

Impacts of soil nutrient management practices on soil fertility, nutrient uptake, rice (*Oryza sativa* L.) productivity, and profitability

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ABSTRACT

A field experiment was conducted at the experimental area of Caraga State University, Butuan City, the Philippines, to determine the effects of different soil nutrient management practices on soil fertility, plant nutrition, productivity, and rice profitability. There were six fertilizer management guidelines evaluated, namely: T₁-Control, T₂-Farmer's Fertilizer Practice (FFP), T₃-Soil-test-based (STB) fertilizer application, T₄-Rice Crop Manager (RCM), T₅-Organic Fertilizer+ Nitrogen (OF+N), and T₆-sole OF. Results showed that OF and OF+N application substantially increased soil fertility after harvest while STB and OF+N increased tissue N and K uptake. STB fertilizer application markedly increased grain yield and profit by 31% and 30% over the control. In comparison, grain yield in the RCM and FFP increased by 24% and 22%. Furthermore, profit increased by 17% and 20% in RCM and FFP, respectively. Further, the OF+N application boosted rice productivity and profitability. The OF+N treatment increased the yield and profit by 26% and 7%. Conversely, the control and the sole OF treatments got the lowest yield and profits. Based on the results, STB treatment was the most productive and profitable nutrient management practice with a 4.95 t/ha yield and ₱41,040.00 net income.

1. INTRODUCTION

Rice is considered the most important agricultural commodity in the country. It is a primary dietary source of energy and protein for nearly 104.9 million Filipinos. In the country, rice continues to be the main growth driver of the Philippine economy, contributing about 350,132.00 million pesos in the Gross Domestic Product [1]. The country's rice output for the past 5 years has slowed down with only a 1.3% increase in yield from 18.44 million metric tons (MT) in 2013 to 19.28 million MT in 2017 [1]. This is very low compared to other neighboring Asian countries (e.g., Thailand, Vietnam, and Indonesia).

Moreover, the rice production volume also declined for three successive years from 2014 up to 2016 [2]. Yield per hectare also dropped from 3.93 MT in 2017 to 3.87 MT in 2018. With the growing rice consumption and increasing population in the country, rice production must be increased significantly. However, up until now, rice-self-sufficiency is still a quest. The incapability to meet the need for increasing rice consumption is associated with relatively low yields, low cropping intensity, high post-harvest losses, and damage due to floods and typhoons. Furthermore, soil fertility reduction, continuous cropping without fertilizer application, and imbalance soil fertilization have contributed to the lower crop production.

Soil fertility affects crop productivity/yield. Fertile soil supplies nutrients to plants without causing nutrients toxicity or deficiency or nutrient imbalance. Soil fertility and crop productivity can be increased through proper soil nutrient management (SNM), a process that optimizes the use of fertilizer (e.g., chemical fertilizer, compost, and animal manure) as a source of plant nutrients. SNM is aimed at improving soil health at the same time meeting the nutrient requirements of crops. This can be achieved by applying fertilizer in the right amount, using the right source, the correct placement, and proper timing [3]. Thus, SNM can maximize nutrient uptake to crops while minimizing nutrient losses.

Chemical (inorganic) and organic fertilizers (OFs) have been widely used by farmers to supplement soil nutrients. Chemical fertilizers are produced artificially to provide rapid nutrition to plants. Chemical fertilizers contain mineral nutrients in high concentrations (N, P, and K) that are soluble and readily plant-available. On the other hand, OFs are derived from animal manure and crop residues. OF application in soil offers several benefits such as building up soil organic matter, increases soil water holding capacity, reduces soil compaction, increases soil porosity, and improves soil structure [4-8].

Moreover, OF could boost soil microbial activity by providing an energy source to microorganisms and enhanced plant growth by providing a broad array of nutrients (macro and micronutrients) [9-12]. In general, OFs contain plant nutrients that are slowly available and at a low level. Thus, integrating chemical fertilizer with OF would bring more relevant improvement in soil fertility and crop productivity than applied solely [13,14]. The combined application of inorganic and

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OFs provides a balanced source of nutrients to plants and increases fertilizer use efficiency. Fertilizer application enriches soil nutrients, enhances nutrient uptake, and increases crop yield. However, improper fertilizer application, inappropriate timing, and application in excessive doses may lead to environmental degradation, reduces nutrient use efficiency, crop yield reduction, and profit loss. Therefore, proper SNM practices that consider the timing, quantities, and type of fertilizer can significantly maximize crop yield and profit.

A sound nutrient management program requires basic knowledge of the fertility status of the soil. Soil chemical test (a diagnostic tool for monitoring soil fertility) measures soil's nutrient level, which provides a basis for fertilizer recommendations. This nutrient management tool optimizes crop production, helps farmers develop a correct diagnosis of plant nutritional problems, avoids excessive use of fertilizer, minimizes nutrient losses, and saves farm inputs by applying only the actual amount of fertilizer required. Studies have shown that soil test-based fertilizer application increased crop yield and profit. Mittal and Sharma [15] reported higher grain and straw yield, nutrient uptake, and net return of rice over Farmer's fertilization practice and the control. Likewise, the application of fertilizers based on soil-test value significantly improved grain and straw yield of rice, soil nutrient contents, and soil microbial activities [16].

Another management approach to maximize crop production is the rice crop manager (RCM), a web-based generated site-specific nutrient recommendation. This crop and nutrient management tool were developed by the International Rice Research Center and Africa Rice Center for rice production. RCM already provided crop nutrient advisory to several countries such as India, Bangladesh, Indonesia, and the Philippines. In the Philippines, RCM was formally launched in 2013 and has already provided more than 1 million fertilizer recommendations to farmers. RCM recommendation provides an additional yield increase of 0.3–0.4 t/ha¹ and added net income to about US\$ 100 ha⁻¹ per season [17]. In the study conducted by Sharma *et al.* [18], consistent higher yield was recorded in RCM recommendation compared to Farmer's filed practice and blanket fertilizer recommendation due to improved N management. The study involved 209 field trials in India for 2 years (covering two dry and two wet cropping seasons) involving different rice varieties in six agro-climatic zones.

Ensuring higher rice productivity requires appropriate nutrient management practices which have become an essential component of modern rice production technology [19]. Soil test-based fertilizer and RCM recommendations are among the right tools to aid farmers in making decisions related to nutrient management. Both tools provide field-specific fertilizer recommendations aimed to maximize both yield and profit. Conducting field trials to validate these tools' effectiveness will give additional information for future crop management decisions. In the study, we evaluated different fertilizer management practices (Farmer's Fertilizer Practice [FFP], soil-test-based [STB] fertilizer application, RCM, OF+N, and sole OF) to determine its effects on soil fertility and nutrient uptake of rice. Further, the study aimed to identify the most productive and profitable nutrient management practices for rice production.

2. MATERIALS AND METHODS

2.1. Site Description, Soil Collection, Preparation, and Analysis

The study was conducted from March to July 2019 at the Rice Experimental Site (8°57'07"N, 125°35'53"E, 27.7 m above sea level) in Caraga State University (CSU), Butuan City, the Philippines. The site has a level topography with proper irrigation and had a history of

rice farming for more than 10 years. The soil belongs to the Butuan series, classified as *Typic Epiaquepts*, had a loamy texture which was developed from older alluvial terraces of the Agusan River and poorly drained [20]. Further, Butuan City belongs to type IV climate, and rainfall is evenly distributed throughout the year. Butuan has a mean annual temperature of 26.8°C and a yearly rainfall of 2470 mm. One month before the study commenced, 20 soil samples (0–20 cm depth) were randomly collected from the experimental site for initial chemical analysis. The collected samples were air-dried, pulverized, sieved (2-mm mesh), and composited. A 1 kg samples were brought to the Regional Soils Laboratory, Butuan City, the Philippines for pH, total organic carbon (OC), total N, extractable P, and exchangeable K, Ca, Mg, and Na analysis. The result of the chemical analysis was the basis for fertilizer application in the STB treatment.

2.2. Experimental Design and Treatment Details

The experiment was arranged in a Randomized Complete Block Design with three replications. There were six fertilizer management guidelines evaluated in the study, namely: T₁-Control, T₂- FFP, T₃ -STB fertilizer application, T₄- RCM, T₅- OF+ Nitrogen (OF+N), and T₆- sole OF.

The FFP treatment (53-7-37 kg N, P₂O₅, and K₂O/ha) was based on the current fertilization practice in CSU rice production. The chemical fertilizers were split applied into three: 1st application at 21 days after transplanting (DAT) using two bags of urea (46-0-0); 2nd application at 45 DAT using one bag of complete (14-14-14), and 3rd application at 60 DAT using one bag of muriate of potash (0-0-60).

RCM recommendation (60-14-14 kg N, P₂O₅, and K₂O/ha) was generated using the RCM mobile android application. The recommendation was satisfied using two bags of complete fertilizer and two bags of urea. Complete fertilizer was applied at 21 DAT, while urea was applied at 45 DAT.

STB treatment (70-7-37 kg N, P₂O₅, and K₂O/ha) was based on soil analysis performed at the Regional Soils Laboratory, Butuan City, the Philippines. Three split applications of fertilizers were made. The first application of fertilizer was made at 21 DAT using one bag of complete and 1.5 bags of ammonium sulfate (21-0-0). Second fertilizer application was made at 32 DAT using 2.25 bags of ammonium sulfate. The third fertilizer application was made at 45 DAT using 2.25 bags of ammonium sulfate and one bag of muriate of potash (0-0-60).

The OF+N treatment was a combination of 80% (16 t/ha) goat manure (GM), and 20% (4 t/ha) carbonized rice hull (CRH) applied at 20 t/ha plus two bags of urea. The GM and CRH were obtained from the Organic Farm in CSU. Both organic amendments were broadcasted in the designated plot and immediately incorporated by hands 4 weeks before planting to allow mineralization of nutrients. On the other hand, urea was applied 15 DAT.

Sole OF treatment was a combination of 80% GM and 20% CRH applied at 20 t/ha without chemical fertilizer (urea) addition. Both organic amendments were applied basally 4 weeks before transplanting. In addition, a control treatment was added where no fertilizer was applied.

2.3. Land and Seedling Preparation

The area was prepared by plowing and harrowing twice at weekly intervals using hand tractor. The field was leveled after the last harrowing, and three feet high ridges (levees) were constructed to avoid water and fertilizer movement. NSIC Rc122 (also known as Angelica

variety), an inbred rice variety was used in the study. This variety has an average of 4.7 t/ha yield and resistant to blast and stem borer with intermediate reaction to bacterial blight, tungro, brown planthopper, and green leafhopper. The seeds were placed in a durable sack (half-filled) and soaked in clean water for 24 h. After soaking, the water was drained, and the sack was placed on top of a wooden platform in a shaded area. The seeds were incubated for 24 h or until white “dots,” or swollen embryos were observed. Raised seedbeds (4–5 cm above the original soil level) were then prepared for rice seedlings. The seedbed was 1 m wide of any convenient length. A 40 cm spaces between seedbeds were provided to facilitate seedbed management. The sprouted seeds were grown in the seedbeds for 24 days and then transplanted in each experimental plot, which measures 4 m wide × 5 m length. A total of 1500 seedlings were planted in each plot (3 seedlings hill⁻¹) at a planting distance of 20 cm × 20 cm, respectively. Ten sample hills were selected per plot as an observational unit.

2.4. Rice Management, Harvesting, Soil, and Plant Tissue Analysis

After transplanting, the water in each plot was drained to facilitate root development and was re-irrigated seven DAT. Water in each plot was maintained at 5-inch depth throughout the growing period. Commercial herbicide and pesticides were used to control weeds and insect pests. Molluscicide was also used to control water snails infecting rice. Rice was harvested after reaching its maturity/harvesting stage (122 DAT). Ten representative hills were manually harvested per plot for data collection (plant height, tiller number, panicle weight, total number of grains panicle⁻¹, total number of filled grains panicle⁻¹, and % filled spikelet). The remaining hills were mechanically harvested using a combine harvester, and the yield data (grain yield and straw yield) were collected. Plant samples were collected after harvest and were sent to the laboratory for plant tissue analysis (N and K). Soil samples after harvest were also collected for residual analysis (pH, total OC, total N, extractable P, and exchangeable K).

2.5 Statistical Analysis

Treatment means significance was determined through analyses of variance using Statistical Tool for Agricultural Research version 2.0.1 2014. If the significance is detected, a *post hoc* analysis was conducted and the differences between means were identified using Tukey's Honest Significant Difference Test.

3. RESULTS AND DISCUSSION

3.1. Initial Soil Chemical Analysis

Table 1 presents the initial analysis of the soil samples from the experimental field. Nutrient level in the area ranged from low to high. Soil pH was slightly acidic, with moderately low OC, low total N, very high extractable P, and sufficient exchangeable K, Na, Ca, and Mg.

3.2. Chemical Composition of GM and CRH

Chemical analysis of the two organic amendments used in the study showed that GM and CRH had alkaline pH (pH >7.0) [Table 2]. The OC content in GM was 33-fold higher than CRH. Furthermore, GM had more top nutrient composition (N, P, K, and Mg) than CRH, except Na and Ca. Superior nutrient concentrations in GM was probably related to animal diet. With high pH and Ca content, CRH may serve as an alternative liming material on acidic soil. On the other hand, GM could be an excellent source of nutrients, particularly in nutrient-depleted soil.

Table 1: Selected chemical properties of soil before the experiment

Property	Soil
pH	6.19
Total OC (%)	1.91
Total N (%)	0.002
Extractable P (ppm)	27.00
Exchangeable K (ppm)	107.00
Exchangeable Ca (ppm)	502.00
Exchangeable Mg (ppm)	658.73
Exchangeable Na (ppm)	74.18

OC: Organic carbon, N: Nitrogen

Table 2: Selected chemical properties of goat manure and carbonized rice hull

Property	GM	CRH
pH	7.43	10.46
Total OC (%)	49.39	1.51
Total N (%)	2.55	0.06
P (%)	2.02	0.74
K (%)	3.31	1.07
Ca (%)	BDL	0.34
Mg (%)	1.81	2.47
Na (%)	1.73	0.43

OC: Organic carbon, BDL: Below the detection limit, GM: Goat manure, CRH: Carbonized rice hull, N: Nitrogen

3.3. Impacts of SNM Practices on Soil Chemical Properties After Harvest

3.3.1. Soil pH

Nutrient management practice had a strong influence on soil pH after harvest [Table 3]. Soil pH in plots that received OF with or without inorganic N addition had slightly higher pH over the control treatment. Maximum pH of 6.65 was observed in the plots fertilized with OF + N, which was statistically at par with that in lone OF, RCM, and control. Higher pH in the organic plots may be attributed to the alkaline nature of CRH and GM [21,22]. In contrast, FFP and STB fertilizer applications decreased soil pH. The largest dropped in pH (6.47) was observed in the STB treatment, where ammonium sulfate was used as a source of N. Oxidation of ammonium ions into nitrate (nitrification) during prolonged aerobic conditions in the soil may have led to pH reduction. Fageria *et al.* [23] reported a decreasing trend in pH with an increasing rate of ammonium sulfate and urea application. However, the ammonium sulfate application resulted in a greater magnitude of pH decrease than by urea. In general, the pH in all treatment plots was slightly acidic, which is suitable for tropical rice that grows in a wide pH range from 4 to 8 [24].

3.3.2. Soil total OC

OF application remarkably increased soil total OC after harvest [Table 3]. The most substantial increase was recorded in the sole OF treatment, with a 32% increase in OC over the control. Similarly, the OF+N application increased soil OC content by 27%. Meanwhile, a comparable increase in OC was noted in control, FFP, STB, and RCM treatments. The substantial rise in OC in the OF amended plots were attributed to high carbon inputs from GM. Animal manures are rich in labile (bio-available) form of carbon that rapidly decomposed in the soil. Based on the chemical analysis, GM contained 49.39% carbon. The total amount of carbon applied from GM was 7902 kg/ha.

A similar increase in soil OC was reported by Putra *et al.* [25] with a GM application at 6 t/ha. Furthermore, Tayyab *et al.* [26] noted a substantial increase in soil total carbon with GM application. Higher soil carbon availability may be attributed to the rapid decomposition of soluble organic compounds from manure.

3.3.3. Soil total nitrogen

Soil N content, as presented in Table 3, follows a similar trend with OC. Total N ranged from 0.22% to 0.33%, with the highest N increase (50%) obtained in the sole OF treatment relative to the control. Combined OF+N followed this with a 36% increase in N. Meanwhile, the plot that did not receive fertilizer (control) got the lowest N increase. Nitrogen content in the FFP, RCM, and STB treatments was statistically at par with the control. Lesser N content in the STB and FFP could partly be explained by plant N removal. Meanwhile, N enrichment in the OF and OF+N treatment was probably due to N-mineralization from manure. Mineralization occurs most readily when the C:N ratio of the material is low (<24:1) [27].

Moreover, a very strong positive correlation ($r = 0.86$; $P \leq 0.01$) was observed between total N and soil organic OC [Table 4]. This indicates

Table 3: Means for the residual soil chemical properties of lowland rice as affected by soil nutrient management practices

Treatments	pH	Total OC (%)	Total N (%)	Extractable P (ppm)	Exchangeable K (ppm)
T ₁ =Control	6.57 ^{ab}	1.86 ^c	0.22 ^c	17.67 ^c	159.33 ^b
T ₂ =FFP	6.53 ^{ab}	1.95 ^{bc}	0.26 ^{bc}	15.33 ^c	136.33 ^b
T ₃ =STB	6.47 ^b	2.07 ^{abc}	0.26 ^{bc}	14.67 ^c	143.00 ^b
T ₄ =RCM	6.60 ^{ab}	1.93 ^c	0.26 ^{bc}	15.67 ^c	136.33 ^b
T ₅ =OF + N	6.65 ^a	2.36 ^{ab}	0.30 ^{ab}	34.67 ^b	296.67 ^a
T ₆ =OF	6.60 ^{ab}	2.46 ^a	0.33 ^a	49.33 ^a	370.00 ^a

Means in a column followed by common letters are not significantly different at 5% level of significance. FFP: Farmer's Fertilizer Practice, STB: Soil-test-based, RCM: Rice Crop Manager, OF: Organic fertilizer, OF + N: OF + Nitrogen, OC: Organic carbon

that the addition of fresh carbon from manure might have stimulated soil microbial activity, which speeds up the rate decomposition and mineralization of nutrients from manure. Furthermore, OF applications may have increased the cation exchange capacity of the soil resulting in higher nutrient retention. Furthermore, organically bound nutrients such as in manure are not readily lost from the soil as it is being tied up in the carbon to carbon structure of the organic matter, hence increased availability of residual N in the soil. In contrast, N from chemical fertilizers is more soluble, leachable and prone to run-off losses, volatilization, and denitrification, particularly in paddy soils [28,29]. Similar results were reported by Uwah and Eyo [30] and Uwah *et al.* [31], who documented higher nutrient availability in soil with GM application. According to them, manure application may have stimulated microbial activity which hastens the decomposition of the organic forms of N, P, and K. Meanwhile, Cai *et al.* [32] reported a significant increase in soil OC and total N in bulk soil with long-term application of manure, with or without chemical fertilizer application.

3.3.4. Soil extractable phosphorus

The residual P content of the soil after harvest significantly increased with nutrient management [Table 3]. The plot treated with sole OF increased soil P by 179% over the control plot. This was followed by the OF+N treatment with a 96% increase in P. Meanwhile, the control, FFP, RCM, and STB treatments have the same comparable increase in soil P. The massive increase in P with manure application may have been attributed to rapid P-mineralization. Animal manures are an excellent source of essential micro and macronutrients (N, P, and K) which are necessary for normal growth and development of plants. Furthermore, it is noteworthy to mention that GM had a low C:P ratio of 24. Organic materials with a low C:P ratio (<200:1) are rapidly mineralized, thus releasing more available nutrients to plants. Correlation analysis showed a strong positive relationship ($r = 0.79$; $P \leq 0.01$) between soil extractable P and total OC [Table 4]. This indicates that soil P availability increases with increasing OC content. According to Hou *et al.* [33], soil OC provides energy and carbon structure for microbes which stimulate microbial activity,

Table 4: Pearson correlation matrix for the selected parameters

Parameter	Soil pH	Total OC	Total N	Extractable P	Exchangeable K	Tissue N	Tissue K	N uptake	K uptake	Plant height	Percentage filled spikelet	Straw yield	Grain yield	Net income
Soil pH	-													
Total OC	-0.27	-												
Total N	-0.10	0.86**	-											
Extractable P	0.17	0.79**	0.82**	-										
Exchangeable K	0.12	0.83**	0.83**	0.96**	-									
Tissue N	-0.24	0.06	0.06	-0.17	-0.12	-								
Tissue K	0.24	0.30	0.42	0.46	0.41	0.19	-							
N uptake	0.10	0.08	0.06	-0.10	-0.06	0.77**	0.19	-						
K uptake	0.37	0.25	0.29	0.33	0.32	0.84**	0.84**	0.60**	-					
Plant height	0.49*	0.32	0.36	0.48	0.49*	-0.12	0.54*	0.30	0.70**	-				
Percentage filled spikelet	-0.36	0.06	0.09	-0.13	-0.16	0.66**	0.66**	0.43	0.22	0.04	-			
Straw yield	0.33	0.09	0.07	-0.01	0.02	0.38	0.15	0.88**	0.64**	0.54*	0.15	-		
Grain yield	0.01	0.08	0.11	-0.16	-0.14	0.43	0.41	0.73**	0.70**	0.39	0.43	0.76**	-	
Net income	-0.05	-0.07	-0.06	-0.28	-0.27	0.39	0.20	0.71**	0.56*	0.27	0.37	0.75**	0.92**	-

*Significant at $P < 0.05$, **Significant $P < 0.01$. OC: Organic carbon, N: Nitrogen

leading to high production of phosphatase enzyme which aid in the mineralization of soil organic P. Significant increases in soil P with GM application has been well documented by Ojeniyi *et al.* [34]; Gichangi *et al.* [35]; and Kihanda *et al.* [36]. According to them, post-harvest increase in soil fertility was due to the direct contribution of nutrients from manure. The results clearly showed that soil fertility and productivity in nutrient-depleted soil could be improved through manure application.

3.3.5. Soil exchangeable potassium

OF application markedly increased available soil K after harvest [Table 3]. Sole OF and combined OF+N increased available soil K by 132% and 86%, respectively, over the control. Meanwhile, the FFP, STB, and RCM have the same comparable increase in soil K with the control. Potassium enrichment in the plot fertilized with OF may have been attributed to direct nutrient addition and mineralization of nutrients from manure. Correlation analysis between soil K and OC showed a very strong positive relationship ($r = 0.83$; $P \leq 0.01$) [Table 4]. The correlation pattern indicated increasing soil K availability with increasing OC in the soil. Organic matter, which comprised 58% carbon, is one of the primary sources of nutrients in the soil which is released during mineralization. Rapid mineralization is favored by low substrate's C:N ratio, neutral to alkaline soil pH, warm temperature, moist soil, and high microbial population. The total amount of K applied in sole OF and combined OF+N treatments was 573 kg/ha, which was 16-fold higher than K added in FFP and STB and 41-fold higher than RCM treatments. However, nutrient availability from manure is dependent on the rate of mineralization. A positive increase in the soil available K with manure application alone or in combination with chemical fertilizer has been reported by other workers [13,37,38].

3.4. Impacts of SNM Practices on Tissue N and P Concentration of Rice

Table 5 presents the N and K content in the above-ground plant parts of rice (straw) after harvest. Fertilizer management practices did not significantly influence nutrient concentration in rice. However, nutrient contents in plants applied with fertilizer were numerically higher than those in control. The N content varied from 0.69% to 0.92%, which was below the optimal range (2.8–3.6%) for rice [39]. Lower N concentration in the leaves may have been attributed to the remobilization of plant N from the leaves to panicles and grains during the reproductive stage [40,41]. In rice, N promotes grain fillings and improves protein content in grains.

Similarly, rice K content slightly increased with fertilizer application [Table 5]. The lowest K concentration was recorded in the control

treatment (2.04 %), while combined organic and inorganic fertilizer (OF+N) increased K content to 3.74%. In general, K contents in plants were above the optimal range value of 1.5–2.7%, except in the control and FFP treatments [39].

3.5. Impacts of SNM Practices on Total N and P Uptake of Rice

The N uptake of rice significantly increased with fertilizer management practices [Table 5]. The values went up from 24.36 kg N/ha in control to 46.66 kg N/ha in the STB management. The highest plant N accumulation was recorded in the STB practice, with a 92% increase in N over the control. Furthermore, the FFP and RCM treatments increased plant N uptake by 66% and 48%, respectively. Similarly, higher N accumulation was recorded in the sole OF and OF+N practice, which was statistically similar to control. Higher N uptake of rice with STB fertilizer application may be attributed to high application rates of N (70 kg/ha) and improved N use efficiency. Correlation analysis showed that N uptake was strongly associated with tissue N ($r = 0.77$; $P \leq 0.01$) and K uptake ($r = 0.60$; $P \leq 0.01$) [Table 4]. The correlation suggests that plants with high tissue N content would accumulate more N in their biomass. Moreover, increasing levels of K in plant tissue stimulates N uptake. At optimum levels of nutrition, rice takes up about 6 kg of N in straw for every ton of grain yield [42]. In rice, N promotes rapid plant growth and tillering. Nitrogen also increases grain yield, grain filling, and quality of grains (protein content) [41,43,44].

Nutrient management significantly influenced K uptake in plants [Table 5]. The K uptake values ranged from 71.95 kg/ha to 190.92 kg/ha. The highest K uptake was recorded in the OF+N practice with a 165% increase over the control. This was followed by STB and sole OF treatments with 128% and a 109% increase in K. Meanwhile, K uptake in FFP and RCM was statistically at par with that in control. Higher K accumulation in the OF+N practice was probably due to the rise in soil available K. Moreover, K uptake was strongly associated with K tissue ($r = 0.84$; $P \leq 0.01$) and N uptake ($r = 0.60$; $P \leq 0.01$) [Table 4]. Hence, greater K accumulation in the leaf was mainly due to an increase in tissue K and N uptake. Approximately 14 kg of K is absorbed in straw per ton of grain yield [45]. In rice, K promotes root growth, prevents the crop from lodging, and increases grain size and weight and grain fillings [46,47]. Thus, a deficiency of K would severely limit grain production, lower grain weight, and produced higher numbers of unfilled grains. The result of our study corroborates with the findings of Moe *et al.* [48], who reported higher N, P, and K uptake of rice with manure and chemical fertilizer application. Similarly, STB inorganic fertilizer application alone or integrated with organic manure significantly increased the total uptake of N, P, and K of rice plant [49].

3.6. Impacts of SNM Practices on the Growth and Yield Components of Rice

3.6.1. Plant height at 45 DAT

Table 6 presents the height of rice at 45 DAT as affected by fertilizer management practices. Tallest plant height was recorded in the OF+N treatment, followed by OF and FFP. Meanwhile, shorter heights were observed in control, STB, and RCM treatments. Plant height is often found both as an indicator of growth and as a parameter used for environmental influences. Superior growth seen in the OF+N treatment was attributed to the increase in soil available K, plant tissue K, and soil pH improvement [Tables 3 and 5]. Correlation analysis showed a moderate to strong positive correlation between plant height and soil pH ($r = 0.49$; $P \leq 0.05$), available K ($r = 0.49$; $P \leq 0.05$), tissue K ($r = 0.54$; $P \leq 0.05$), and total K uptake (0.70;

Table 5: Means for the N and P tissue content and uptake of lowland rice as affected by soil nutrient management practices

Treatments	N content (%)	K content (%)	N uptake (kg/ha)	K uptake (kg/ha)
T ₁ =Control	0.69	2.04	24.36 ^b	71.95 ^b
T ₂ =FFP	0.77	2.22	40.37 ^{ab}	115.59 ^{ab}
T ₃ =STB	0.92	3.22	46.66 ^a	164.20 ^a
T ₄ =RCM	0.80	3.05	35.98 ^{ab}	135.93 ^{ab}
T ₅ =OF + N	0.74	3.74	38.90 ^{ab}	190.92 ^a
T ₆ =OF	0.78	3.22	36.87 ^{ab}	150.54 ^a

Means in a column followed by common letters are not significantly different at 5% level of significance. FFP: Farmer's Fertilizer Practice, STB: Soil-test-based, RCM: Rice Crop Manager, OF: Organic fertilizer, OF + N: OF + Nitrogen

Table 6: Means for the growth and yield components of lowland rice as affected by soil nutrient management practices

Treatments	Plant height (cm)	Tiller number	Average panicle weight (g)	Total panicle weight hill ⁻¹ (g)	Tot. number of grains panicle ⁻¹	Total number of filled grains panicle ⁻¹	Percentage filled spikelet
T ₁ =Control	56.67 ^c	21	1.76	18.05	115.00 ^a	89.00	77.00 ^b
T ₂ =FFP	63.18 ^b	23	2.08	24.07	86.00 ^b	71.00	83.00 ^{ab}
T ₃ =STB	60.48 ^{bc}	21	2.18	22.68	79.00 ^b	69.00	88.00 ^a
T ₄ =RCM	58.85 ^{bc}	22	2.04	21.80	82.00 ^b	68.00	83.00 ^{ab}
T ₅ =OF + N	69.22 ^a	23	2.14	23.32	99.00 ^{ab}	78.00	79.00 ^b
T ₆ =OF	64.20 ^{ab}	25	2.45	24.37	105.00 ^{ab}	87.00	83.00 ^{ab}

Means in a column followed by common letters are not significantly different at 5% level of significance. FFP: Farmer's Fertilizer Practice, STB: Soil-test-based, RCM: Rice Crop Manager, OF: Organic fertilizer, OF + N: OF + Nitrogen

$P \leq 0.01$) [Table 4]. These soil factors positively influenced plant growth of rice during the rapid tillering stage. Soil pH controls the soil's solubility, mobility, and bioavailability of plant nutrients [50]. At near neutral pH, most of the macro and micronutrients (trace elements) becomes available. On the other hand, K is involved in various biochemical (protein synthesis, carbohydrate metabolism, and enzyme activation) and physiological processes (stomatal regulation and photosynthesis) that are responsible for plant growth and development [51]. Moreover, K also improves plant resistance against pest and disease infestation, metal toxicity, and drought, ultimately affecting plant growth. A similar growth improvement with manure application either applied solely or combined with chemical fertilizer was reported by Iqbal *et al.* [38] and Escasinas and Zamora [52]. Combined application of organic and chemical fertilizers provides a balanced mixed nutrient (macro and micronutrients) essential for plant growth and survival.

3.6.2. Plant tillers at 45 DAT

Table 6 shows the number of plant tillers at 45 DAT as influenced by fertilizer management practices. High grain production in rice is closely associated with tillers production. High tiller numbers produce more yields. Statistical analysis revealed no significant differences in tiller numbers with nutrient management practice. Tiller number per plant varied from 21 to 25 tillers, with the lowest tiller number recorded in control and the highest in the OF treatment. On average, the tiller numbers were 23. The average number of tillers produced by modern rice varieties ranged from 20 to 25 tillers, with 14–15 of them become productive (produce panicles) while the remaining tillers are unproductive [53].

3.6.3. Total panicle weight plant⁻¹ and average panicle weight of rice

Total panicle weight plant⁻¹ and average panicle weight of rice are presented in Table 6. Both of these parameters were not significantly affected by fertilizer management practices. On average, the total panicle weight and mean panicle weight plant⁻¹ in the FFP, RCM, STB, OF+N, and sole OF were 23 g and 2 g, respectively. These values were numerically higher compared to those in the control plants (18.05 g and 1.76 g). In general, nutrient management practice had resulted in heavier panicle weights and a higher panicle number than those in the control plants.

3.6.4. Total grains panicle⁻¹ and total number of filled grains panicle⁻¹ of rice

The total number of grains panicle⁻¹ significantly varied with nutrient management practice [Table 6]. Panicle grain numbers ranged from 79 to 115 grains, with 68–89 grains filled (productive grains). The highest number of grains counted was in control, irrespective of the weight

and filled grain numbers. This was followed by sole OF and combined OF+N. On the other hand, lower panicle grain numbers were counted in the FFP, STB, and RCM treatments.

Interestingly, it was also in the control and the OF treatments where the highest percentage of unfilled grains were recorded, with 23% and 17% empty grains (data not shown). Whereas, higher filled grains percentage were recorded in the FFP, RCM, and STB treatments that received chemical fertilizer. A higher ratio of filled grains in plants treated with chemical fertilizer may be attributed to higher nutrient use efficiency and improved N nutrition in plants. Plants with higher filled grain percentages are more efficient in partitioning photosynthetic products (carbohydrates), resulting in higher economic yield. Contrary to our findings, Siavoshi *et al.* [54] reported that chemical fertilizer application resulted in higher numbers of hollow spikelets per panicle against sole organic and combined organic and chemical fertilizers. Meanwhile, Xu *et al.* [55] reported higher filled grain rate in rice treated with sole manure or manure combined with chemical fertilizer over chemical fertilizer alone.

3.6.5. Percent filled spikelet of rice

Fertilizer management practices significantly increased the filled spikelet percentage of rice [Table 6]. The values varied from 77% to 88%, with the lowest and highest filled spikelets recorded in the control and STB, respectively. A higher but statistically comparable filled spikelets values over the control were also noted on the FFP, RCM, OF+N, and sole OF treatments. The high percentage of filled spikelets in the STB treatment may be attributed to higher use of fertilizer N (70 kg/ha) over FFP (53 kg/ha) and RCM (60 kg/ha) as well as higher plant N-accumulation. Correlation showed a strong positive relationship between filled-spikelet percentage and tissue N concentration ($r = 0.66$; $P \leq 0.01$) [Table 4]. Thus, grain filling percentage increases as tissue N content also increases. Nitrogen in rice increases spikelet number and the number of filled spikelets, which largely determined the yield potential of a plant [41,56,57]. Contrary to the result of our study, Gebrekidan and Seyoum [58] observed a reduction in filled spikelets with an increasing N. Similarly, the combined P with increasing N decreased spikelet fertility in rice [59].

3.7. Impacts of SNM Practices on Fresh Straw Yield of Rice

Straw yield production of rice significantly increased with fertilizer management practices [Table 7]. The plots amended with OF+N increased straw yield by 50% over the control. Likewise, the FFP, STB, sole OF, and RCM treatments increased straw yield production by 48%, 45%, 35%, and 27%, respectively. Conversely, the lowest biomass produced was observed in control plants, which was statistically similar to the rest of the treatments, except OF+N. On

Table 7: Means for the straw and grain yield and net income of lowland rice as affected by soil nutrient management practices

Treatments	Straw yield (t/ha)	Grain yield (t/ha)	Net income (₹/ha)	Production cost (₹/ha)	Gross income (₹/ha)
T ₁ =Control	10.63 ^b	3.78 ^c	33,198.00 ^{ab}	23,552.00 ^d	56,750.00 ^c
T ₂ =FFP	15.78 ^{ab}	4.62 ^{ab}	39,698.00 ^{ab}	29,552.00 ^e	69,250.00 ^{ab}
T ₃ =STB	15.38 ^{ab}	4.95 ^a	41,040.00 ^a	33,260.00 ^b	74,300.00 ^a
T ₄ =RCM	13.53 ^{ab}	4.69 ^{ab}	38,870.00 ^{ab}	31,530.00 ^b	70,400.00 ^{ab}
T ₅ =OF + N	15.93 ^a	4.75 ^{ab}	35,515.00 ^{ab}	35,735.00 ^a	71,250.00 ^{ab}
T ₆ =OF	14.30 ^{ab}	4.35 ^{bc}	32,075.00 ^b	32,408.33 ^b	65,250.00 ^{bc}

Means in a column followed by common letters are not significantly different at 5% level of significance. FFP: Farmer's Fertilizer Practice, STB: Soil-test-based, RCM: Rice Crop Manager, OF: Organic fertilizer, OF + N: OF + Nitrogen

average, straw yield produced under various nutrient management practices was 15 t/ha, notably higher than the unfertilized control (10.63 t/ha). Moreover, the mean straw yield was 3 times heavier than the grain yield produced per hectare. Correlation analysis showed a strong to very strong positive and significant relationship between straw yield production and N uptake ($r = 0.88$; $P \leq 0.01$) and K uptake ($r = 0.64$; $P \leq 0.05$) [Table 4]. Hence, straw yield production increases with increased N and K uptake. Furthermore, straw yield was moderately correlated with plant height ($r = 0.54$; $P \leq 0.05$) [Table 4]. Thus, plants that are taller in heights were likely to produce heavier biomass. Our result concurs with Arif *et al.* [60] findings, who reported higher biological yield (straw yield) of rice with organic manure combined with inorganic fertilizer. Furthermore, Islam *et al.* [61] reported that the application of animal manure combined with chemical fertilizer notably increased the straw yield of rice.

3.8. Impacts of SNM Practices on Grain Yield of Rice

Nutrient management practice significantly increased grain yield production in rice [Table 7]. The highest production was recorded in the STB at 4.95 t/ha. This represented a 31% increase in yield over the control. Similarly, OF+N, RCM, FFP, and sole OF increased yield by 26%, 24%, 22%, and 15%, respectively. Conversely, the control treatment obtained the lowest yield at 3.78 t/ha, which was statistically comparable with sole OF. Higher grain yield obtained in the STB practice may be attributed to higher nutrient/fertilizer use efficiency and improved crop nutrition (N and K). Grain yield was strongly correlated with N uptake ($r = 0.73$; $P \leq 0.01$) and K uptake ($r = 0.70$; $P = 0.01$) [Table 4]. The association was positive and significant. Hence, grain yield increased was directly related to the increase in N and K uptake of plants. Moreover, grain yield was strongly associated with straw yield ($r = 0.76$; $P \leq 0.01$) [Table 4]. The correlation suggests that with the increase of vegetative growth, grain yield also increases. Plants that produced more tillers intercept more solar radiation resulting in higher grain yield production.

Similarly, RCM practice significantly increased grain yield of rice. This increase might be associated with higher use of fertilizer N (60 kg N/ha) and improved crop nutrient acquisition [18]. Furthermore, the superior yield obtained in STB and RCM might be attributed to better timing of fertilizer application, which resulted in higher and more efficient crop nutrient utilization. Fertilizers in the RCM and STB were split applied during tillering and panicle initiation, where nutrient demand is higher. On average, the yield obtained in the FFP, RCM, STB, sole OF, and OF+N surpassed the mean yield in the region in 2019, which is currently at 3.20 t/ha [62]. It also surpassed the average national rice production in 2018, which is at 3.97 t/ha [63] Nutrient management practice, which undoubtedly

increased soil fertility and improved crop nutrition, has contributed to higher grain production in rice. The present findings concur with the result of Sarkar *et al.* [49]. They reported maximum numbers of filled grains, grain, and straw yields of rice applied with STB inorganic fertilizer, solitary, or co-applied with manure. Similarly, higher grain yield with STB fertilizer application was reported by Mamun *et al.* [64]. Fertilizer recommendations are based on crop nutrient requirement, current soil fertility level, and target yield. Therefore, fertilizer dose applied is more precise compared to other management practices.

Moreover, in areas where organic manures are abundant and where chemical fertilizer is less accessible and expensive, the farmers may opt using combined organic and inorganic fertilizer to maximize crop yield. In the study, the OF + N treatment posted a 26% increase in yield over the control and had a comparable return over STB treatment. This is possible because OF combined with inorganic fertilizer may increase the fertilizer use efficiency and improve soil's physical and chemical properties. This would be the reason for increased yield [13,38]. Islam *et al.* [61] reported the same increase in rice grain yield with organic manure plus inorganic fertilizer application. Likewise, integrating organic and inorganic fertilizers enhanced yield and yield components of rice [48,65].

3.9. Impacts of SNM Practices on the Net Income of Rice Production

The total gross income, production cost, and net income hectare⁻¹ of rice are presented in Table 7. Net income is a parameter used to measure profitability in rice production. Net income is determined by getting the difference between gross income and production costs. Total production cost includes labor (e.g., land preparation, transplanting, weeding, pesticide and fertilizer application, and harvesting), supplies, and materials (pesticide, seeds, and fertilizer). The most profitable fertilizer management practice in the study was STB, with a total net income amounting to ₹41,040.00. This represented a 24% increase in profit over the control. The second most profitable treatment was the FFP, with a net profit of ₹ 39,698.00, which represented a 20% increase in profit over the control. Higher profitability observed in STB and FFP was attributed to higher grain yield and lower production cost, respectively. On the contrary, the lowest profit of ₹ 32,075.00 was obtained in the sole OF treatment. The untreated control followed this with a net income of ₹ 33,198.00. Lower profitability found in the sole OF was due to high cost of fertilizers. Meanwhile, RCM treatment had a total net profit of ₹ 38,870.00, which was higher by 17% over the control.

Moreover, rice profitability could be augmented by integrating organic manure with commercial fertilizer. The combined OF+N obtained a comparable net income (₹ 35,515.00) with

STB, despite the highest production cost incurred. The order of net income increase with nutrient management practice is as follows: STB>FFP>RCM>OF+N>Control>OF. On the other hand, total production cost was observed in the order of OF+N>STB>OF>RCM>FFP>Control. Moreover, net income had a very strong association with grain yield ($r = 0.92$; $P \leq 0.01$) [Table 4]. The relationship was positive and significant. Hence, net income increased significantly with the increase in grain yield. The results from this study are consistent with what was reported by Sharma *et al.* [66] that superior yield and high net return in rice production were obtained with STB fertilizer recommendation against farmer's practice and general recommended fertilizer dose. Likewise, fertilizer application based on soil test values increased grain yield and net return of rice over general fertilizer recommendation [67]. Furthermore, net profit and benefit-cost ratio of rice were higher in STB fertilizer dose applied solely or co-applied with organic manure [49]. Similarly, Mamun *et al.* [64] reported a higher grain yield of rice with soil test-based fertilizer application and RCM. However, higher profitability was observed in the RCM compared to other fertilizer treatments due to the lower fertilizer costs.

4. CONCLUSION

SNM practice significantly increased soil fertility, nutrient uptake, rice productivity, and profitability. Sole OF and OF+N application substantially increased soil OC, total N, available P and K content after harvest. Meanwhile, sole OF and STB management markedly increase the N and K uptake of rice, respectively. The maximum yield (4.95 t/ha), and net profit (₹ 41,040.00) were obtained in the STB practice. Likewise, the FFP (4.62 t/ha, ₹ 39,698.00) and RCM (4.69 t/ha, ₹ 38,870.00) practice attained a comparable increase in profit and yield with STB. Furthermore, combined application of organic and inorganic fertilizer boosted rice profitability and productivity. In the study, the OF+N treatment registered a 4.75 t/ha yield and a net income of ₹ 35,515.00. Conversely, lower yield and profits were obtained in control (3.78 t/ha; ₹33,198.00) and sole OF (4.35 t/ha; ₹32,075.00) treatments. Based on the above results, STB was the most profitable and productive nutrient management practice.

5. AUTHOR CONTRIBUTIONS

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agree to be accountable for all aspects of the work. All the authors are eligible to be an author as per the international committee of medical journal editors (ICMJE) requirements/guidelines.

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