ORIGINAL RESEARCH

Assessment of crop growth, soil properties and crop yield in an upland acidic soil with inorganic fertilizer blended with organic amendments in summer rice cropping seasons

Madhumita Ghosh[1] · Ashalata Devi[1]

Abstract

Purpose Intensification of rice cultivation to meet the growing demand has imbalanced the nitrogen level in soil. Amendments of inorganic fertilizers increase yield, but at the same time affects the environment. Hence, different amendments are to be investigated which acting sustainably on soil and the environment upholds yield gains.

Methods A study was carried out on acidic sandy loam soil in the irrigated summer seasons of the years of 2015–2016 and 2016–2017 to examine the effects of various amendments on rice growth, soil health and yield. The applied amendments were inorganic fertilizer blended with crop residues, farm yard manure and compost made of daily household green wastes.

Results The highest yield of 53.33 ± 2.09 Q/ha was recorded with application of inorganic fertilizer blended with compost and the lowest yield of 32.71 ± 3.09 Q/ha without amendment. Strong positive correlations were found between soil moisture and volumetric water content (0.982 at $p < 0.001$), manganese and copper (0.900 at $p < 0.001$), whereas available phosphorus and manganese showed a strong negative correlation (-0.901 at $p < 0.001$). Performing stepwise regression analysis, yield was found affected mostly by soil moisture and total carbon out of evaluated 17 soil traits.

Conclusion The inorganic fertilization blended with the compost increased rice yield by 13.61% over inorganic fertilizer but a higher yield associated with compost demoted total nitrogen contents in soil, leading to lower soil nitrogen fertility and providing a negative feedback to sustainable agriculture. More research is required on compost development and application in different rice agroecosystems.

Keywords Inorganic fertilizer · Organic amendments · Soil properties · Rice field

Introduction

Rice (*Oryza sativa* Lin.) is the most demanding cereal in the world. It appears as an indispensable food for more than 50% of the world's population. Its requirement is increasing rapidly for fulfilling the demand of ever growing human population. To meet this rising demand, different approaches are being practised, such as boosting rice production with the application of different fertilizers (Cassman et al. 1998),

cultivating high yielding rice varieties and going forward with instructions issued by governments.

The application of nitrogen fertilizer promotes the rice yield, but it also has unfavourable effects on the environment and soil health (Leip et al. 2014). One of the most common steps taken in the direction of maintaining soil health and environment is the use of organic fertilizers. Such fertilizers provide essential nutrients to soil, and also improve other soil properties, such as water-holding capacity, nutrient-holding capacity and microbial activity of soil. However, a huge volume of organic fertilizer is required for achieving potential of high yielding rice varieties, which will directly step up the cost of farming (Baruah and Baruah 2015; Baruah et al. 2016). In addition, the decomposition of an organic matter under humid tropical condition is relatively hasty and its gathering is minimal in upland irrigated soils.

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Hence, a balanced approach that can be used to sustainably improve rice yield and soil quality is to apply wastes produced from kitchen, garden and farm (crop residues and farm yard manure) in combination with inorganic fertilizers. The application of such a blended amendment will have a greater chance to endure a fairly lofty amount of nutrients required for a high yielding rice variety and also to improve soil traits. Moreover, composting of eco-friendly organic wastes is a good option to provide a high-quality green fertilizer as a supplement to inorganic fertilizer. The use of compost increases organic carbon and moisture retention ability of soil, while decreases its bulk density. Soil organic carbon and total nitrogen act as basic elements of green agriculture (Franzluebbers and Stuedemann 2009). Hence, restoration of soil organic carbon is required for enhancing rice production by maintaining soil quality, and also to raise the soil carbon store to decrease the release of carbon dioxide from soil. On the other hand, the renewal of nitrogen is desirable for lowering the need of nitrogen fertilizers by avoiding the percolation of nitrogen and release of nitrous oxide to the atmosphere.

Motivated by above, a field trial was undertaken with the rice variety of *Naveen* in the summer cropping season. With the aim of enhancing rice production, the investigation was concentrated on studying the effects of organic waste-blended inorganic fertilizer on rice growth, soil properties and rice yield. Finally, the cloud of data related to plant growth, soil properties and rice yield were analyzed through statistical tools to identify the soil attributes affecting the yielding of rice.

Materials and methods

Experimental design and field management

A 2-year field trial in the summer rice cropping system was performed on an experimental site inside the Tezpur University Campus (26°41′ N, 92°50′ E) situated in the north bank plain zone of Agroclimatic division of Assam in India. The area is under moist subtropical monsoon climate. The study period was from the last week of February to the third week of June in the years of 2016 and 2017. Before starting the experiment, the physico-chemical properties of the soil were determined using applicable methods.

Two months prior to the starting of the field trial, the compost was prepared using eco-friendly organic waste materials. For this, a mixture was prepared first with kitchen wastes (peels of vegetables and fruits, rotten vegetables, leftover cooked food, used tea leaves, etc.), garden wastes (grasses and bushes) and farm waste (cow dung manure) in the ratio of 1:2:2. Then, the compost was formed by concealing the mixture for 2 months in a ditch under ambient air temperature.

In the field experiment, 6 treatments were replicated 4 times in a random block design (RBD), for which a total of 24 plots were prepared in 4 parallel blocks. Each plot was 2 m × 2 m in size. A gap of 50 cm wide was left between two adjacent plots for preventing intermixing of amendments. The six treatments were marked by T1 through T6 as follows: T1 = No amendment, T2 = NPK (inorganic fertilizer), T3 = NPK + crop residue of 5 t/ha (ton per hectare), T4 = NPK + farm yard manure (FYM) of 5 t/ha, T5 = NPK + FYM of 10 t/ha, and T6 = NPK + compost of 2.5 t/ha. Although the package of practices published by the Government of Assam recommends to apply 10 t/ha FYM during field preparation (Anonymous 2015), treatment T4 was considered to assess the impact of its half (i.e., 5 t/ha). Along with the amendments as per the field layout, urea, single superphosphate (SSP) and muriate of potash (MOP) were applied in the ratio of 60:30:30 as the NPK (inorganic fertilizer). Fifty percent (50%) of the portion of urea was added with the whole portions of SSP and MOP as the basal fertilizer, 25% was applied in the middle of the tillering stage and the remaining 25% was applied in the panicle initiation stage of active vegetative growth of rice. The moisture contents in the organic materials (crop residue, FYM and compost) and the corresponding C:N ratios at the time of the application of the amendments were assessed as (12.70%, 48.97), (46.94%, 14.41) and (35.49%, 10.58), respectively.

Approved seedlings of 35 days old of *Naveen* rice variety were gathered from the Regional Agriculture Research Station, Nagaon, and they were transplanted manually in row to row of 20 cm × 20 cm and plant to plant spacing of 20 cm with two seedlings per hill. The field was irrigated twice a week as per a scheme of intermittent irrigation. The plots were irrigated in a way to hold 5 cm of standing water until panicles initiated. Manual weeding, application of insecticides and pesticides were also done regularly as per the suggestion set out by the Government of Assam.

Plant sampling and analysis

Plant height is obtained from the plants of three hills selected from three random plots per amendment, excluding the boarder hills of the plots. The plant height was measured from the stem base of a plant to the tip of its longest leaf or panicle, whichever was longer.

In the case of biomass, a destructive sampling of three plants per amendment was collected and removed the stuck soil by washing with water. Separating the roots, shoots and leaves of the plants, they were dried in an oven at 75 ± 2 °C temperature until their constant weights were obtained. Those dried weights were their respective biomass

values, i.e., root biomass, shoot biomass and leaf biomass, respectively.

Soil sampling and analysis

For determining the properties of the initial soil, a composite soil sample was prepared by mixing soil samples collected from four different sites of the experimental field. For the properties of the soil after the experiment, another composite soil sample was prepared by collecting soil samples after harvest from three plots per amendment. In both cases, soil samples were obtained from a depth of 0–15 cm using an iron probe of 2 cm diameter.

Soil moisture (SM) content was measured from a portion of each composite sample using the gravimetric method. For obtaining other soil properties, the remaining portion of the composite sample was first dried in open air, then grounded, and finally passed through a sieve having pores 2 mm in size. The concentration of soil organic carbon (SOC) was evaluated through the potassium dichromate oxidation process conceived by Walkly and Black (1934). Total nitrogen (TN) and total carbon (TC) in soil were estimated by a carbon hydrogen nitrogen (CHN) analyser (model: 2400 series 2, USA). The soil catalase activity (CAT) was determined using the method provided by Zhang et al. (2012). The available nitrogen, available phosphorus and available potassium in the soil were evaluated using the method proposed by Page et al. (1982). The iron, copper, manganese and zinc were first extracted by diethylene-triamine-pentaacetic acid (DTPA) and then quantified through a mass spectrophotometer (Model: Perkin Elmer Optima 2100DV).

For obtaining the soil bulk density (BD), three soil cores, each of 15 cm in length and 5 cm in diameter, were taken from plots under each treatment, and dried at 105 °C temperature. Then, BD for each core was calculated by dividing the difference in its initial and dried weights by the core volume. Then, the average of the BD values of the three cores under a treatment is taken as the ultimate BD under the treatment.

Finally, the volumetric water content (VWC) and water-filled pore space were calculated from the obtained SM and BD values using the formula proposed by Brzezinska et al. (2005).

Yield and yield-related parameters

From three random plots under each treatment, an area of 1 m × 1 m was chosen from each plot for determining productive tillers and sterility percentage. The matured grains containing 14% moisture were harvested from the areas, and then the harvest index was calculated using the formula as given by Liu et al. (2013). Further, the panicle length, filled grain and weight of thousand grains were also determined.

In addition, using the average yield of 2 years of experimentation, the partial factor productivity and nitrogen agronomic efficiency were calculated through the formulae given by Guo et al. (2017) and yield contribution of nitrogen was calculated through the formula given by Tian et al. (2017).

Statistical analysis

In the statistical software package SPSS (version 15), one-way ANOVA was conducted to investigate if any significant difference exists among the calculated mean values of the crop growth, soil property and yield-related parameters under different amendments. The Tukey's HSD test was also performed for identifying the mean values under amendments T2 through T6, which are significantly different from the corresponding mean values under amendment T1. Further, the PCA (principal component analysis) tool of SPSS was used to identify the correlated soil properties and to isolate the disparate ones. Next, the stepwise linear regression was performed for relating rice yield with the applicable soil properties, i.e., to investigate how soil properties influence rice yielding.

Results and discussion

The soil texture of the experimental site was sandy and slightly acidic having pH value of 5.6. The SM and BD values were found to be 36.7% and 1.31 g/cm^3, respectively. The physico-chemical properties of the soil in detail are presented in Table 1.

Crop growth

For the data pooled from the summer cropping seasons of the years of 2016 and 2017, the variations in the plant morphological attributes under different treatments are shown in Table 2, where it is observed that the amendments brought noticeable changes in the growth of the rice plants.

The plant height during the crop growth period increased almost equally under all the amendments, recoding the maximum of (106.40 ± 0.30) cm under T2 and the minimum of (80.36 ± 0.31) cm under T1 at the final stage (i.e., at harvest). Treatment T2 contained only NPK, which released nutrients speedily causing the plants to grow faster.

Unlike plant height, the number of tillers per hill showed a growing trend from the tillering stage to the flowering stage and then decreased at the harvest, showing the highest value of 18 ± 0.57 under T6 and the lowest value of 9 ± 0.57 under T1. The result was similar to that of Yung-Yu (2005), where a rice pot experiment was performed with two different composts.

Table 1 Soil physico-chemical properties (mean ± standard deviation) of the experimental site (at 0–15 cm depth) before starting the experiment

Property	Value
Sand (%)	60.5 ± 0.61
Slit (%)	20.2 ± 0.82
Clay (%)	19.3 ± 0.96
Moisture (%)	36.7 ± 2.64
Bulk density (Mg/m^3)	1.31 ± 0.10
Porosity (%)	50.60 ± 1
Volumetric water content (%)	48.04 ± 1
Water-filled pore space (%)	94.94 ± 1
pH	5.6 ± 0.67
Organic carbon (%)	1.59 ± 0.71
Total carbon (g/kg)	20.7 ± 2.07
Total nitrogen (g/kg)	6.0 ± 0.01
Available nitrogen (kg/ha)	212.0 ± 6.99
Available phosphorus (kg/ha)	12.15 ± 4.52
Available potassium (kg/ha)	70.65 ± 8.90
Micronutrients	
Iron (mg/kg)	23.1 ± 2.01
Copper (mg/kg)	1.75 ± 0.1
Zinc (mg/kg)	0.74 ± 0.01
Manganese (mg/kg)	3.40 ± 0.1

The number of leaves per hill showed a similar trend like the number of tillers per hill, increased from the tillering stage to the flowering and then decreased at the harvest. The maximum of 40 ± 0.33 number of leaves were found under T5 and the minimum of 24 ± 0.33 under T1 at the harvest.

Increasing trend in root length was noticed under T2–T4 and T6 in the period in between the tillering and flowering stages, and under T1, T3 and T5 at the harvest; while a decreasing trend under T2, T4 and T6 at the harvest. Such trends of variation in the root length indicate that the soil faced alternate wetting and drying.

Due the above-stated trends in the growth of the plants, there were significant differences in both above and below ground biomass under different amendments in comparison to those under T1 during the investigation of all the three cropping stages (tillering, flowering and harvest stages). Both above and below ground biomass showed uprising trends from the tillering stage to the flowering stage under all the six treatments; while decreasing trends at the harvest were shown by the above ground biomass under T2 and T4, and by the below ground biomass under T1–T3. Both above and below ground biomass attained their maximum values under T5 and minimum values under T1.

Table 2 Variation in plant morphological attributes (mean ± standard error) under different treatments in a 2-year field experiment in the summer cropping seasons (Tukey's HSD test at significance level of 5%)

Treatment	Growth stage	Height (cm/hill)	Tiller number/hill	Leaf number/hill	Root length (cm/hill)	Above ground biomass (g/hill)	Below ground biomass (g/hill)
T1	Tillering	30.10 ± 0.05	8 ± 0.57	19 ± 1.20	5.4 ± 0.12	0.68 ± 0.01	0.19 ± 0.01
T2		41.5 ± 0.28*	12 ± 0.57	28 ± 1.85*	5.03 ± 0.88	1.41 ± 0.02*	0.26 ± 0.01*
T3		42.10 ± 0.05*	18 ± 0.88*	37 ± 0.88*	4.96 ± 1.20	1.79 ± 0.01*	0.35 ± 0.01*
T4		39.10 ± 0.05*	13 ± 0.33*	35 ± 0.33*	4.30 ± 0.05*	1.85 ± 0.01*	0.44 ± 0.01
T5		60.26 ± 0.12*	14 ± 1.20*	42 ± 0.88*	8.16 ± 0.88*	2.50 ± 0.01*	0.65 ± 0.01*
T6		39.36 ± 0.27*	12 ± 0.88*	33 ± 1.80*	7.16 ± 0.88*	1.85 ± 0.01*	0.47 ± 0.00*
T1	Flowering	74.10 ± 0.49	11 ± 0.57	47 ± 0.57	5.3 ± 0.08	14.35 ± 0.01	2.14 ± 0.00
T2		79.23 ± 0.38*	16 ± 0.33*	51 ± 0.57*	10.16 ± 0.16*	43.76 ± 0.01*	3.20 ± 0.01*
T3		92.50 ± 0.05*	14 ± 0.00*	64 ± 0.33*	8.10 ± 0.10*	35.92 ± 0.04*	3.21 ± 0.01*
T4		87.00 ± 0.57*	18 ± 0.33*	67 ± 0.33*	11.23 ± 0.25*	39.12 ± 0.28*	3.94 ± 0.01*
T5		94.00 ± 0.57*	17 ± 0.66*	63 ± 0.33*	5.10 ± 0.10	24.11 ± 0.01*	2.54 ± 0.01*
T6		92.00 ± 0.57*	20 ± 0.33*	68 ± 0.33*	11.46 ± 0.05*	35.90 ± 0.01*	4.49 ± 0.01*
T1	Harvest	80.36 ± 0.31	9 ± 0.57	24 ± 0.33	8 ± 0.25	24.62 ± 0.21	1.87 ± 0.01
T2		106.40 ± 0.30*	11 ± 0.33	34 ± 0.57*	10 ± 0.26*	39.64 ± 0.74*	3.05 ± 0.02*
T3		93.43 ± 0.64*	17 ± 0.57*	36 ± 0.33*	9 ± 0.05*	44.90 ± 0.34*	4.39 ± 0.10*
T4		98.43 ± 0.31*	15 ± 0.57*	20 ± 0.33*	8 ± 0.05	34.16 ± 0.41*	2.67 ± 0.00*
T5		107.83 ± 0.44*	14 ± 0.88*	40 ± 0.33*	11 ± 0.11*	55.55 ± 0.17*	3.15 ± 0.01*
T6		104.50 ± 0.28*	18 ± 0.57*	36 ± 0.33*	6 ± 0.10*	56.71 ± 0.24*	6.82 ± 0.06*

Values with * in the same column are significantly different from the corresponding value under T1 of each growth stage. T1: No amendment, T2: NPK, T3: NPK + crop residue (5 t/ha), T4: NPK + farm yard manure (5 t/ha), T5: NPK + farm yard manure (10 t/ha), T6: NPK + compost (2.5 t/ha)

Table 3 Variation in soil properties under different amendments at the harvest treatments in a 2-year field experiment in the summer cropping seasons (Tukey's HSD test at significance level of 5%)

Treatment	pH	Redox potential (mV)	Electrical conductance (μS/cm)	Bulk density (mg/m³)	Soil moisture (%)	Volumetric water content (%)	Soil catalase activity (ml/g)	Soil organic carbon (g/kg)	Total nitrogen (g/kg)	Total carbon (mg/g)	Available nitrogen (kg/ha)	Available phosphorus (kg/ha)	Available potassium (kg/ha)	Iron (mg/kg)	Zinc (mg/kg)	Manganese (mg/kg)	Copper (mg/kg)
T1	4.90	118.33	34.33	1.13	29.54	33.33	0.23	11.70	8.76	18.28	226.00	10.90	79.78	15.09	0.79	9.30	2.40
T2	4.79	125.66	45.00	1.17	34.57	40.38	0.35	14.38*	12.31	21.83	285.83*	11.42	114.93	19.23*	0.89	11.37	2.50
T3	4.73	126.00	37.33	1.16	34.00	39.71	0.33	14.86	9.35	22.90	305.00*	13.00	102.56	20.03*	0.89	11.65	2.46
T4	4.98	124.00	30.83	1.13	33.76	38.39	0.31	13.22	8.93	19.58	309.83*	10.74	94.99*	20.39*	0.88	11.64	2.52
T5	4.93	122.83	28.66	1.12	32.24	36.31	0.34	15.63*	10.31	23.56	295.00*	12.31	119.26	22.00*	0.96	11.79	3.04
T6	5.15	112.50	40.83	1.12	38.87*	43.65*	0.35	16.93*	9.70	22.75	307.50*	11.35	93.34	21.39*	0.91	11.81	2.72
p value	0.262	0.907	0.404	0.036	0.057	0.030	0.316	0.000	0.306	0.009	0.000	0.745	0.008	0.665	0.000	0.995	0.592

Values (mean) with * in the same column are significantly different. T1: No amendment, T2: NPK, T3: NPK+crop residue (5 t/ha), T4: NPK+farm yard manure (5 t/ha), T5: NPK+farm yard manure (10 t/ha), T6: NPK+compost (2.5 t/ha)

Soil properties

The variations in soil properties at the harvest under different amendments are shown in Table 3, where it is observed that the soil under T6 (compost-blended amendment) had the best/highest values of soil moisture (SM), volumetric water content (VWC), soil catalase activity (CAT), soil organic carbon (SOC), and iron and manganese; while their lowest values occurred in the soil under T1. Also, the best/highest value of pH was found under T6 and its lowest under T3. The soil bulk density was the best/lowest under T6 (also under T5), and the highest under T2. Moreover, the maximum and minimum values of available phosphorus were found under T3 and T4, respectively. Further, T1 showed the lowest values of total nitrogen (TN), total carbon (TC), available nitrogen (N), available phosphorus (P), available potassium (K), zinc and copper also, with their better/highest values occurring under other amendments out of T2–T5. It is to be mentioned that different organic materials, used as composting materials, release different nutrients, e.g., Laos et al. (2000) and Kowalijiow and Mazzarino (2007) found higher release of phosphorus by the compost prepared with fish bio-solid as one of the constituents, and Watanabe et al. (2018) found higher release of total carbon by the compost prepared with straw as one of the constituents.

The best SM and VWC under the compost-blended T6 directly supported the work of Zemanek (2011). The presence of higher SM and VWC in compost enhances the microbial activity, which helps in the growth of crops by releasing easily absorbable nutrients.

The finding of the best bulk density under T6 (also under T5) and the worst under T2 was in the line of the work of (Gudadhe et al. 2015), who reported that the effect of organic blended inorganic fertilizer on bulk density is more pronounced than that of inorganic fertilizer alone. Further, Santhy et al. (1999) also found that the application of organic manure in a blended experiment reduces the bulk density. The fact is that the organic carbon contained in organic materials reduces bulk density when such materials are used as a fertilizer.

As the addition of organic materials to soil channels the accumulation of extra carbon (Bharali et al. 2017; Baruah and Baruah 2015; Kirkby et al. 2013), SOC was found enhanced under T3, T5 and T6, i.e., under the inorganic fertilizer blended with organic materials. The increased SOC helps microbes to provide nutrients to plants by keeping carbon and nitrogen balanced in soil, otherwise microbes would decompose existing organic carbon of the soil (Fontaine et al. 2004; Murphy et al. 2015; Poeplau et al. 2017). The SOC was found increased under inorganic T2 also, which might be due to the fact that the application of urea

assimilated carbon by improving leaf, shoot and root bio-masses of rice plants (Liu et al. 2017; Ge et al. 2016; Zhu et al. 2018).

The highest available nitrogen was found under T4, which lowered the uptake of nutrients by the plants, thus lowered the rice yield in comparison to that under T2, T5 and T6. On the other hand, the total nitrogen replenished through T2, T5 and T6 was enough to balance the nutrients absorbed by the rice plants.

There was reduction in electrical conductance under T3–T6 in comparison to that under T2, which was in the lines of the findings by Claassen and Carey (2007), Walia et al. (2010) and Al-Bataina et al. (2016) from experiments with organic material-blended inorganic fertilizers. The reduction in electrical conductance under organic material-blended inorganic fertilizers slow down the release of dissolved nutrients than that under pure inorganic fertilizer, which helps plants to get nutrients progressively over their growing period. Performing the statistical Pearson correlation test with a significance level of 0.1%, a strong positive correlation was found between SM and VWC with the correlation coefficient of 0.982, and between manganese and copper with the correlation coefficient of 0.900. The reason of it is that an increase in pH increases SM and VWC along with decreasing both redox potential (Eh) and electric conductance (EC), which in turn increase the availability of potassium, manganese, copper and zinc. A significant positive correlation with the correlation coefficient of 0.518 was found between TN and TC also, which indicates balanced fertilization in soil retaining enough moisture for decomposition of organic materials to SOC. On the other hand, available phosphorus and manganese showed a strong negative correlation with the correlation coefficient of − 0.901. The CAT also showed negative relations with SOC (having correlation coefficient of − 0.291) and VWC (having correlation coefficient of − 0.237), which was due to the fact that an increase in VWC shifts microflora from aerobic to anaerobic ones and ultimately decreases the CAT (Brzezinska et al. 2005). The results obtained from PCA are summarized in Table 4 and also visualized in Fig. 1, where only those components having eigenvalues more than 1 are shown as they address 82.82% of the total variance. The first component of PCA (Component 1 in Fig. 1) showed strong correlations with pH, Eh, EC, SM, VWC, P, K, Cu, Mn and Zn, where decrease in SM and VWC means a drop in the availability of P (phosphorus). Similarly, hydrogen ions (pH) and flow of electrons (Eh and EC), linked to dissolved materials, determine the availability of micronutrients (Cu, Mn and Zn). The second component of PCA (Component 2 in Fig. 1) correlated AN and Fe, where the high correlation value with AN indicates the application of fertilizer. Finally, the third component of PCA (Component 3 in Fig. 1) showed positive correlation with TN and TC,

Table 4 Soil properties obtained through the principal component analysis (PCA) with the *Varimax* rotation method by satisfying the Kasier–Meyer–Olkin and Bartlett's tests

Component	1	2	3	4
Eigenvalue	7.434	3.391	1.998	1.25
% Variance	43.731	19.946	11.751	7.39
Cumulative variance %	43.73	63.67	75.43	82.82
Rotated component matrix				
pH	**− 0.816**	0.212	− 0.167	0.260
Eh	**0.844**	− 0.148	0.334	− 0.011
Ec	0.448	− 0.168	**0.626**	0.016
BD	0.228	− 0.073	0.324	**− 0.824**
SM	**− 0.723**	0.561	− 0.179	− 0.003
VWC	**− 0.704**	0.564	− 0.122	− 0.165
CAT	0.240	0.089	**0.904**	0.074
SOC	0.325	**0.700**	0.395	0.098
TN	0.038	− 0.017	0.241	**0.746**
TC	− 0.217	0.320	**0.643**	0.540
N	− 0.137	**0.873**	0.212	0.024
P	**− 0.855**	0.230	− 0.225	− 0.068
K	0.457	0.199	**0.645**	− 0.237
Cu	**0.917**	0.142	0.141	− 0.150
Fe	− 0.145	**0.931**	− 0.132	0.072
Mn	**0.888**	− 0.042	0.400	− 0.094
Zn	**0.889**	0.354	− 0.137	− 0.153

Eh redox potential; *EC* electrical conductance; *BD* bulk density; *SM* soil moisture; *VWC* volumetric water content; *CAT* soil catalase activity; *SOC* soil organic carbon; *TN* total carbon; *TC* total carbon; *N* nitrogen; *P* phosphorus; *K* potassium; *Cu* copper; *Fe* iron; *Mn* manganese; *Zn* zinc

which indicated the mineralization/immobilization ability of the soil affecting BD of soil on the fourth component of PCA.

Crop yield

The rice yields and yield-attributing parameters obtained in the field experiment are presented in Table 5, where it is observed that the lowest yield of (32.71 ± 3.09) Q/ha was found under T1 and the highest yield of (53.33 ± 2.09) Q/ha under T6. The absorption of a higher level of nitrogen (C:N = 10.58) by plants under T6 increased grain yields, which on the other side reduced the total nitrogen contents in the soil under T6. There was no statistical meaningful contrast in yield under T3 (NPK + crop residue) and T4 (NPK + 5 t/ha FYM. On the other hand, the yield under T4 (NPK + 5 t/ha FYM) was less than that under T5 (NPK + 10 t/ha FYM), which was due to the fact that the increased FYM enhanced soil properties. However, the efficiency of T2 (inorganic fertilizer NPK) could be enhanced only under T5 (NPK + FYM) and T6 (NPK + compost).
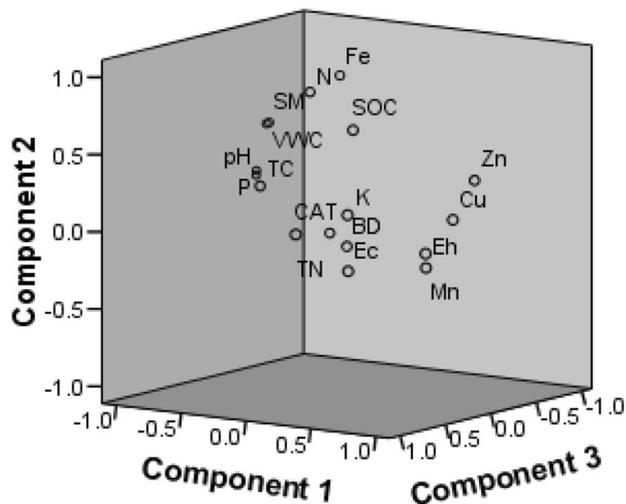
Fig. 1 Component plot of the principal component analysis (PCA) with the *Varimax* rotation method. Eh, redox potential; Ec, electrical conductance; BD, bulk density; SM, soil moisture; VWC, volumetric water content; CAT, soil catalase activity; SOC, soil organic carbon; TN, total nitrogen; TC, total carbon; N, nitrogen; P, phosphorus; K, potassium; Cu, copper; Fe, iron; Mn, manganese; Zn, zinc

Further, T5 was better than T6 in terms of many soil properties (refer Table 3). Still T5 cannot be considered as the finest fertilization practice in an acidic sandy soil, but T6 which showed better nitrogen-based factors (Table 6).

To optimize yield, it is necessary to identify the factors which affect the yielding and also the extents of their influences on yielding. However, no acceptable procedure has been established so far to analyze the yield-determining factors. The progression of plants and their net productivity in an ecosystem are usually evaluated by interacting different attributes. In the present study, the method of stepwise regression analysis proposed by Kosaki et al. (1989) was employed for evaluating the soil parameters which significantly contributed on rice yielding. Conducting the analysis with 17 soil parameters, only 2 of them (soil moisture and total carbon) were found affecting the rice yield significantly. About 70.4% variation in yield could be explained by soil moisture and additional 11.4% by incorporating total carbon with soil moisture. As soil moisture was found to enhance rice yield on a large degree, the dryness of soil in the summer season lessened the rice production in the experimental site.

Conclusion

Performing a 2-year field experiment on an acidic sandy loam soil under moist subtropical monsoon climate, rice yield could be improved through the application of NPK blended separately with organic crop residue, farm yard manure and compost made of bio-degradable household wastes. The highest yield was recorded under NPK blended with the compost, while the moisture and total carbon of the soil were found having significant positive impact on rice yielding. Various soil properties were also found improved from the application of organic materials with NPK. Further research may be carried out to investigate if such effects can be maintained in a sustainable way on large-scale application as well as for a longer period of time.

Table 5 Effect of amendments on crop yield and its related attributes in a 2-year field experiment in the summer cropping seasons (Tukey's HSD test at significance level of 5%)

Treatment	Productive tillers/m^2	Sterile tillers (%)	Panicle length (cm)	Filled grain (%)	Thousand grain weight (g)	High-density grains (%)	Harvest index (%)	Yield (Q/ha)
T1	200.16 ± 14.46	19.13 ± 0.52	20.78 ± 0.24	54.30 ± 4.39	17.50 ± 4.39	48.12 ± 6.03	21.81 ± 1.19	32.71 ± 3.09
T2	272.50 ± 6.29	15.13 ± 1.35	23.40 ± 0.32	72.79 ± 4.01	17.93 ± 0.50	60.73 ± 2.76	25.59 ± 1.01	46.07 ± 4.31
T3	244.66 ± 4.21	10.26 ± 1.33	24.91 ± 0.38	79.35 ± 2.12	17.24 ± 0.61	60.86 ± 2.76	25.67 ± 0.88	43.40 ± 4.06
T4	244.66 ± 6.86	14.25 ± 1.32	23.57 ± 0.44	80.04 ± 2.76	17.97 ± 1.29	70.53 ± 2.40	27.86 ± 1.16	43.63 ± 4.14
T5	246.66 ± 5.72	13.57 ± 2.16	23.65 ± 0.73	78.28 ± 2.51	19.19 ± 0.53*	71.26 ± 3.25	27.01 ± 0.93	47.46 ± 2.51
T6	251.00 ± 2.95	11.74 ± 0.71	23.85 ± 0.77	82.63 ± 2.75	21.02 ± 0.47	73.66 ± 2.07	26.60 ± 1.27	53.33 ± 2.09

Values (mean ± standard error) with * in the same column are significantly different. T1, No amendment, T2, NPK; T3, NPK + crop residue (5 t/ha); T4, NPK + farm yard manure (5 t/ha); T5, NPK + farm yard manure (10 t/ha); T6, NPK + compost (2.5 t/ha)

Table 6 Evaluation of amendments in the perspective of N partial factor productivity (PFP$_N$), N agronomic efficiency (AE$_N$), increased yield over T2 and yield contribution of N (YC$_N$), using mean data obtained from a 2-year field experiment in the summer cropping seasons

Treatment	PFP$_N$ (kg/kg)	AE$_N$ (kg/kg)	Increased yield (%) over T2	YC$_N$ (%)
T1	–	–	− 40.84	–
T2	52.27	14.77	–	28.26
T3	35.24	8.19	− 6.15	23.25
T4	41.70	10.42	− 5.59	25.00
T5	38.21	11.38	2.92	29.78
T6	56.34	21.18	13.61	37.73

T1, No amendment; T2, NPK; T3, NPK + crop residue (5 t/ha); T4, NPK + farm yard manure (5 t/ha); T5, NPK + farm yard manure (10 t/ha); T6, NPK + compost (2.5 t/ha)

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