, farmyard manure, crop remnants, vermicompost, and other types of urban waste are among the most popular organic manures. Lack of and/or decline in the source of organic manure is one of the causes for not using enough organic manure in the crop field of Bangladesh and finding other sources is necessary. Another potential source of organic matter is humanure, which is compost made from human waste and urine. According to Aktar*et al.* (2018), co-composting with municipal solid waste and faecal sludge was helpful for the growth of agricultural crops. Co-composting was the process of composting two or more raw materials at the same time, such as faecal sludge and solid waste or other organics like animal manure, sawdust, wood chips, bark, abattoir waste, sludges, or solid leftovers from industries (Enayetullah and Sinha, 2013; Giagnoni *et al.*, 2020). Faecal matter had been recycled and used effectively as co-composted fecal sludges (CCFS) in crop cultivation in some Asian countries (Debnath, 2018; Hafiz *et al.*, 2017) due to its high content of organic carbon, good bulking properties and good source of micro and macronutrients (Eawag and ENPHO, 2014). Co-composting showed to boost soil fertility and improved growth and development of plants (Rohini *et al*., 2017). However, in order to employ CCFS effectively in crop fields, it is required to evaluate its potential impact on crop yield, financial success, and soil health. Thus, this study was conducted to assess the impact of co-composted fecal sludge integration with chemical fertilizer on yield and economic return of *Aman* rice, and to find out the optimum and most economic combination of composted fecal sludge and chemical fertilizer for sustainable *Aman* rice production.

Materials and Methods

Experimental Site

This study was carried out at the Agronomy Field Laboratory of Bangladesh Agricultural University (90°25'35.2"E and 24°43'07.3"N; 18 meters above sea level) during May to December. The experimental field was medium high under the Old Brahmaputra Floodplain, Agroecological Zone (AEZ)-9. The soil was non-calcareous dark-grey floodplain type, silty loam textured, with soil pH value 6.8, average organic matter content of 0.93 %. The climate of the locality is sub-tropical. The monthly average air temperature, relative humidity and total rainfall during the period of experiment ranges from 20.6 to 30.2°C, 81.5 to 88.1% and 0.0 to 349.9 mm, respectively.

Treatment and Design of the Experiment

The experiment was conducted following randomized complete block design replicated thrice. Treatments comprised 2 transplant Aman (T. *Aman*) rice varieties, i) Inbred BRRI dhan 49 and ii) hybrid Dhanigold; and 10 synthetic chemical fertilizer and co-composted fecal sludge (CCFS) combinations, *viz.* i) BRRI recommended dose of synthetic fertilizer (RDF), ii) CCFS @ 5 t ha^{-1}, iii) RDF+CCFS @ 2 tha^{-1}, iv) RDF+CCFS @ 1.5 t ha^{-1}, v) RDF+CCFS @ 1 t ha^{-1}, vi) RDF+0.5 t ha^{-1}, vii) 75% RDF+CCFS @ 2 tha^{-1}, viii) 75% RDF+CCFS @ 1.5 t ha^{-1}, ix) 75% RDF+CCFS @ 1 t ha^{-1}, and x) 75% RDF+CCFS @0.5 t ha^{-1}. The size of the unit plot was 5 m^2 (2.5 m × 2 m) and the spaces between the blocks and plots were 1 m and 0.5 m, respectively. Therefore, the total number of plots were 60 (variety 2 × treatment 10 × replication 3).

Crop Husbandry

Seeds of BRRI dhan 49 were collected from the Bangladesh Rice Research Institute (BRRI), Joydebpur, Gazipur and the hybrid variety Dhanigold were purchased from the local market. Prepared and ready to use CCFS was collected from NGO Forum for Public Health, Mymensingh. In general, the nutritional status of the co-compost was as per Soil Resource Development Institute (SRDI) standard range (according to government regulation): OC = 14.38% N = 2.04% P = 0.728 ppm K = 1.34% and S = 0.445 ppm. The common heavy metals, *viz.* zinc (Zn), cadmium (Cd), lead (Pb), nickel (Ni), chromium (Cr) and and copper (Cu) level were 0.062, 2.8, 10.51, 10.97, 7.38 and 0.0077%, respectively. All the heavy metals level was also within the standard range.

Forty-days-old seedlings were transplanted in the puddled field using 2 seedlings $hill^{-1}$ following 25 cm row and 15 cm hill spacing. Co-compost was applied at the time of final land preparation (week before transplanting) as per treatment and mixed thoroughly with the soil. For recommended dose of chemical fertilizers (BRRI recommended), urea, triple super phosphate, muriate of potash, gypsum and zinc sulphatewere applied at the rate of 296, 161, 210, 124 and 12 kg ha^{-1}, respectively, as the source of nitrogen (N), phosphorus (P), potassium (K), Sulphur (S) and Zn for both varieties. All the fertilizers except urea were applied as basal one day before transplanting. Urea was applied in three equal splits at 10, 30 and 50 days after transplantion (DAT).

Intercultural operations were done as and when necessary. Gap filling was done at 7 days after transplanting where it was necessary. Flood irrigation was applied to maintain water level up to 4–5 cm in early stage and 8–10 cm in later stage. The field was finally drained out 10 days before harvest to enhance maturity. Manual weeding was done thrice at 15, 30 and 50 DAT. Since no remarkable diseases/insect infestations were observed, no plant protection measures were taken. Harvesting was done when 90% of the grains became golden yellow in color.

Data Collection

Prior to harvest, five rice hills (aside from boundary hills) were randomly chosen from each unit plot to collect data on the yield of rice and various yield components. After harvesting, the crop was threshed, cleaned and dried until the grain moisture content was 14%. Weight of grain (14% moisture content) and straw were recorded and converted into t ha^{-1}. Data on the growth, yield contributing charactersand yield: plant height, number of total tillers $hill^{-1}$, number of effective tillers $hill^{-1}$, number of grains $panicle^{-1}$, weight of 1000-grain (g), grain yield, straw yield and harvest index were recorded.

Economic Analysis

Economic analysis was performed to determine the benefit cost ratio (BCR) of using CCFSas a component of integrated nutrient management for *Aman* rice cultivation. Labor wages, price of different inputs and product were calculated based on local rate/market price. The BCR was calculated using the following formula:

BCR = Gross return/Total cost of production.

Gross return was calculated by multiplying rice yield and market price of the unit rice weight.

Statistical Analyses

All the data were compiled and tabulated in proper form for statistical analyses. Analysis of variance was done with the help of MSTAT–C computer package program. The mean differences between treatments were tested with Duncan's Multiple Range Test at 5% level of probability.

Results and Discussion

Effects of Co-composted Fecal Sludges (CCFS) and Synthetic Fertilizer Combination on Growth of Aman Rice Varieties

The variety and CCFS-based integrated nutrient management treatments showed significant effect on plant height and total tillers hill^{-1} at harvest (Table 1). Plant height ranged from 88.80 to 115.47 cm, and the hybrid variety Dhanigold was significantly taller than (99.2 to 115.47 cm) the inbred BRRI dhan 49 plant (88.80 to 104.40 cm). In general, the tallest plant was found in the C_2 (RDF+CCFS @ 2 t ha^{-1}) and C_3 (RDF+CCFS @ 1.5 t ha^{-1}) treatments in both varieties and the shortest when only CCFS (C_1) was applied to the field. It is well documented from the literature that application of organic manure in combination with chemical fertilizers in right proportion could enhance plant height (Khan *et al*., 2007; Rehman and Qayyum, 2020). As stated by Latare *et al*. (2014) combined application of composted fecal sludge with chemical fertilizers improved soil fertility and increased the availability of nitrogen and phosphorus along with trace elements to plants, thus indirectly enhanced plant development. Furthermore, release of nutrients from composted fecal sludge increased the availability of different nutrients resulting in increased leaf area and higher dry matter accumulation and plant stature. Similarly, Zhang *et al.* (2016) reported a significant increase in rice plant height after applying fecal sludge amendments.

The variation in production number of total tillers hill^{-1} showed significant difference among the varieties and CCFS and chemical fertilizer combination (Table 1). The variation of total tiller number hill^{-1} ranged from 6.80 to 14.83 considering both varieties. BRRI dhan49 produced more total tiller hill^{-1} than the Dhanigold. The highest total tiller hill^{-1} was produced when RDF was applied along with CCFS @ 2 t ha^{-1} (C_2) to the BRRI dhan49, which was statistically similar to the similar treatment of Dhanigold. The lowest number of tillers was found when CCFS (C_1) was applied sole to the field. The improvement of soil fertility associated with the application of decomposed fecal sludge and chemical fertilizers would have supported improved rice plant growth in terms of tillering. Combining organic manure like decomposed fecal sludge with inorganic fertilizers ensures efficient and judicious use of all the major sources of plant nutrients in an integrated manner, and thus contribute to increased plant height, tillering ability and dry matter accumulation (Farouque and Takeya, 2007; Rehman and Qayyum, 2020). Similar findings have also been reported by many researchers (Larijani and Hoseini, 2012; Saba *et al.*, 2013) from where a positive influence of composted fecal sludge application on tillering ability of rice is evident.

Effects of Co-composted Fecal Sludges (CCFS) and Synthetic Fertilizer Combination on the Yield and Yield Contributing Characters of Aman Rice Varieties

The variety and CCFS based integrated nutrient management treatments had showed significant effect on the yield and yield contributing characters of transplant Aman (T. *Aman*) rice (Table 2 and Figure 1). The highest number of effective tillers hill^{-1} (12.46) was found from the treatment of RDF+CCFS @ 1.0 t ha^{-1} (V_1C_4) in the field of BRRI dhan 49 while the lowest number of effective tillers hill^{-1} (4.73) was recorded from CCFS @ 5.0 t ha^{-1} (V_2C_1) in the field of hybrid Dhanigold variety (Table 2). But in both varieties CCFS alone applied @ 5.0 t ha^{-1} (V_1C_1) showed the lowest number of effective tillers hill^{-1}. So, the combined application of CCFS with RDF significantly increased the effective tillers hill^{-1}. Better availability of different macro- and micro-nutrients as the consequence of integrating co-composted fecal sludge with chemical fertilizers might be reason for higher number of effective tillers in rice. Similar findings have also been reported by Kumar *et al*. (2014).

Table 1. Effect of variety, and synthetic fertilizer and co-composted fecal sludge (CCFS) combination on the plant height and number of total tillers hilll^{-1} of T. *Aman* rice at harvesting

Variety	Fertilizer and CCFS combination	Plant height (cm)	Number of total tillers hill^{-1}
BRRI dhan 49	C_0	98.97^{d-g}	11.90^{c-g}
	C_1	88.80^{g}	8.63^{ijk}
	C_2	104.40^{a-f}	14.83^{a}
	C_3	101.33^{b-f}	14.20^{ab}
	C_4	99.70^{c-g}	13.73^{abc}
	C_5	98.90^{d-g}	12.80^{a-e}
	C_6	98.20^{d-g}	11.63^{c-g}
	C_7	97.37^{efg}	10.30^{f-j}
	C_8	97.03^{efg}	9.96^{g-j}
	C_9	96.10^{fg}	9.33^{hij}
Dhanigold	C_0	109.13^{a-d}	11.23^{d-h}
	C_1	99.20^{d-g}	6.80^{k}
	C_2	115.47^{a}	13.06^{a-d}
	C_3	112.20^{ab}	12.43^{b-f}
	C_4	110.97^{abc}	11.60^{c-g}
	C_5	109.13^{a-d}	11.23^{d-h}
	C_6	108.43^{a-e}	10.63^{e-i}
	C_7	108.33^{a-e}	10.20^{g-j}
	C_8	107.37^{a-f}	9.33^{hij}
	C_9	104.17^{a-f}	8.16^{jk}
	$S\bar{x}$	5.75	1.08
	LS	**	**
	CV (%)	6.82	11.88

In a column, figures having similar superscript letter(s) do not differ significantly at $P \leq 0.05$, whereas figures with dissimilar superscript letter(s) differed significantly as per DMRT. ** = significant at 1% ($P \leq 0.01$) level of probability. LS = Level of significance, CV = Co-efficient of variation.

C_0 = Recommended dose of synthetic fertilizer (RDF), C_1 = Co-compost (CCFS) @ 5 t ha^{-1}, C_2 = RDF+CCFS @ 2 t ha^{-1}, C_3 = RDF+CCFS @ 1.5 t ha^{-1}, C_4 = RDF+CCFS @ 1 t ha^{-1}, C_5 = RDF+CCFS @ 0.5 t ha^{-1}, C_6 = 75% RDF+CCFS @ 2 t ha^{-1}, C7 = 75% RDF+CCFS @ 1.5 t ha^{-1}, C_8 = 75% RDF+CCFS @ 1 t ha^{-1}, C_9 = 75% RDF+CCFS @ 0.5 t ha^{-1}.

Number of grains panicle^{-1} was significantly varied from 89.20 to 139.77 among the variety and CCFS based integrated nutrient management treatments (Table 2). From the above variation it was found that the variety BRRI dhan49 showed better response than hybrid Dhanigold. The highest number of grains panicle^{-1} (139.77) was found when RDF+CCFS @ 2.0 t ha^{-1} (V_1C_2) was applied on the plot of BRRI dhan49, followed by the same variety treated by RDF+CCFS @ 1.5 and 1.0 t ha^{-1} (134.90 and 131.60, respectively). On the other hand, the variety hybrid Dhanigold had the least significant response and produced the lowest number of grains panicle^{-1} (89.20) while the plot of this variety was treated by

CCFS @ 5.0 t ha^{-1} (V_2C_1). Rice grain formation mostly depends on dry matter accumulation and partitioning. Dry matter accumulation is determined by nutrient availability. Co-compost based integrated nutrient management ensured sufficient nutrients for grain formation which resulted in higher number of grains panicle^{-1}. These findings are in conformity with those of many others (Satyanarayana *et al*., 2002; Larijani and Hoseini, 2012).

Number of sterile spikelets panicle^{-1} was significantly varied from 11.66 to 28.33 among the variety and RDF+CCFS combinations (Table 2). BRRI dhan49 produced higher number of sterile spikelets than the Dhanigold. The highest number of sterile spikelets panicle^{-1} (28.33) was observed when CCFS @ 5.0 t ha^{-1} (V_1C_1) applied to BRRI dhan49, while the lowest number of total spikelets panicle^{-1} (11.66) was observed when Dhanigold was treated with 75% RDF+CCFS @ 2.0 t ha^{-1} (V_2C_6). Spikelet sterility is one of the major yield retarding characters of rice. Since Aman rice didn't enjoy drought and/or high temperature stress nutrient deficiency and insufficient dry matter accumulation were the major reasons behind high spikelet sterility when only co-compost was used. But integrated nutrient management resulted in a smaller number of sterile spikeletspanicle^{-1} due to sufficient nutrient supply and dry matter accumulation. Ahsan *et al.* (2007) and Islam *et al.* (2016) also recorded similar findings in their studies where integration of organic manure with inorganic fertilizers resulted in reduced spikelet sterility compared to sole application of either.

The total spikelets panicle^{-1} was significantly varied from 107.90 to 157.43 with the highest number recorded from the application of RDF+CCFS @ 2.0 t ha^{-1} to BRRI dhan 49 and the lowest number when 75% RDF+CCFS @ 5.0 t ha^{-1} was applied to Dhanigold (Table 2). The weight of 1000-grain also varied significantly from 20.86 to 27.66 g among the variety and CCFS based integrated nutrient combinations (Table 2). The highest weight of 1000-grain was obtained when hybrid Dhanigold treated with RDF+CCFS @ 2.0 t ha^{-1} (V_2C_2) and the lowest weight was obtained when BRRI dhan49 grown under sole application of CCFS (V_1C_1). Thousand-grain weight is highly governed by genetic makeup of a variety but can be influenced to some extent by different agronomic management including nutrient management. In this study, a clear advantage of integrating co-compost with chemical fertilizers on the improvement of 1000-grain weight of rice is evident. This was might be due to the better supply of different essential nutrient elements. Saba *et al*. (2013) also opined in the same tune.

The yield of both grain and straw also varied significantly from 3.34 to 7.30 t ha^{-1} and 4.50 to 7.86 t ha^{-1}, respectively, among the variety and CCFS based integrated nutrient management treatments (Figure 1 and Table 2). The hybrid Dhanigold showed the highest grain (7.30 t ha^{-1}) and straw (7.86 t ha^{-1}) yields while CC @ 2.0 t ha^{-1} was applied along with RDF (V_2C_2). However, CCFS@ 1.5 t ha^{-1} incorporation with both 100% RDF showed numerically identical second highest yield of straw (7.06 and 7.36 t ha^{-1}, respectively). The lowest grain and straw yield were obtained from BRRI dhan 49 while it was treated with the sole application CCFS @ 5.0 t ha^{-1}. Harvest index varied from 42.57 to 43.52% among the variety and fertilizer and CCFS combinations of *Aman* rice (Table 2). Rice grain yield is the cumulative outcome of the yield parameters like effective tillers hill^{-1}, grains panicle^{-1} and thousand-grain weight. In this study the maximum grain yield was recorded from hybrid variety Dhanigold when fertilized with recommended chemical fertilizers along with co-composted fecal sludge@ 2 t ha^{-1}. This was the consequences of highest effective tillers hill^{-1}, grains panicle^{-1} and 1000-grain weight in that combination. Due to higher yield potential hybrid variety Dhanigold out yielded BRRI dhan 49. The improvement of soil fertility associated with the application of co-compost along with recommended chemical fertilizer would have supported improved rice yield. The yield increment could be explained by the fact that co-compost as a source of organic matter contains various nutrients (macro and micro) and provideed them to crops slowly after their decomposition (Jatav *et al*., 2022). As stated by Gill and Walia (2014), the combined use of organic manures and inorganic fertilizers helped in maintaining yield stability through correction of marginal deficiencies of secondary and micronutrients, enhancing efficiency of applied nutrients and providing favorable soil physical conditions. Similar findings have also been reported by Zhang *et al*. (2016).

Table 2. Effect of variety and chemical fertilizer+co-composted fecal sludge (CCFS) combination on the yield and yield contributing charactersof T. *Aman* rice

Variety	Fertilizer and CCFS combination	Effective tillers hill^{-1} (no.)	Grains panicle^{-1} (no.)	Sterile spikelets panicle^{-1} (no.)	Total spikelets panicle^{-1} (no.)	1000-grain weight (g)	Straw yield (t ha^{-1})	Harvest index (%)
BRRI dhan 49	V_1C_0	10.80^{c-g}	123.57^{b-e}	18.00^{b-e}	141.57^{ab}	23.15^{cd}	7.20^{abc}	46.82^{abc}
	V_1C_1	6.50^{kl}	110.47^{e-i}	28.33^{a}	138.80^{b}	20.86^{e}	4.50^{e}	42.57^{c}
	V_1C_2	13.60^{a}	139.77^{a}	17.66^{b-f}	157.43^{a}	23.51^{c}	7.56^{ab}	47.46^{abc}
	V_1C_3	13.10^{ab}	134.90^{ab}	17.33^{c-f}	152.23^{ab}	23.35^{cd}	7.10^{abc}	48.16^{ab}
	V_1C_4	12.46^{abc}	131.60^{abc}	18.00^{b-e}	149.60^{ab}	23.0^{cd}	6.76^{bcd}	48.71^{ab}
	V_1C_5	11.63^{a-e}	127.67^{a-d}	18.00^{b-e}	145.67^{ab}	23.08^{cd}	6.83^{bcd}	47.02^{abc}
	V_1C_6	10.53^{c-h}	122.37^{b-f}	18.66^{bcd}	141.03^{b}	22.96^{cd}	6.66^{bcd}	47.09^{abc}
	V_1C_7	9.20^{f-j}	121.20^{b-f}	19.66^{bc}	140.87^{b}	22.56^{cd}	6.76^{bcd}	46.22^{abc}
	V_1C_8	8.93^{g-j}	118.77^{c-g}	18.00^{b-e}	136.77^{bc}	22.35^{cd}	6.46^{cd}	45.56^{abc}
	V_1C_9	8.26^{ijk}	116.87^{d-h}	19.33^{bc}	136.20^{bc}	21.95^{de}	6.13^{d}	46.48^{abc}
Dhanigold	V_2C_0	10.06^{d-i}	103.70^{hij}	13.66^{d-g}	117.37^{d}	27.31^{a}	7.43^{ab}	48.09^{ab}
	V_2C_1	4.73^{l}	89.20^{k}	22.66^{b}	111.87^{d}	25.38^{b}	4.53^{e}	44.46^{abc}
	V_2C_2	12.00^{a-d}	108.02^{f-j}	13.33^{efg}	121.35^{cd}	27.66^{a}	7.86^{a}	48.10^{ab}
	V_2C_3	11.33^{b-f}	106.53^{g-j}	12.00^{g}	118.53^{d}	27.46^{a}	7.36^{abc}	48.98^{a}
	V_2C_4	10.46^{c-i}	105.20^{g-j}	13.66^{d-g}	118.87^{d}	27.05^{a}	7.56^{ab}	47.43^{abc}
	V_2C_5	10.26^{c-i}	102.86^{h-k}	12.66^{fg}	115.53^{d}	27.11^{a}	7.10^{abc}	48.20^{ab}
	V_2C_6	9.56^{e-i}	101.65^{ijk}	11.66^{g}	113.31^{d}	26.98^{a}	7.13^{abc}	46.81^{abc}
	V_2C_7	9.03^{g-j}	100.73^{ijk}	13.33^{efg}	114.07^{d}	26.78^{ab}	6.83^{bcd}	46.50^{abc}
	V_2C_8	8.33^{h-k}	97.67^{ijk}	13.00^{efg}	110.67^{d}	26.70^{ab}	6.66^{bcd}	45.79^{abc}
	V_2C_9	7.03^{jk}	95.23^{jk}	12.66^{fg}	107.90^{d}	26.66^{ab}	6.43^{cd}	43.68^{bc}
	$S\bar{x}$	1.09	7.13	2.52	8.07	0.73	0.47	2.51
	LS	**	**	**	**	**	**	**
	CV (%)	13.49	7.73	18.64	7.63	3.61	8.51	6.59

In a column, figures having similar superscript letter(s) do not differ significantly at $P \leq 0.05$, whereas figures with dissimilar superscript letter(s) differed significantly as per DMRT. ** = significant at 1% ($P \leq 0.01$) level of probability. LS = Level of significance, CV = Co-efficient of variation.

C_0 = Recommended dose of synthetic fertilizer (RDF), C_1 = Co-compost (CCFS) @ 5 t ha^{-1}, C_2 = RDF+CCFS @ 2 t ha^{-1}, C_3 = RDF+CCFS @ 1.5 t ha^{-1}, C_4 = RDF+CCFS @ 1 t ha^{-1}, C_5 = RDF+CCFS @ 0.5 t ha^{-1}, C_6 = 75% RDF+CCFS @ 2 t ha^{-1}, C_7 = 75% RDF+CCFS @ 1.5 t ha^{-1}, C_8 = 75% RDF+CCFS @ 1 t ha^{-1}, C_9 = 75% RDF+CCFS @ 0.5 t ha^{-1}.

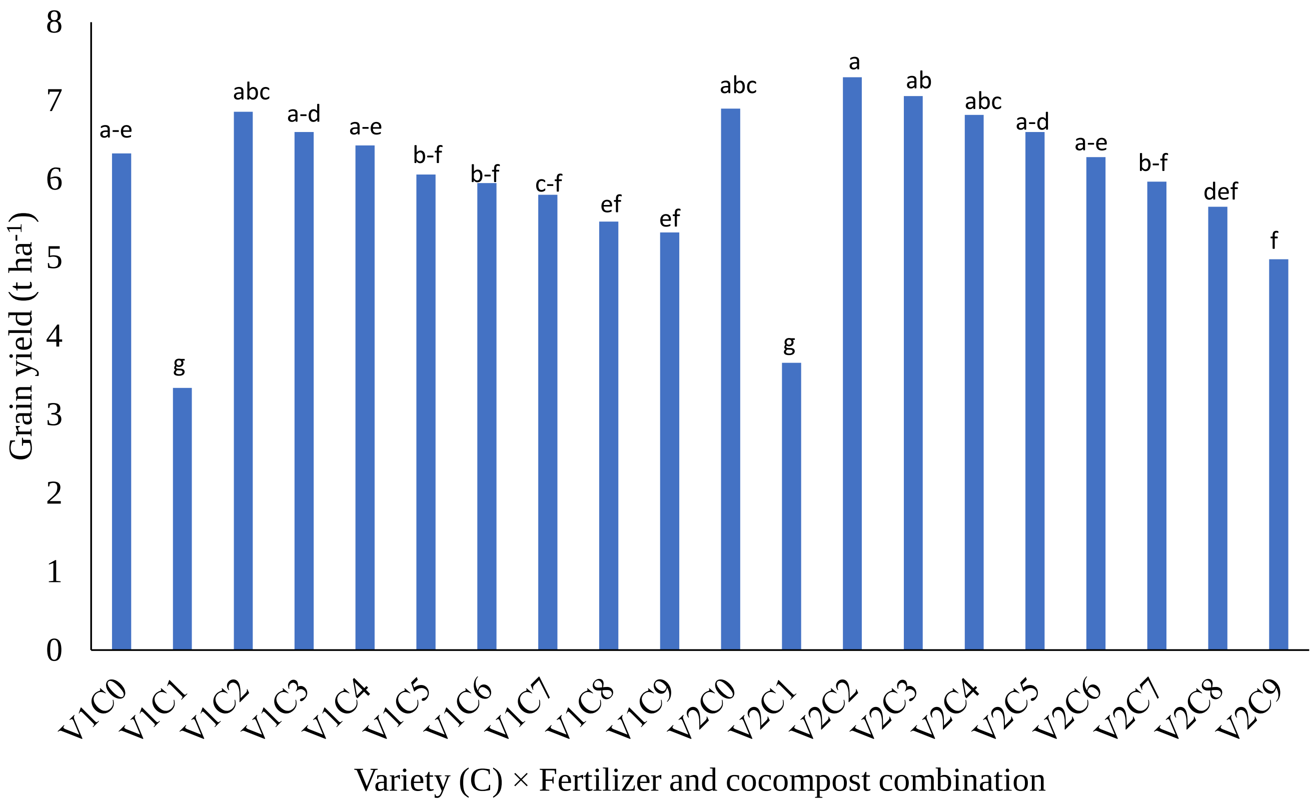

Figure 1. Effects of variety, and chemical fertilizer+co-compost (CC) combination on the grain yield of T. *Aman* rice. On a column in the graph, similar letter(s) do not differ significantly at $P \leq 0.05$, whereas column with dissimilar letter(s) differed significantly as per DMRT.

C_0 = Recommended dose of synthetic fertilizer (RDF), C_1 = Co-compost (CCFS) @ 5 t ha^{-1}, C_2 = RDF+CCFS @ 2 t ha^{-1}, C_3 = RDF+CCFS @ 1.5 t ha^{-1}, C_4 = RDF+CCFS @ 1 t ha^{-1}, C_5 = RDF+CCFS @ 0.5 t ha^{-1}, C_6 = 75% RDF+CCFS @ 2 t ha^{-1}, C_7 = 75% RDF+CCFS @ 1.5 t ha^{-1}, C_8 = 75% RDF+CCFS @ 1 t ha^{-1}, C_9 = 75% RDF+CCFS @ 0.5 t ha^{-1}.

Economic Performance

Looking at the fertilizer and CCFS application related cost, the highest variable cost (1,55,000 to 1,60,000 Tk ha^{-1}) was spent when only CCFS was applied to the field and the lowest one (127784 to132784 Tk ha^{-1}) was spent when 75% RDF+CCFS 0.05 t ha^{-1} was applied which was comparable to the cost (128712 to 133712 Tk ha^{-1}) when only RDF was applied to the field. Although the only CCFS application resulted in the highest cost, it failed to produce the highest income. This is expected since application of CCFS only supplied a tiny portion of nutrients required by the crop and yielded lower rice grain. Gross income ranged between 1.16 to 2.29 lac Tk. ha^{-1} for both BRRI dhan 49 and Dhanigold (Table 3). In both rice varieties, the lowest gross income was obtained from sole application of CCFS and the highest from the combined application of RDF+CCFS @ 2 t ha^{-1}.

Even though the Dhanigold variety produced higher grain yield than BRRI dhan49, the latter one gave higher gross income due to the lower price of course rice grain of hybrid Dhanigold variety. In both varieties, the highest benefit (84,528 and 82,838 Tk. ha^{-1} for BRRI dhan 49 and Dhanigold, respectively)

Table 3. Economic efficiency of application of different chemical fertilizer+co-composted fecal sludge (CCFS) combinations in two varieties of T. *Aman* rice

Variety	Fertilizer and CCFS combinations	Variable cost (Tk ha^{-1})				Gross return (Tk ha^{-1})	Net return (Tk ha^{-1})	Benefit cost ratio
		Variable cost (except fertilizer/ CCFS)	Fertilizer Cost	CCFS cost	Total variable Cost			
BRRI dhan 49	V_1C_0	105000	23712	-	128712	213240	84528	1.66
	V_1C_1	105000	-	50000	155000	116020	-38980	0.75
	V_1C_2	105000	23712	20000	148712	229880	81168	1.55
	V_1C_3	105000	23712	15000	143712	220300	76588	1.53
	V_1C_4	105000	23712	10000	138712	213840	75128	1.54
	V_1C_5	105000	23712	5000	133712	203830	70118	1.52
	V_1C_6	105000	17784	20000	142784	199600	56816	1.39
	V_1C_7	105000	17784	15000	137784	196200	58416	1.42
	V_1C_8	105000	17784	10000	132784	185180	52396	1.39
	V_1C_9	105000	17784	5000	127784	179610	51826	1.40
Dhanigold	V_2C_0	110000	23712	-	133712	216550	82838	1.61
	V_2C_1	110000	-	50000	160000	117810	-42190	0.73
	V_2C_2	110000	23712	20000	153712	229100	75388	1.49
	V_2C_3	110000	23712	15000	148712	220360	71648	1.48
	V_2C_4	110000	23712	10000	143712	215120	71408	1.49
	V_2C_5	110000	23712	5000	138712	207100	68388	1.49
	V_2C_6	110000	17784	20000	147784	198930	51146	1.35
	V_2C_7	110000	17784	15000	142784	189370	46586	1.33
	V_2C_8	110000	17784	10000	137784	180200	42416	1.30
	V_2C_9	110000	17784	5000	132784	161630	28846	1.22

V_1 = BRRI dhan 49, V_2 = Dhanigold, C_0 = Recommended dose of synthetic fertilizer (RDF), C_1 = Co-compost (CCFS) @ 5 t ha^{-1}, C_2 = RDF+CCFS @ 2 t ha^{-1}, C_3 = RDF+CCFS @ 1.5 t ha^{-1}, C_4 = RDF+CCFS @ 1 t ha^{-1}, C_5 = RDF+CCFS @ 0.5 t ha^{-1}, C_6 = 75% RDF+CCFS @ 2 t ha^{-1}, C_7 = 75% RDF+CCFS @ 1.5 t ha^{-1}, C_8 = 75% RDF+CCFS @ 1 t ha^{-1}, C_9 = 75% RDF+CCFS @ 0.5 t ha^{-1}.

Labor wage = Tk 500/day; Urea = Tk 28/kg; TSP = Tk 28/kg; MoP = Tk 30/kg; Gypsum = Tk 14/kg; Zinc sulphate = Tk 240/kg; Co-compost = Tk 10/kg; BRRI Dhan49 rice grain = Tk 28/kg; Dhanigold rice grain = Tk 26/kg; Rice straw = Tk 5/kg.

was obtained from sole application of RDF since this treatment produced higher grain yield and needed the lowest cost for application of fertilizer and CCFS. The second highest profit was obtained when RDF+CCFS @ 2 t ha^{-1} was applied to either variety. The highest benefit:cost ratio for BRRI dhan 49 and Dhanigold (1.66 and 1.61, respectively) were calculated from sole application of RDF which was closely followed by application of RDF+CCFS @ 2 t ha^{-1} (1.55 and 1.49, respectively). In case of both the varieties, application of only CCFS @ 5 t ha^{-1} resulted in negative net return and <1 benefit:cost ratio (0.75 and 0.73, respectively, for BRRI dhan 49 and Dhanigold) due to poorer yield and higher cost for CCFS.

Conclusions

The best yield for both the varieties was obtained by applying 100% of the required fertilizers together with 2 t ha^{-1} of co-composted fecal sludge; however, the yield was nearly identical to that obtained by reducing the recommended fertilizers to 75%. Incorporating co-composted fecal sludge at a rate of 2 t ha^{-1} with 100% prescribed fertilizers would be economically viable, even after accounting for profitability and potential improvements to soil health. In summary, co-composted fecal sludge can be added to synthetic fertilizers for rice cultivation, which will contribute to green agriculture by enhancing soil health and reducing pollution to the environment. To verify the viability of co-composted fecal sludge as a manure to increase crop productivity and as a soil conditioner to improve soil health, multi-location trials on successive years' worth of different crops must be carried out.

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Declaration

The authors declare no conflicts of interest.

Authors’ Contributions

MPA and SY conceptualized and planned the study; NBM, NS and SG conducted the field experiment and collected data; AKMMI and MSBJ statistically analyzed the data. All the authors contributed to writing, revising, and approving the final manuscript.

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