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E-mail: bjsir07@gmail.com

Mineral nutrition of rice and post-harvest soils influenced by self-made organic composts

S. Akter*, H. R. Khan and M. K. Saha

Department of Soil, Water and Environment, University of Dhaka, Dhaka 1000, Bangladesh

Abstract

Using self-made organic composts i.e., rice hull compost (RHC), rice straw compost (RSC), sawdust compost (SDC), and Vermicompost (V) an experiment was conducted to evaluate their responses on mineral nutrition of rice and post-harvest soils under field condition. The total nitrogen contents among the treatments ranged from 9.6 - 21.4, phosphorus: 1.1 – 4.42, potassium: 3.86 - 7.27, sulfur: 11.9 – 19.7, calcium: 3.30 – 11.87 and magnesium: 2.76 – 5.54 g kg^{-1} at the maturity stage of rice plants which were found to be positively influenced by the applied organic composts. The nutrient status of the post-harvest soils was also influenced by the applied organic composts. The maximum amount of 78.29 mg kg^{-1} available N was recorded in the T_3 treatment, where available nitrogen content increased by 85.65% as compared to the control plot. There were significant ($p \leq 0.05$) increases in other nutrient contents with the increased doses of the composts under rice production.

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Introduction

Rice (*Oryza sativa* L.) is the second most important staple food as it fulfills the dietary requirement of over half of the human population and considers the major food crop of economic significance in Asia (Ahmed *et al*. 2021). Among South Asian countries, Bangladesh ranks second in terms of areas and production of rice, where it is being cultivated on over 82% of the total cropped land, while Aman rice shares over 37% of total rice production (BBS, 2020). In the country, with advancement of time, nutrient mining increases due to increasing cropping intensity (191%; BBS, 2017), use of modern varieties, nutrient leaching, gaseous loss, soil erosion and imbalanced application of fertilizers with no or little addition of organic manure. To ensure the food security of the increasing population, high-yielding rice cultivars are being cultivated on large scale with intensive use of chemical fertilizers, which not only degraded soil fertility but also polluting associated environments and affecting food chain and ultimately affect human health. Higher is the crop yield, higher is the nutrient removal from soil. Nutrient deficiency in this country's soils has arisen chronologically N, P, K and S (Jahiruddin and Satter, 2010). About 45% of net cultivable areas of Bangladesh contain less than 1% organic matter (FRG, 2012). Organic manure is a good source of nutrients, especially N, P and S and it's a good means of soil rejuvenation (Jeptoo *et al*. 2013). So, use of organic matter could be an inevitable practice in the coming years for ensuring sustainable crop productivity without affecting soil fertility (Heikamp *et al*. 2011).

Numerous actions have been taken to improve soil fertility and productivity. The most effective measure is increasing the organic input, such as application of organic manure or compost (Xin *et al*. 2017) and straw incorporation (Zhang *et al*. 2016). Crop straw, an easy-to-get, nutrient-rich resource, has great value for improving soil fertility (Tan *et al*. 2017). Several studies have reported that crop straw is rich in nutrients and organic materials, can be treated as a natural organic fertilizer, and used as an alternative to chemical fertilizers (Wang *et al*. 2017). Therefore, straw amalgamation seems hopeful to maintain and restore soil fertility.

*Corresponding author's e-mail: suma.soil93@gmail.com

However, until now, the use of straw incorporation to increase crop yield is still a matter of argument since studies in different climates and soil types have led to inconclusive results (Pituello *et al*. 2016). It has been reported that straw incorporation has significant valuable effects on crop yields and soil properties. For instance, straw incorporation can increase crop yields (Yang *et al*. 2016), soil organic matter and other soil nutrients (Zhang *et al*. 2018). Straw return can also improve soil physical properties, such as by increasing hydraulic conductivity, decreasing bulk density, and enhancing aggregate formation (Yang *et al*. 2016).

Vermicompost is a nourishing organic fertilizer having high amount of humus, nitrogen 2–3%, phosphorous 1.55–2.25%, potassium 1.85–2.25%, micronutrients, more beneficial for soil microbes like 'nitrogen fixing bacteria' and mycorrhizal fungi. Vermicompost has been scientifically proved as miracle plant growth enhancer (Guerrero, 2010). Ansari and Ismail (2012) reported that worms vermicompost contains 7.37 % nitrogen and 19.58% phosphorous as P_2O_5. Microbial population of N_2- fixing bacteria and actinomycetes increases by the application of vermicompost. The amplified microbial activities improve the availability of soil phosphorous and nitrogen.

Vermicomposting is an aerobic, biological method and is proficient to convert eco-friendly hummus like organic substances (Chanda *et al*. 2011). Vermicompost stimulates to influence the microbial activity of soil, increases the availability of oxygen, maintains normal soil temperature, increases soil porosity and infiltration of water, improves nutrient content and increases growth, yield and quality of the plant (Arora *et al*. 2011). Rice hull and sawdust are also important agricultural amendments. Growth and yield components of rice grown in saline soil were found to be increased significantly ($p \leq 0.05$) by the application of rice hull, rice straw and sawdust alone and in combination (Akter *et al*. 2018). The physico-chemical properties and nutrient status of post-harvest soils were also found to be influenced by the application of these amendments (Akter and Khan, 2019).

Composting is a low-cost natural way of recycling and stabilizing organic matter under thermophilic temperature that forms a pathogen-free substrate, beneficial to crops (Gurtler *et al*. 2018; Somerville *et al*. 2020). Low-income farmers found it more advantageous to them. Composting was found to be a promising practice that brought organic materials to a certain stage by narrowing down its C:N ratio where nutrients are easily accessible to plants (Palaniveloo *et al*. 2020). Partey *et al.* (2018) and Dinesh *et al*. (2011), had consolidated that biomass needs to decompose for making N available to crops. Thus, composting locally available organic amendments (OAs) is essential for a healthy and sustainable agro-ecosystem in different climatic conditions. Therefore, the objectives of the study were to evaluate the nutrient statuses of post-harvest soils and rice plants grown in Aman season as influenced by the different rates of organic composts applied under field condition.

Materials and methods

Study site and experimental design

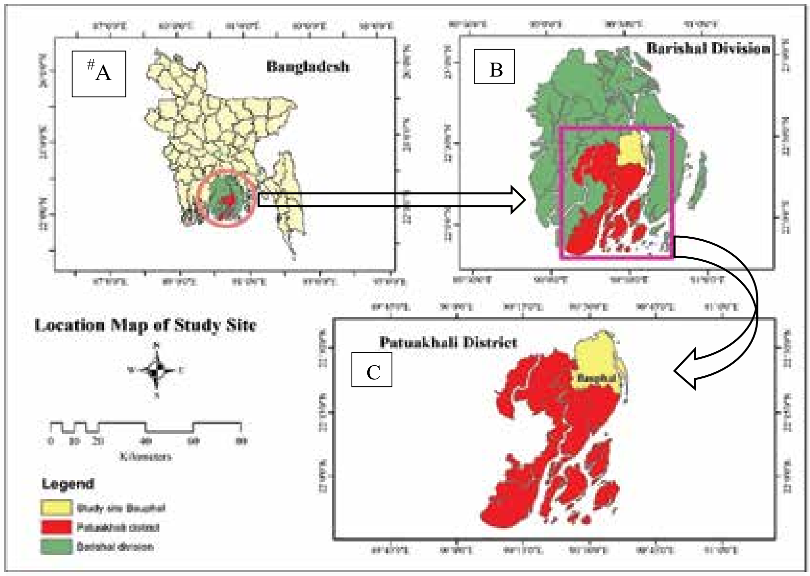
In Patuakhali a district of Bangladesh, the field experiment was conducted in Bilbilash of Bauphal Upazila (Map I), which is located between 22°20′00″N and 90°20′00″E longitude within agro-ecological zone-13 named as Ganges Tidal Floodplain. The climatic condition of this area is usually known as 'tropical monsoon climate'. The area mainly enjoys three seasons such as rainy, dry and summer season.

The experiment was carried out following completely randomized block design with the self-made organic composts, such as, Rice Hull Compost (RHC), Rice Straw Compost (RSC), Sawdust Compost (SDC) and Vermicompost (V) corresponding to the rates of 0, 2, 4 and 8 t ha^{-1} of each organic compost at Aman season during August to December, 2018. There were 13 plots having individual treatment (Table I) in the experimental area, each unit plot size was 16 m^2 (4m×4m) and replications were considered within the plot. Selected properties of potential amendments used and initial soils at field site are presented in the Tables II and III.

Transplantation following subsequent protocols

Basal doses of N, P_2O_5, and K_2O from urea, TSP, and MoP fertilizers were applied at the rates of 40, 30, and 15 kg ha^{-1}, respectively considering soil amendments and initial contents of the nutrients.

During field preparation, the TSP, MoP, and half of the urea were applied in their entirety after being thoroughly mixed with the field soil. The remaining urea was top dressed in two splits, one at the beginning of the rice panicle and another at the active tillering stage. Three seedlings per hill of the BR 25 variety, which were thirty days old and in good health,



#A = Barishal division in Bangladesh map; B = Patuakhali district in Barishal divisional map and C = Bauphal upazila (study site) in Patuakhali district map.

Map I. Location map of the study site

Table I. Description of the treatments used for the experiment

Treatment			
No.	Description	No.	Description
T_0 = Control	No amendments were made	$T_7 = SDC_2$	Sawdust compost @ 2 t ha^{-1}
$T_1 = RHC_2$	Rice hull compost @ 2 t ha^{-1}	$T_8 = SDC_4$	Sawdust compost @ 4 t ha^{-1}
$T_2 = RHC_4$	Rice hull compost @ 4 t ha^{-1}	$T_9 = SDC_8$	Sawdust compost @ 8 t ha^{-1}
$T_3 = RHC_8$	Rice hull compost @ 8 t ha^{-1}	$T_{10} = V_2$	Vermicompost @ 2 t ha^{-1}
$T_4 = RSC_2$	Rice straw compost @ 2 t ha^{-1}	$T_{11} = V_4$	Vermicompost @ 4 t ha^{-1}
$T_5 = RSC_4$	Rice straw compost @ 4 t ha^{-1}	$T_{12} = V_8$	Vermicompost @ 8 t ha^{-1}
$T_6 = RSC_8$	Rice straw compost @ 8 t ha^{-1}		

Table II. Nutrient compositions of different organic amendments used in the field experiment

Nutrient element (%)	Organic composts			
	RHC	RSC	SDC	V
Org. C	11.37	20.17	13.28	16.15
Total N	0.57	1.07	1.02	1.05
Total P	0.15	0.36	0.31	0.72
Total K	0.14	0.43	0.23	0.79
Total S	0.23	0.29	0.22	0.28
Total Ca	0.08	0.21	0.14	0.24
Total Mg	0.07	0.18	0.09	0.15

Table III. Selected properties of initial soil (on oven dry basis: 0-15 cm) used in the field experiment

Properties	Values
A. Physical	
Particle density (g cm^{-3})	2.53
Bulk density (g cm^{-3})	1.25
Porosity (%)	50.21
Moisture content (%)	3.15
Particle size distribution	
Sand (%)	5.67
Silt (%)	57.47
Clay (%)	36.86
Textural class	
B. Chemical	
pH	4.57
EC (Saturation extract, 1:5; dS m^{-1})	0.21
Organic matter (%)	1.56
Total nitrogen (g kg^{-1})	0.54
Available nitrogen (mg kg^{-1})	63.07
Available phosphorus (mg kg^{-1})	7.21
Available sulfur (mg kg^{-1})	19.18
Exchangeable Cations (c mol_c kg^{-1}):	
Potassium (K^+)	0.21
Calcium (Ca^{2+})	5.41
Magnesium (Mg^{2+})	3.88
Cation Exchange Capacity (c $mol_c kg^{-1}$)	12.87

were transplanted. Row to row and hill to hill distances were each 20 and 22 cm, respectively. No irrigation was required for this study for the growth of rice in this season. Intercultural operations such as, weeding, pesticide use, etc. were done as per requirement.

Sample collection and analyses

Plant samples were collected from each plot just after harvesting. Soil samples were collected from 3 spots as replications of each plot of active root zone (0-15 cm) with the help of an auger. Soil samples were then stored treatment wise in polythene bags with proper labeling. After sun drying and grounding the samples were then passed through 2 mm sieve and stored properly in air tight plastic pots for further analyses. The collected plant samples were sun dried and weighed. After sun drying a portion of the collected plant samples were oven dried at 65°C and then grinded and stored in air tight plastic pots for laboratory analyses. All the laboratory analyses were done following standard methods.

Statistical analyses

Pearson correlation and regression analyses between treatments and mineral nutrition of rice plants, Analysis of Variance (ANOVA) and Tukey's Range Test at 5% ($p \leq 0.05$) level were done for the interpretation of the experimental results.

Results and discussion

Mineral nutrition of rice plants

The total nitrogen, phosphorus, potassium, sulfur, calcium and magnesium contents at maturity stage of rice plants grown under field condition were significantly ($p \leq 0.05$) influenced by the application of variable indigenous organic amendments (rice hull compost, rice straw compost, sawdust compost and vermicompost) during Aman season (Table IV and Fig.1). Pearson correlation and regression analyses have been performed between the different treatments and mineral nutrition of rice plant tissues (Table V).

Significance has been determined based on p values whether they were <0.05 or not. The total nitrogen (r = 0.78***), phosphorus (r = 0.77**), potassium (r = 0.75**), sulfur (r = 0.82***), calcium (r = 0.82***) and magnesium (r = 0.60*) contents of the tested rice plant (BR 25) tissues were significantly correlated with the applied organic composts and these correlations confirmed that the different sources of organic materials positively influenced the nutrition of rice plant tissues which ultimately regulate the edible part (grain) of the rice crops.

According to Graham *et al.* (2012), people taking cereal based diets still suffering from hidden hunger of nutrients due to low level and low bioavailability of essential elements. The present results demonstrated that the nitrogen content in rice straw increased with the increased rate of the application of organic composts. The maximum nitrogen contents in the rice plant tissues were recorded at V_8 treatment for the tested variety. Among the applied composts, vermicompost (18.63 g kg^{-1}N) ranked first followed by rice straw compost (17.40 g kg^{-1}), sawdust compost (14.57g kg^{-1}) and rice hull compost (13.33 g kg^{-1}), regardless of their doses. Phosphorus contents in rice plant tissues increased with the higher rates of the different composts. The highest (4.42 g kg^{-1}) and lowest (1.10 g kg^{-1}) contents of total phosphorus were recorded in the T_{12} (V_8) and T_0 (control) treatments. The rest of the above-mentioned nutrients were exerted the similar trends as those

Table IV. Impacts of applied organic composts on mineral nutrition of rice plant tissues grown during Aman season in Patuakhali district of Bangladesh

Treatment	Nitrogen	Phosphorus	Sulfur	Potassium	Calcium	Magnesium
	Total (g kg^{-1})					
T_0 = Control	9.6 e	1.1 a	11.9 b	3.86 ab	3.3 a	2.76
T_1 = RHC_2	11.3 be	1.34 a	13.6 ab	3.32 a	3.92 ab	3.18
T_2 = RHC_4	13 ab	1.58 ab	13.8 ab	4.5 abc	5.6 abc	3.29
T_3 = RHC_8	15.7 acd	2.24 ab	14.7 abc	4.96 abc	7.21 cdef	3.35
T_4 = RSC_2	14.6 ac	2.05 ab	14 ab	3.9 ab	6.13 abcd	3.66
T_5 = RSC_4	17.1 cdf	2.7 ab	15.5 acd	5.2 abc	8.77 defg	4.71
T_6 = RSC_8	20.5 gh	3.65 ab	17.9 de	6.79 bc	11.3 gh	4.68
T_7 = SDC_2	11.6 be	1.78 ab	13.7 ab	4.52 abc	5.05 abc	3.53
T_8 = SDC_4	14 ab	2.23 ab	14.6 abc	5.09 abc	5.94 abcd	3.82
T_9 = SDC_8	18.1 dfg	3.12 ab	17.3 cde	6.9 c	9.67 fgh	4.65
T_{10} = V_2	15.7 acd	2.35 ab	16.3 acd	4.55 abc	6.64 bcde	4.09
T_{11} = V_4	18.8 fgh	3.13 ab	17 cde	6.17 abc	9.13 efgh	4.96
T_{12} = V_8	21.4 h	4.42 b	19.7 e	7.27 c	11.87 h	5.54

In a column, means followed by a common letter are not significantly different at 5% level by Tukey's Range Test

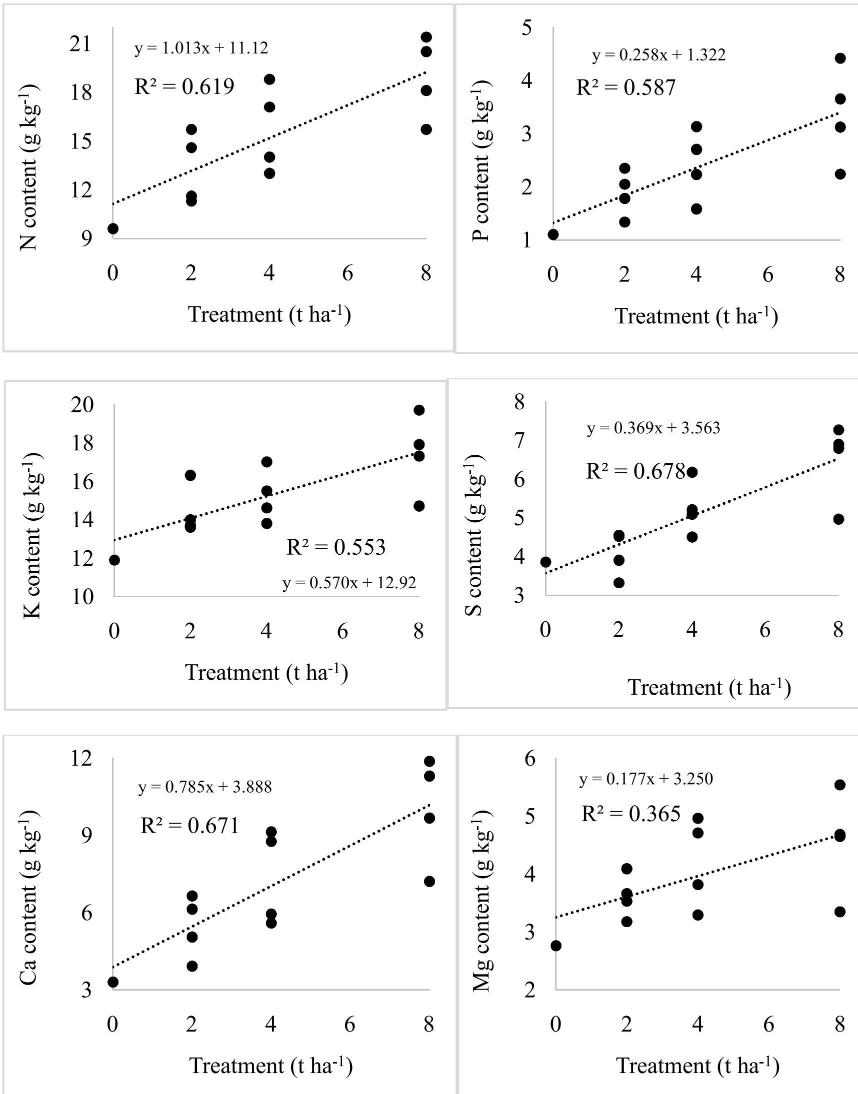
Table V. Correlation between the treatments and mineral nutrition of rice plant tissues

Nutrition	Coefficient	Stand. Error	t Stat	P-value	Lower 95%	Upper 95%
Nitrogen	1.0133	0.2394	4.2322	0.0014	0.4863	1.5403
Phosphorus	0.2588	0.0655	3.9541	0.0023	0.1148	0.4029
Potassium	0.6295	0.1663	3.7864	0.0030	0.2636	0.9955
Sulphur	0.3697	0.0767	4.8205	0.0005	0.2009	0.5385
Calcium	0.7854	0.1656	4.7437	0.0006	0.4210	1.1498
Magnesium	0.1778	0.0706	2.5189	0.0285	0.0224	0.3332

obtained by the P and N contents by the different organic composts. The nutrition of rice shoots was influenced by the direction of vermicompost > rice straw compost > sawdust compost > rice hull compost for the studied variety of rice grown under field condition.

Nutrient status of post-harvest soils

Rice production during T. Aman season, the available N contents in the post-harvest soils increased significantly ($p \leq 0.05$) by the application of vermicompost, rice hull compost, rice straw compost and sawdust compost (Table VI and Fig. 2). The maximum amount of available N (78.29 mg kg^{-1}) was recorded in T_3 (RHC_8) treatment, where available nitrogen content increased 85.65% as compared to control plot. At the same dose (8 t ha^{-1}), the sawdust compost treatment ranked second for the available nitrogen content (62.31 mg kg^{-1}) at post-harvest soils followed by RSC_8 treatment (60.76 mg kg^{-1}). There were significant ($p \leq 0.05$) increase in available phosphorus and sulfur, exchangeable potassium, calcium and magnesium at post-harvest soils with the increased doses of the organic amendments under rice production (Table VI). Soils treated with vermicompost at the rate of 8 t ha^{-1} was found to have significantly more phosphorus (12.57 mg kg^{-1}) as compared to control plot. The rice straw compost and sawdust compost each at 8 t ha^{-1} were showed almost similar trends in the increment of available phosphorus contents in post-harvest soils followed by rice hull compost. The other nutrients of post-harvest soils followed the similar trends as that of phosphorus, except for the exchangeable potassium,



*,**,*** indicate the significant levels of correlation at 5%, 1% and 0.1%, respectively.

Fig. 1. Relationship between applied organic composts and mineral nutrition of rice plant tissues

where rice straw compost at the highest rate (8 t ha^{-1}) exhibited the best response (0.97 c mol_c kg^{-1}) than those of the other treatments. The maximum amounts of available sulfur, exchangeable calcium and magnesium were obtained from the highest dose of vermicompost and the minimum amounts were attained by the control plot. The trend of increments of all these nutrients were more pronounced with the higher rates of the applied organic amendments indicate that all the applied organic composts are suitable sources for improving nutrient statuses of soils. Pearson correlation and regression analyses also indicate the strong positive relationship between the treatments and nutrient statuses of post-harvest soils (Table VII).

The current findings are in consistent with those of Xin *et al*. (2017). Many steps have been made to improve soil fertility and productivity, according to them. Increased organic input, such as organic manure, compost, and straw integration, are the most effective approaches. Crop straw, a cheap and nutrient-dense material, offers a lot of potential for enhancing soil fertility (Tan *et al*. 2017). Crop straw, which is high in nutrients and organic elements, can be treated as a natural organic fertilizer and utilized as an alternative to chemical fertilizers, according to the studies of Wang *et al*. (2017).

As a result, straw integration appears to be a potential method for maintaining and restoring soil fertility, the burning issue

Table VI. Impacts of applied organic composts on nutrient statuses of post-harvest soils under rice production during Aman season in Patuakhali district of Bangladesh

Treatment	Nitrogen	Phosphorus	Sulfur	Potassium	Calcium	Magnesium
	Available (mg kg^{-1})			Exchangeable (c mol$_c$kg^{-1})		
T_0 = Control	42.17 d	7.17 e	19.83 c	0.23 g	5.52 c	2.93 d
T_1 = RHC_2	56.75 bc	8.37 e	21.38 bc	0.44 e	6.26 b	3.12 cd
T_2 = RHC_4	61.14 b	9.89 cd	22.51 bc	0.87 ab	7.14 b	3.37 c
T_3 = RHC_8	78.29 a	10.56 c	23.64 b	0.93 ab	8.17 ab	3.85 b
T_4 = RSC_2	51.54 cd	9.85 cd	22.14 bc	0.52 d	6.57 b	3.20 cd
T_5 = RSC_4	58.24 bc	10.16	23.21 b	0.71 c	7.29 b	3.46 bc
T_6 = RSC_8	60.76 b	11.84 ab	24.19 b	0.97 a	8.36 ab	4.19 ab
T_7 = SDC_2	49.68 cd	8.83 de	22.34 bc	0.35 f	5.79 c	2.96 cd
T_8 = SDC_4	56.87 bc	10.19	23.15 b	0.62 cd	6.78 b	3.54 bc
T_9 = SDC_8	62.31 b	11.86 ab	24.78 ab	0.94 ab	8.13 ab	3.81 b
T_{10} = V_2	47.32 d	9.63 cd	25.21 ab	0.61 cd	7.13 b	3.16 cd
T_{11} = V_4	53.76 c	10.85 bc	26.93 ab	0.85 b	8.27 ab	3.54 bc
T_{12} = V_8	57.74 bc	12.57 a	27.62 a	0.94 ab	8.92 a	4.48 a

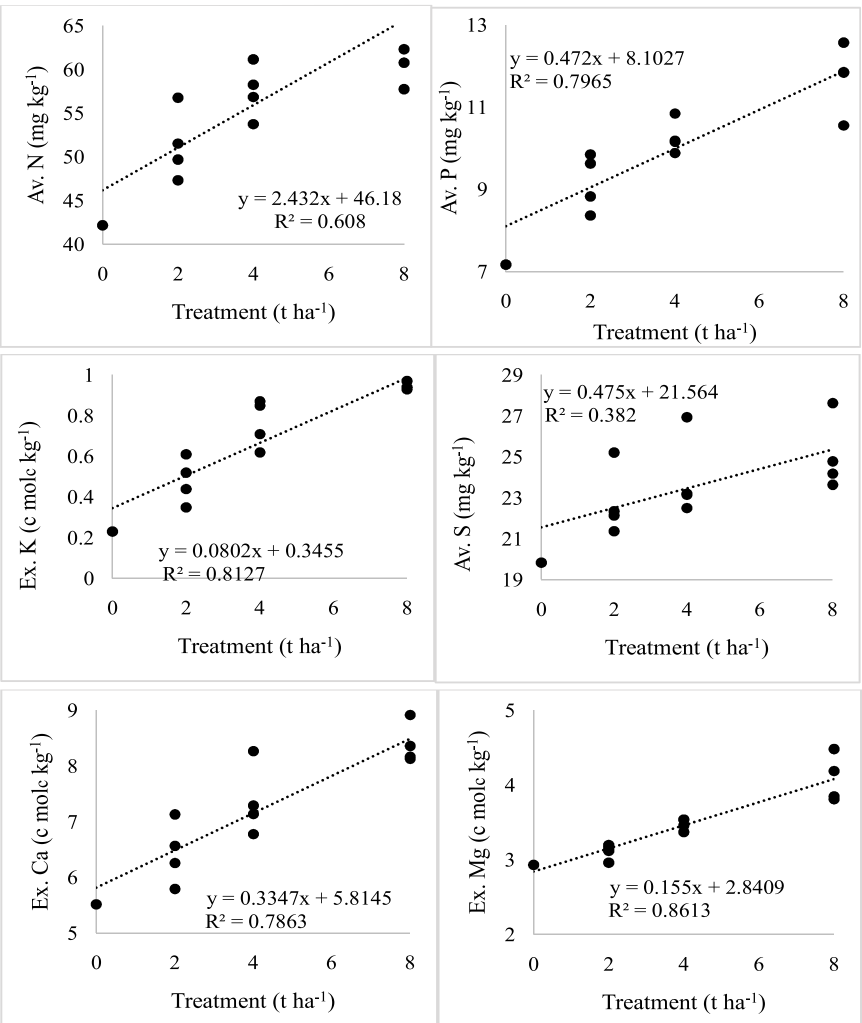


Fig. 2. Relationship between applied organic composts and nutrient statuses of post-harvest soils

Table VII. Correlation between the treatments and nutrient statuses of post-harvest soils

Nutrition	Coefficient	Stand. Error	t Stat	P-value	Lower 95%	Upper 95%
*Av. Nitrogen	2.4323	0.5879	4.1374	0.0017	1.1384	3.7262
Av. Phosphorus	0.4720	0.0719	6.5611	0.0000	0.3137	0.6304
#Ex. Potassium	0.0802	0.0116	6.9098	0.0000	0.0546	0.1057
Av. Sulphur	0.4750	0.1822	2.6076	0.0244	0.0741	0.8760
Ex. Calcium	0.3347	0.0526	6.3628	0.0001	0.2189	0.4504
Ex. Magnesium	0.1550	0.0188	8.2649	0.0000	0.1137	0.1962

*Av. Indicate available and #Ex. Indicate exchangeable.

of present day. Because, mineral elements are required for the healthy growth and development of both plants and humans. The plant roots take up the mineral nutrients from soil and transported them to the edible parts for human consumption through various transporters. For human health, an ideal future crop should be rich in essential mineral elements but with less toxic elements in the edible parts. Still, it is estimated that nearly 2 billion people are suffering from deficiency of nutrients because of low availability of mineral elements in soil and/or low accumulation/bioavailability of mineral elements in edible parts (Graham *et al*. 2012). This so-called hidden hunger is an especially serious health problem for people subsisting on cereal-based diets because cereals such as rice usually contain a low level of mineral elements as well as low bioavailability (Grebmer *et al*. 2014; Nakandalage and Seneweera, 2018). On the other hand, rapid urbanization and industrialization cause contamination by toxic elements in many soils used for crop production (Zhao *et al*. 2010; Clemens and Ma, 2016), which threaten our health throughout the food chain. Therefore, it is extremely important to boost essential nutrients (both density and bioavailability) and reduce toxic elements in edible parts of cereals for human health.

Conclusion

The present research findings conclude that the locally made organic composts using indigenous organic materials had potential to improve soil fertility and provide nutrients for rice production. Significant positive correlation between the treatments and mineral nutrients of rice plants confirmed the strong relationship of organic farming for sustainable agriculture. There were significant ($p \leq 0.05$) increase in available phosphorus and sulfur, exchangeable potassium, calcium and magnesium at post-harvest soils with the increased doses of amendments under rice production. The nutrition of rice plants grown under field condition was influenced most by the vermicompost and followed the order of the treatments as rice straw compost > sawdust compost > rice hull compost for the studied variety of rice. These results resemble that the further researches are needed to find out the suitable doses and types of the amendments. However, the applied organic fertilizers were found to have responses on the nutritional statuses of rice shoot and post-harvest soils and these might be effective for the nutritional balance of the rice variety and ultimately will be helpful for country's penniless people to combat their existing and future demand of quality rice.

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