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APPLICATION OF VERMICOMPOST TO BORO RICE (BRRI dhan 28) CAN SAVE PHOSPHATE FERTILIZER WITH SUSTAINING PRODUCTIVITY AND SOIL FERTILITY

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Abstract

The study was conducted to investigate the application outcome of vermicompost (VC) and phosphorus (P) on the growth, yield contributing traits, yield, and post-harvest soil fertility status. Six treatment combinations were used and which were T_1: $VC_{0\%}$ $P_{0\%}$ (Control treatment); T_2: $VC_{100\%}$ $P_{0\%}$ (VC @ 6 t ha^{-1} + P @ 0 kg ha^{-1}); T_3: $VC_{75\%}P_{25\%}$ (VC@ 4.5 t ha^{-1} + P @ 22.5 kg ha^{-1}); T_4: $VC_{50\%}$ $P_{50\%}$ (VC @ 3 t ha^{-1} + P @ 45 kg ha^{-1}); T_5: $VC_{25\%}$ $P_{75\%}$ (VC @ 1.5 t ha^{-1} + P @ 67.5 kg ha^{-1}) and T_6: $VC_{0\%}P_{100\%}$ (VC @ 0 t ha^{-1} + P @ 90 kg ha^{-1}). Recommended doses of VC and P were 6 t ha^{-1} and 90 kg TSP ha^{-1}, correspondingly. Recommended amount of urea, muriate of potash, gypsum and zinc sulphate was implemented to each study unit, and TSP and VC were applied as per treatments specification. Different growth and yield influencing traits namely the plant height, number of leaf hill^{-1}, number of effective tillers hill^{-1}, number of spikelet panicle^{-1}, number of grains panicle^{-1}, number of filled grains panicle^{-1}, as well as grain yield and biological yield were obtained with the highest values in T_3 ($VC_{75\%}$ $P_{25\%}$), and almost all the values were statistically analogous to T_4 ($VC_{50\%}$ $P_{50\%}$) treatment, in some cases with T_5 ($VC2_{75\%}$ $P_{75\%}$) treatment. Contrastingly, the lowest values were found in T_1 treatment (control). Addition of VC with P improved soil properties by increasing significantly the soil pH, soil organic matter, total N and available P content as well as by increasing numerically in the content of post-harvest soil regarding exchangeable K and available S. The studied soil properties are positively correlated between each other, in which the relation of grain yields with P, K and S was more significant. In most of the cases, remarkable improvement in the soil fertility status was observed due to the addition of VC (3.0-4.5 t ha^{-1}) with lessened P level (22.5-45.0 kg ha^{-1}). Thus, the results indicate that application of 3.0-4.5 t VC ha^{-1} reduced the use of phosphatic fertilizer at a substantial level (50-75%) for attainable grain yield with improving soil fertility which ultimately reduced the chemical fertilizer use in rice. So, for long time sustaining yield and soil fertility, VC @ 3.0-4.5 t ha^{-1} can be employed into the soil that can save inorganic P fertilizer, and it may be an efficient approach for boro rice cultivation.

Key words: Vermicompost, Phosphorus, Spikelet sterility, Yield, Soil properties, Rice.

Introduction

Amongst the most profound cereal crops worldwide for producing food is Rice (*Oryza sativa* L.). Overly 50% of the world population depends on rice, and known as a leading staple food in south-east Asia (Khan *et al*., 2011; Jehangir *et al*., 2022). Rice will continue to be primary sources of food of this area due to the increasing demand by the huge population (Islam *et al*., 2021). It is very difficult to maintain food security in future for over increasing population owing to increasing pressure on natural resources. The response of chemical fertilizers (CFs) in raising agricultural production is well recognized, and farmers are mostly relied on CFs specially nitrogenous fertilizers to increase rice yield but yield is not sustain over time. Farmers are used less amount of P and K fertilizers particularly in Asian (Myint *et al*., 2011). Hence, imbalance use of CFs and intensive rice cultivation leads to several problems in crop production like decline in soil organic matter, soil structure, biological activities and fertility (Zhong & Cai, 2007), increase acidification (Chen *et al*., 2006), salinity and heavy metals in soil (Savci, 2012; Kulkarni & Goswami, 2019), soil pollution (Savci, 2012) and incidence of pest and diseases (Yardım & Edwards, 2003), and reduce water quality (Mullins, 2009), and finally reduce yield (Singh *et al*., 2001; Ladha *et al*., 2003). Sometimes, improper use of CFs in rice field causes major nutrients discrepancy in soil owing to less N retrieval (30%) (Krupnik *et al*., 2004) and N usage efficacy (35%) (Cao *et al*., 2013). Therefore, inappropriate and indiscriminate uses of fertilizers in rice field are making major constraints for increasing yield worldwide. Properly use of fertilizer inputs ensured higher grain yield as well as securing maximum profitability (Khuong *et al*., 2008).

In terms of importance to the crop nutrients, phosphorus (P) is the second most valuable one after nitrogen, and P deficiency proves itself as a major hindrance to crop production worldwide. Adequate P stimulates root development, increases the strength of cereal straw, promotes flowering, fruiting and seed formation, earlier crop maturity, and increases yield and quality of crop (Amanullah & Wali, 2010; Amanullah *et* *al*., 2010). In semiarid condition, it is one of the least available mineral nutrients (Shenoy & Kalagudi, 2005) especially in soils with high in $CaCO_3$ (Ibrikci *et al*., 2005) and high soil pH (Aziz *et al*., 2005), which reduce P availability to crops (Amanullah *et al*., 2014). P availability in these soils is restricted due to P adsorption by Fe and Al oxides as well as Fe and Al phosphate complex conformation with humic acids (Gerke, 1992). Inorganic P desorption, transformation and availability depends on the decomposition organic matter (Zibilske *et al*., 2002; Nziguheba & BůNemann, 2005). Organic acids originated from microbial decomposition of organic matter (OM), reduce the pH in rhizosphere (Chen *et al*., 2006) and increase the availability of locked P from Fe and Al oxides and phosphate complexes (Hue *et al*., 1986; Tiessen & Shang, 1998). Therefore, organic manuring is important for intensive rice cultivation with maintaining soil fertility (Haque *et al*., 2021).

Vermicompost (VC) as an organic input for attaining sustainable agricultural production is a potential source of beneficial microorganisms, prime (NPK) and micro nutrients, enzymes and metabolites (Probodhini, 1994; Sinha *et al*., 2009). VC provides required plant elements notably nitrate, phosphate and exchangeable calcium and soluble potassium (Das, 1996). VC significantly increased the water holding capacity, porosity, drainage as well as microbial activity in soil (Albanell *et al*., 1988). It proves itself as a ‘miracle growth promoter and plant protector’ from pests and disease incidences and provides nutrients for long time as well (Sinha *et al*., 2009), bio-suppressor regulators (Simsek-Ersahin, 2011; Joshi *et al*., 2013).

Today recognized economic and environmental losses are due to excessive use of CFs in agriculture. Therefore, it must be considered as a good alternative for these types of fertilizers. But agriculture in a clarified organic way will not serve as a substitute to fend off the detrimental consequences of distinct chemical agriculture due to its association with yield risk for low nutrients supply. Hence, it is essential to build up and adopt environment friendly alternatives that can supplement or replace CFs. Significant increase in the availability of P was noticed owing to the integrated usage of organic manures and phosphatic chemical inputs (Maharajan *et al*., 1997), improved P use efficiency (Vats *et al*., 2001; Sakhen *et al*., 2011). Use of organic and CFs is imperative to improve P use efficiency, sustain crop productivity, and restore soil health (Hegde & Dwivedi, 1993). So, integrated use of fertilizer inputs is indispensable to increase productivity, quality and to sustain agriculture. At this juncture, our concern now centers on how crucial it is to evolve and implement an integrated nutrient approach comprising a judicious amalgamation of CFs and organic manures like VC. The ambition of the current research work is to figure out the best integrated dose of P and VC as a source of phosphorus and to assess the conjugated impact of P and VC on the growth and production of BRRI dhan28 as well as the soil status after rice cultivation.

Material and Methods

Location, duration, soil and climate: At the period from December 2016 to May 2017, this investigation was administered in Hajee Mohammad Danesh Science and Technology University, Dinajpur. Contingent upon AEZs distribution, Old Himalayan Piedmont Plain (AEZ-1) occupies the experimental site (Anon., 2012). The pH of initial soil was 5.57 i.e., the soil was slightly acidic having 1.49% organic matter, 0.085% total N, 15.10 ppm soil P, 0.09 meq/100 g of soil K, 11.33 ppm soil S,0.27 ppm B and 0.85 ppm Zn (Table 1).

The conducted experiment was situated in subtropical climatic conditions. Throughout the crop growing phase, the average values regarding methodological climatic information are exposed in the (Fig. 1) having the specific data on temperature (maximum, minimum and average temperature, °C), rainfall (mm), and relative humidity (%) of the experimental site. Mean monthly maximum temperatures of the site spanned between 19.8 and 34.9°C with an average of 26.58°C, while the monthly mean minimum temperatures fluctuated between 9.6 to 24.7°C with an average of 16.42°C. The mean relative humidity ranged from 73 to 91% with an average of 81.67%. A total rainfall of 87 cm with an average of 14.50cm was received during normal growth period.

Treatments, design and experimentation: Six (6) treatments were comprised in the experiment *viz*., T_1: $VC_{0\%}P_{0\%}$(Control treatment), T_2: $VC_{100\%}P_{0\%}$(VC @ 6 t ha^{-1}+ P @ 0 kg ha^{-1}), T_3: $VC_{75\%}P_{25\%}$(VC @ 4.5 t ha^{-1} + P @ 22.5 kg ha^{-1}), T_4: $VC_{50\%}P_{50\%}$(VC @ 3 t ha^{-1} + P @ 45 kg ha^{-1}), T_5: $VC_{25\%}P_{75\%}$ (VC @ 1.5 t ha^{-1} + TSP @ 67.5 kg ha^{-1}), and T_6: $VC_{0\%}P_{100\%}$ (VC @ 6 t ha^{-1} + P @ 0 kg ha^{-1}). As per statistical designs, Randomized Complete Block Design (RCBD) was adopted for the research set-up comprising four replications. Therefore, 24 plots were prepared for setting up the experiment. The farmers practiced dose of VC was 6 t ha^{-1} and urea, MoP, TSP, gypsum and zinc sulphate were administered in conformity with the prescribed doses at quantities of 300, 120, 90, 45, and 6 kg ha^{-1}, correspondingly (Anon., 2012). One third of recommended doses of urea fertilizer along with full doses of MoP, gypsum and zinc sulphate fertilizers were properly incorporated into the finally prepared land. TSP was applied as per treatment specification as basal dose with other fertilizers. Following transplanting of seedlings, the rest two thirds of urea fertilizer were applied in two equal portions at 15 and 30 days. Forty (40) days aged two seedlings were planted into each hill of the research plots with the distance of 20 cm × 15 cm on 22 January, 2017. Intercultural operations were carried out whenever applicable. At the stage of harvesting maturity, the crop was harvested properly on 28th April, 2017.

Table 1. General features of initially collected soil from the research site.

Items	pH	OM (%)	Total N (%)	P (µg g^1)	K (meq100^{-1} soil)	S (µg g^1)	B (µg g^1)	Zn (µg g^1)
Initial soil	5.57	1.49	0.085	15.10	0.09	11.33	0.27	0.85
Critical level	-	-	0.12	10.00	0.12	10.00	0.20	0.60
Interpretation	-	-	L	M	VL	L	L	M

L= Low, M: Medium, VL: Very Low

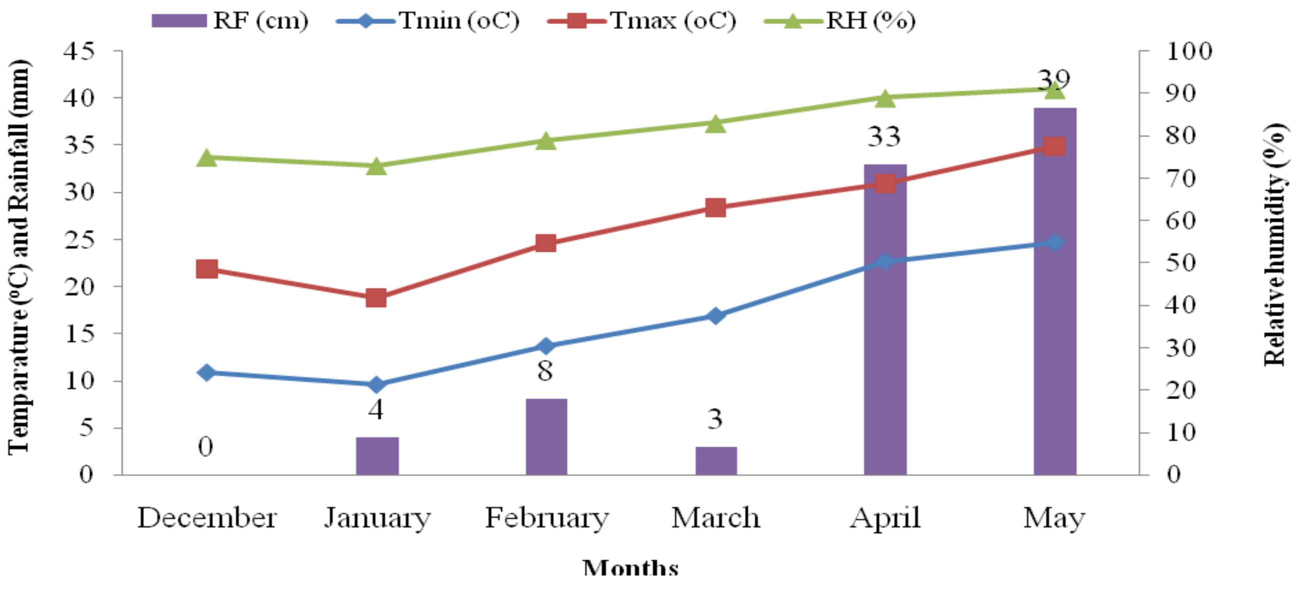

Fig. 1. Monthly temperature (^{0}C), relative humidity (%), and rainfall (mm) at the study location through December 2016 to May, 2017.

Data collection: A random selection of ten hills from each plot was carried out for measuring growth and the characters related to yield contribution. The harvested crop was then brought into the threshing floor with a separate bundled of each plot. The grain was separated from the straw immediately by threshing after harvesting. Then the grain and straw was collected and dried up for data collection. Separate counting of filled and unfilled (sterile) spikelets was done accounting the sample hills in each plot and percentage of spikelet sterility was derived through using the beneath formulae (Islam *et al*., 2021).

$$\text{Spikelet sterility (\%)} = \frac{\text{Number of sterile spikelets panicle} - 1}{\text{Total number of spikelets panicle} - 1\ \text{(filled + non-filled)}} \times 100$$

Just after the experiment's harvest, soil sampling was accomplished to assess the traits of the soil. To do that, field soil samples were drawn in 10 locations at a depth of between 0 and 15 cm. Afterwards, the gathered samples were dispatched to the laboratory in order to assess soil texture as well as chemical composition. Nutrients were analyzed following their respective protocols.

Statistical analysis

A well-recognized statistical tool, SPSS, was utilized to analyze the data, and analysis of variance (ANOVA) was employed for the interpretation. However, in accordance with the researchers (Gomez & Gomez, 1984), the least significant difference (LSD) was employed for mean separation.

Results and Discussion

Effects of VC and P on the yield traits and yield

Plant height: Plant height of BRRI dhan28 was responded significantly as a consequence of different doses of VC and P applications (Table 2). Treatment T_3 was noted with tallest plant (86.83 cm) which was also found statistical similarities with other treatments except T_1, which produced the shortest plant (81.17 cm). VC performed better in promoting plant height compared to phosphatic fertilizer. In agreement with above the findings (Ravi & Srivastava, 1997; Babu *et al*., 2001; Tharmaraj *et al*., 2011; Dekhane *et al*., 2014; Biswas, 2016), disclosed that organic manure and CFs addition considerably boosted the plant height of rice. Inclusion of VC towards the soil enhanced the infiltration and diminished run-off and thereby accelerated the volume of water that was accessible for plant growth (Longsdon & Linden, 1992), which then increased the water holding capacity as well as soil electrical conductivity (Jadhav *et al*., 1993) which might have promoted the plant height of rice. VC with RDF increased the plant height of 6.66 and 14.98% over RDF alone at 30 and 50 DAT, respectively (Daquiado, 2019). The plant height is firmly correlated in a positive manner owing to the application of wormcast into the soil than chemical fertilizer alone (Kale & Bano, 1986) which support our findings (Table 5). The findings confirmed to those of Pandey *et al*., (2001), and Eligio (2012) who reported that higher application rate of nutrients gave high yields of rice. The applied VC and CFs were attributed to provide more available nutrients (Table 4) that would enhanced growth of plants (Jambhekar, 1992; Pandey *et al*., 2001; Islam *et al*., 2015) and finally accelerated the plant height.

Number of leaves hill^{-1}: Considerable increase regarding the number of leaves per hill was noticed by course of effect of VC and P application (Table 2). Though, T_3 treatment was found with the highest number of leaves of 67.87, it was statistically homogenous to T_4, T_2, T_5 and T_6

having the values of 66.97, 66.43, 63.73 and 63.23, respectively. T_1 treatment having the lowest number of leaves of 55.43, differed significantly from other treatments. VC increased the number of leaves by 14.97-22.44% with P, and by 19.84% without P but P increased the trait only by 14.07% without VC indicating that VC has a great contribution on the number of leaves. Application of VC with reduced CFs significantly increased the leaves number in each plant in stevia (Zaman *et al*., 2015a, 2015b, 2018). Our investigation outcomes are in line with those disclosed by Tharmaraj *et al.* (2011) who claimed that the leaf number in rice plant was numerically boosted by VC incorporation. Addition of organic manure (Xu *et al*., 2008) along with VC (Tejada & González, 2009) increased the chlorophyll content that enhanced the rate of photosynthesis along with carbohydrate formation, which in turn enhanced to produce new leaf as they stated. VC increased the soil pH, SOM, and NPKS in soil (Table 4) which might have escalated the leaf number plant^{-1}.

Number of effective tillers hill^{-1}: As a major determinant in output of rice, the number of effective tillers is a crucial agronomic criterion for rice grain yield. The consequence of distinct treatments on the number of effective tillers till^{-1} was statistically considerable at 5% level of significance (Table 2). Higher number of effective tillers hill^{-1} was noticed in all the treatments having different doses of VC and P competent to that of control. The treatment T_3 resulted the greatest number of effective tillers hill^{-1} (18.07) that was statistically closed to by T_4 (17.63), T_2 (15.27), and T_5 (15.10), and the least value (11.20) was noted in the treatment T_1. From the results, it was found that as the addition of VC with and without P, an increment was detected in the number of effective tillers hill^{-1} by 34.82-61.40%. Chander & Pandey (1996) and Siavashi *et al*., (2011) stated a considerable increase in the number of effective tillers in each hill of rice field due to the higher doses addition of organic manure. Increment regarding the effective tillers hill^{-1} of rice owing to VC along with inorganic fertilizers application was revealed by Kumar *et al*., (2014) and Dekhane *et al*., (2014) in *Aman season* (cv. Basmati and GR 11, respectively), Biswas (2016) in *Boro season* (cv. BRRI dhan29) thus validating our findings. Application of VC in combination with inorganic fertilizers produced remarkably higher number of effective tillers hill^{-1} compared to incorporation of inorganic fertilizer alone (Ravi & Srivastava, 1997; Basha *et al*., 2017; Daquiado, 2019). Addition of VC at a amount of 5 t ha^{-1} with 125% RDF in rice field increased the number of panicles by 20.50% (Kumar *et al*., 2014), VC (10 t ha^{-1}) with cow dung (30 t ha^{-1}) increased the effective tillers numerically by 22.36 and 27.32% over control in 2015 and 2016, respectively (Taheri Rahimabadi *et al*., 2017). The increased number of effective tillers in rice with VC was due to increased chlorophyll content, rate of photosynthesis and carbohydrate formation (Xu *et al*., 2008; Tejada & González, 2009), enhancement of soil associated physical aspects (Sarker *et al*., 2004; Kumar *et al*., 2016), having plant growth promoting substances in VC like NAA, cytokinins, and gibberellins (Kale *et al*., 1992), higher macro- and micro-nutrients (Giraddi, 1993; Jambhekar, 1992). Therefore, upgrading of soil pH, SOM, major nutrients (Table 4) and growth promoting hormones might be promoted the plant growth; dry matter yield subsequently caused the maximization in the number of effective tillers.

Panicle length: The plants treated with P fertilizer (TSP) in combination with VC significantly increased the panicle length 7.90-9.67% over control (Table 2). Although, T_3 treatment was found with the highest panicle length of 22.91 cm, it was statistically identical to the other treatments of T_4, T_2, and T_5 having the values 22.87, 22.72 and 22.54 cm, respectively. While, the lowest panicle length of 20.89 cm was noticed in the plants without VC and P (T_1) followed by (21.7 cm) without VC (T_6). VC with P applied treatments possesses the higher panicle lengths (22.54-22.91 cm) than only the P (without VC) applied treatment (21.07 cm). Our study results were strongly supported by Apostol (1989), Ahmed & Rahman (1991), Babu *et al*., (2001), Siavashi *et al*., (2011), Dekhane *et al*., (2014), and Biswas (2016), who concluded that VC with or without RDF significantly increased the panicle length. Application of VC perhaps increased the panicle length because of Ushakumari *et al*., (2006) reported that due to the presence of readily available nutrient (Table 4), plant growth hormones, enzymes and antibiotics, VC is a potential source of plant nutrients. Though, Tejada & González (2009) denoted higher photosynthesis rate and carbohydrate production are responsible for increasing the spike length under VC treatment. Application of VC (5 t ha^{-1}) and 125% RDF boosted panicle length by 23.12% (Kumar *et al*., 2014), by 7.39% with providing 60 kg required N from VC (Biswas, 2016) which are supported in our study where increment ranged from 7.90 to 9.67% with $VC_{25\%}$ $P_{75\%}$ to $VC_{75\%}$ $P_{25\%}$. Therefore, manuring with VC can save 25-75% inorganic P for obtaining desired panicle length.

Number of grains panicle^{-1}: In terms of the number of boro rice grain in each panicle, there was a marked variation among the distinct treatments (Table 2). T_3 treatment generated the grain panicle^{-1} result that was greatest (135.65), which were statistically identical to T_4 (122.75) and T_5 (120.43) treatments, whereas the lowest (113.23) was found in T_1 treatment, statistically similar (115.21) to T_6 treatment. The effect of VC regarding the number of grains panicle^{-1} was substantially greater than phosphatic fertilizers. Previous findings of Hoque (1999), Xu *et al*., (2008), Tejada & González (2009), Zhao & Fitzgerald (2013), Dekhane *et al*., (2014), Biswas (2016) are in agreement with our study results. Application of organic matter as VC enhanced soil physical features (Kumar *et al*., 2016), the uptake of PNK (Basha *et al*., 2017) alike our study (Table 4) might have resulted the increasing the grains panicle^{-1} quantitatively. Rice grains panicle^{-1} raised numerically to 81.22 and 61.52% due to VC with cow manure as compare to control in 2015 and 2016, respectively (Taheri Rahimabadi *et al*., 2017). Plants treated with $VC_{50\%}$ $P_{50\%}$ to $VC_{75\%}$ $P_{25\%}$ noted with materially maximization in the number of grains panicle^{-1} (8.41-19.80%) over control (without TSP and VC).

Number of filled grain panicle^{-1}: Through imposition of different treatments integration with VC and phosphorus, it was observed that application of VC and phosphorus significantly impacted on the number of filled grain panicle^{-1} (Table 2). All the treatments helped in the production of higher number of filled grain panicle^{-1} over the control one. The maximum number of filled grain panicle^{-1} of 123.65 was recorded for the treatment T_3 which has statistical similarities with T_4 and T_5 treatments with the values of 114.02 and 111.12, respectively. In conversely, the minimum filled grins panicle^{-1} (90.51) was recorded in T_1 treatment with same statistical order to T_6 treatment. The observed increase of filled grains panicle^{-1} in rice due to VC is consistent with the studies by several previous observations (Dekhane *et al*., 2014; Biswas, 2016; Taheri Rahimabadi *et al*., 2017). It is noted that VC enriched the soil by increasing nutrients (NPKS), SOM, and decreasing soil acidity (Table 4), which might have enhanced to produce fertile grain.

Weight of 1000-grains: The significant effect of VC and phosphorus has also been observed in case of weight of 1000-grains (Table 2). VC containing treatments showed superior of 1000-grains weight over other treatments of control and sole P. However, T_3 treatment was found with the highest weight of 1000-grains (25.89 g) followed by T_4 (24.50 g), T_2 (24.20 g), and T_5 (24.08 g) with the corresponding statistical level. In contrary, the least was recorded in T_1 treatment (23.17 g) followed by T_6 treatment (23.96 g). Integration of organic manure along with CFs numerically increased the weight of rice 1000-grain (Abedin *et al*., 1999; Hoque, 1999; Dekhane *et al*., 2014). Our results are confirmed by the previous several findings reporting that VC significantly elevated the 1000-grain weight of rice (Tejada & González, 2009; Kumar *et al*., 2014). Unlike VC, OM with CFs significantly increased the weight of 1000-grain (Pandey *et al*., 2001; Xu *et al*., 2008; Khatun *et al*., 2018; Islam *et al*., 2021). Conversely, Daquiado (2019) found a non-significant effect on the 1000-grain weight of rice, not only that our findings surprisingly varied from that of Taheri Rahimabadi *et al*., (2017), who concluded that 1000-grain weight was reduced as compared to the treatment not being treated with VC with cow manure.

Spikelet sterility (%): It is a negatively related important yield contributing index regarding the yield of a crop. In accordance with the results of this study, the least spikelet sterility (SS) was opined at T_4 treatment (8.73%), followed by T_3 (10.00%) and T_5 (10.31%) treatments. Contrastingly, the maximum SS was noted in control plot (22.72%) having no VC and P which statistically differed from T_6 treatment (16.69%) with full doses of P without VC (Fig. 2). The results showed that VC had a significant role in reducing the SS, and P also had a great contribution in this trait. Full dose of P without VC showed lower SS (16.69%), while full dose of VC without P showed 13.65% SS. Therefore, application of VC with reduced rate of P is found to be very effective in this observation. VC improves physical (Longsdon & Linden, 1992; Jadhav *et al*., 1993) and chemical (Dissanayake *et al*., 2014; Amanullah, 2016) and biological (Jambhekar, 1992; Liu *et al*., 2017) properties of soil which supported our study (Table 4) and might enhanced growth and development of plant and ultimately reduced the SS. Despite the fact that P is the second primary fertilizer that had a significant contribution in reducing SS, but adding of VC with P ($P_{25\%}$ to $P_{75\%}$) performed the best result in reducing the SS. Hence, VC can produced sufficient fertile grains with saving 50% inorganic P for cultivation of BRRI dhan28.

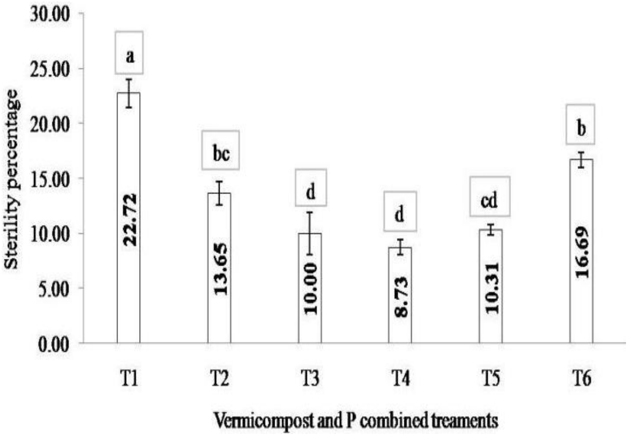

Fig. 2. Effect of VC and P on the sterility percentage of rice (cv. BRRI dhan28).

Grain yield: The grain yields of BRRI dhan28 in all treatments were significantly greater due to application of VC with P fertilizer over the control (Table 3). Grain yield of rice was obtained greater in those treatments where the level of VC was higher. The treatment T_3 was marked with the highest grain yield (5.68 t ha^{-1}) that was found statistically equivalent to T_4 (5.36 t ha^{-1}) and T_5 (5.23 t ha^{-1}) treatments, while the treatment T_1 was having the least grain yield (3.95 t ha^{-1}) amongst the treatments. The intermediate grain yields (4.91 and 4.81 t ha^{-1}) was drawn from T_2 ($VC_{100\%}$ $P_{0\%}$) and T_6 ($VC_{0\%}$ $P_{100\%}$) treatment, respectively. The highest grain yield may happen due to application of VC with P which was also previously stated by some researchers (Senapathi *et al*., 1985; Vasanthi & Kumaraswany, 1996; Ravi & Srivastava, 1997; BalajiNaik & Yakadari, 2004; Dekhane *et al*., 2014), that VC along with CFs significantly increased the grain yield as compare to sole VC or sole P. Our results can be explicated by the fact that the VC is used as the substitute of inorganic fertilizers as it substituted 42.85-71.42% inorganic N (urea) in BRRI dhan29 (Biswas, 2016), saved 50% of recommended NPK fertilizer with 2.5 t ha^{-1} VC in upland and transplanted paddy (Kale & Bano, 1988), 50% N ha^{-1} in hybrid rice from RDF by 2.0 t ha^{-1} VC (Upendrarao & Srinivasulureddy, 2004), 50% N from RDF by 50% N through VC (Dekhane *et al*., 2014) which recorded higher yield traits and yield of rice. Cow dung with zinc positively influenced the aromatic rice yield (Islam *et al*., 2021).

Furthermore, combined application of VC along with N fertilizer and bio-fertilizer augmented the rice grain production by 16% rather than the utilization of solo N fertilizer (Jeyabal & Kuppuswamy, 2001), VC (5 t ha^{-1}) with RDF (125%) boosted the grain yield of rice by 31.15% (Kumar *et al*., 2014), VC (5 and 10 t ha^{-1}) with cow manure reflected with an increase in grain yield by 49.2 and 93.0%, respectively (Taheri Rahimabadi *et al*., 2017), VC (5 t ha^{-1}) significantly escalated aromatic rice (cv. PusaBasmoti) grain yield as compared to control (Murali & Setty, 2004), VC treated rice plants exhibited higher growth rate and productivity over the untreated plants (Sudhakar *et al*., 2002; Tharmaraj *et al*., 2011). Addition of VC with or without CFs improved the physical properties like electrical conductivity, porosity, moisture content, water holding capacity, and chemical properties (N, P, K, Ca and Mg contents) distinctly, consequently increased in the production of rice (Jadhav *et al*., 1993; Anitha & Prema, 2003; Tharmaraj *et al*., 2011), increased organic carbon content (Hapse, 1993; Vasanthi *et al*., 1995), enhanced the infiltration and minimized the run-off and thereby expedited the volume of water that was obtainable for plant growth (Longsdon and Linden, 1992), provided more primary, secondary and micro-nutrients available for plant uptake (Kale & Bano, 1986; Ievinsh, 2011; Dissanayake *et al*., 2014; Amanullah, 2016), auxin and cytokinin, essential plant growth hormones (Ievinsh, 2011), indole acetic acid and gibberellic acid (Jambhekar, 1992), humic acid (Maji *et al*., 2017), auxins, gibberellins, and cytokinins along with phosphate, enzyme, and bacteria those have the ability to dissolve vitamins (Tejada & González, 2009; Liu *et al*., 2017), favorably influenced on soil structure as well as on the colonization of useful microbes *viz*., bacteria like *Azotobacter* and *Azospirillum* besides number of actinomycetes (Jambhekar, 1992), provided ezymes like phosphatases, invertase, chitinase (Jambhekar, 1992) which eventually increased the yield components like number of tillers, panicle length, the number of grains $panicle^{-1}$, and 1000-grain weight (Table 2) and finally grain yield. Fewer incidences of diseases and pests owing to VC are also accountable for positive influence on the rice grain quality and production (Baphna, 1992).

Straw yield: VC with P also significantly influenced the straw yield (Table 3). The recorded straw yield spanned from 4.58 t ha^{-1} (control treatment) to 5.98 t ha^{-1}. Nonetheless, the maximum straw yield of 5.98 t ha^{-1} was noted in $VC_{75\%}$ $P_{25\%}$ (T_3) followed by T_4, T_5 and T_2 treatment. The results are certified by Senapathi *et al*., (1985), Ahmed & Rahman (1991), Ravi & Srivastava (1997), Dekhane *et al*., (2014), Biswas (2016), who disclosed that the combination of VC along with CFs significantly raised the rice straw output. Clear evidence was found that coupling of organic manures and CFs promoted vegetative development of plants which finally increased the straw yield. Kumar *et al*., (2014) reported that VC (5 t ha^{-1}) with RDF (125%) increased 42.81% straw yield as compare to control. Stimulation in the activity of beneficial soil microorganisms was found by the utilization of VC (organic matter) with soil (Ievinsh, 2011) which then ensures the mineral nutrients supplement to plants (Table 4) might enhance more vigorous vegetative growth. Kale & Bano (1986) demonstrated a positive affiliation between shoot weight and application of wormcast than CFs alone. The improvement of physic-chemical properties of soil and more availability of nutrient in roots due to VC (Table 4) are related to more vegetative and dry matter production which may be improved straw yield.

Biological yield: There is a considerable variation in biological yield was found owing to the utilization of distinct quantities of P with VC (Table 3). Meanwhile, the maximum biological yield (11.66 t ha^{-1}) was documented in the treatment T_3 which had the statistical similarities to T_4, T_5 and T_2, whereas the minimum was in T_1 treatment (without VC and P). The outcomes of our present study are corroborated with the results of Biswas (2016), Taheri Rahimabadi *et al*. (2017), who concluded that VC with CFs significantly increased the biological yield in rice. Application of VC @ 5 and 10 t ha^{-1} raised the biological yield by 9.0 and 17.9% in 2015, and 12.3 and 24.8% in 2016, respectively as against the increment of 5.3 and 8.1%, and by 4.3 and 18.1% with 10 and 20 t ha^{-1} cow dung over control, correspondingly (Taheri Rahimabadi *et al*., 2017). In this study, VC with P increased the biological yield ranging from 17.47 to 37.05%, which approve the previous observations. VC stimulates plant growth possibly through providing plant growth hormones and nutrients and increasing chlorophyll which, consequently, increases photosynthesis and dry matter (Ievinsh, 2011), improves leaf area and tiller number (Joshi *et al*., 2015) which might be increased the biological yield.

Influences of VC and P on the properties of soil

Soil pH and organic matter: The application of VC with reduced P fertilizer showed significant consequence on post-harvest soil pH (Table 4). The greatest pH (6.59) was recorded in the soil treated with VC @ 6.0t ha^{-1} + P @ 0 kg ha^{-1} (T_2) which showed statistical similarities to the soil treated with VC @ 4.5t ha^{-1} + TSP @ 22.5 kg ha^{-1} (T_3), VC @ 3.0 t ha^{-1} + P @ 45 kg ha^{-1} (T_4) and VC @ 1.5 t ha^{-1} + P @ 67.5 kg ha^{-1} (T_5). On the contrary, the least (5.54) was obtained in the soil treated with VC @ 0 t ha^{-1} + TSP @ 90 kg ha^{-1} (T_6) followed by (5.57) in control plot (T_1). Results manifested the acidity effect of CFs on the soil, and the soil reaction enhancement with the addition of VC. The output of the current study agreed well in accordance with Tharmaraj *et al*. (2011). Application of VC decreased the acidity both in acidic soil (pH from 4.9 to 5.7) and also in non-calcareous soil (from 6.5 to 7.2) (Zaman *et al*., 2015a).

Treatments with VC and P fertilizers had such a substantial impact on the content of soil organic matter (SOM). The SOM content is followed the similar trends as like pH values in this study. However, the highest SOM content (1.76%) was found under T_2 treatment followed by T_3, T_4 and T_5 treatments which were treated with gradual decrease of VC from 4.5, 3.0 and 1.5 t ha^{-1}, correspondingly, and the lowest (1.24%) was in VC untreated soils at T_6 treatment (1.24%) followed by T_1 treatment (1.35%). This increase in SOM due to VC is consistent to the study by Mahmud *et al*. (2016), Zaman *et al*. (2018), Daquiado (2019), who reported that VC with RDF remarkably increased the SOM content in post-harvest soil. Zaman *et al*. (2015a) also observed that VC considerably increased the OM content in acidic soil (from 1.7 to 2.39%) as well as in non-calcareous soil (from1.28 to 2.61%). VC added OM content in the soil after harvesting showing higher values over the control plot. Application of CFs with organic manure increased the SOM as documented by Xu *et al.* (2008). A 0.27% increment regarding in the content organic of post-harvest soil was reported by the addition of VC (Hapse, 1993), and 17.88% (Vasanthi *et al*., 1995) as compared to application of CFs sole. Vasanthi and Kumaraswamy (1999) also commented that post-harvest soil contained increasing amount organic carbon due to vermicomposting to the soil.

N, P, K and S: VC with reduced P fertilizer had notable effect on the content of total nitrogen percentage in the post-harvest soil of research plot (Table 4). Total nitrogen content (0.087%) which was the maximum amount, found from T_2 having statistical followings by T_3 and T_4 treatments (0.084%), and the minimum (0.070%) was observed in T_1 (control) and T_6 treatments (0.070) followed by T_5 treatment (0.072). This is may be due to the fact that the application of VC added total N in soil as well as minimized the loss of N in soil owing to increasing OM content in soil (Table 4). These results were strongly validated by numerous findings demonstrating that VC materially increases N content in soil (Kale *et al*., 1991; Tharmaraj *et al*., 2011; Mahmud *et al*., 2016). The activity of soil microorganisms is firmly increased in respect of higher soil organic matter presence which ultimately boosts up the plant nutrients availability (Srivastava *et al*., 2010). The soil is enriched with N content due to addition of other organic manures like compost (Bangar *et al*., 1990), cow manure (Arancon *et al*., 2005), farm manure (Zhang *et al*., 2016). Microbes' viz., bacteria like *Azotobacter* and *Azospirillum* are high in VC, and also the number of actinomycetes (Jambhekar, 1992) which might have positively influenced the availability of N in soil.

Addition of VC in combination with P fertilizer showed remarkable effect on the available P content in the procured soil after harvesting of study units (Table 4). All plots containing P treatment with or without VC showed the higher available P in soil than control (without VC and P). Lower P content was observed in soil without VC treated plot suggesting no release of nutrients in absence of VC. Our observations closely resemble with those of Mahmud *et al*., (2016), who pointed out that VC with CFs significantly influenced the soil P content, where the maximal amount of available P was observed with the highest levels of VC and NPKS. It is revealed that soil available nutrients (NPK) occurred in a significant increasing manner by the incorporation of various organic resources of nutrients in amalgamation with chemical fertilizer (Kale *et al*., 1991; Tolanur & Badanur, 2003; Tharmaraj *et al*., 2011). In contrary, our results differed from those of Daquiado (2019) who found the significant reduction of P in the soil treated with VC (2 t ha^{-1}) and N-P-K of 90-60-60 as compare to their separate treatment as well as to control. Phosphate uptake in plants is diminished by soil acidity, and thereby increased soil toxicity and inhibits crop growth (Cooke, 1982), and our results confirmed this statement.

The amount of exchangeable K and available S of after harvesting soil of the research field was not influenced by VC and P fertilizer, which suggested that K and S are not organically bound nutrient. However, numerically the highest amount of exchangeable K and available S was obtained from T_3 treatment, while the least amount was in T_1 treatment (Table 4). The results found in our study were closely supported by the findings obtained by Daquiado (2019) who noted that VC and different doses of NPK had no noteworthy influence on the exchangeable K concentration in the post-harvest soil, although the value was increased numerically with the addition of VC. But there is a clear evident that VC and NPKS in a combination significantly increased the exchangeable K and available S concentration in post rice cultivated soil (Tharmaraj *et al*., 2011; Mahmud *et al*., 2016). VC increased the mineralization rate in beans (Manivannan *et al*., 2009), in stevia (Zaman *et al*., 2018) because of accelerated microbial metabolism throughout the vermicomposting process.

Correlation between grain yield and post-harvest soil properties: Soil properties advocate the growth and development that reflected the yield gain (Islam *et al*., 2012). Thus, correlation of grain yield with soil characteristics like pH, organic matter (%), total N (%), available P (ppm), exchangeable K (meq/100 g soil) and availab le S (ppm) was studied to explain its behavior in relation to the grain yield formation. The grain yield was positively correlated with soil characteristics due to the application of VC and P in the soil. In addition, a substantial positive affiliation was found between the grain yield with P, K and S contents (0.91**), respectively. Others soil characteristics like pH, organic matter (%) and total nitrogen (%), was also remained positive but non-significant (Table 5). The positive correlations between grain the yield with different soil characteristics indicate that the grain yield and its components could be directly affected by soil nutritional status. Confirmatory statistics were also found by Lima *et al*., (2009), and Mahmood *et al*., (2017) who stated that incorporation of VC improves the physico-chemical properties of soil that may have a direct or indirect impact on the plant growth, yield attributes and yield. Normally P remains fixed in the soil particle especially in calcareous type soils. In the present study, P, K and S showed significant positive correlation with each others. Its might be due to VC had positive response to availability the P through breakdown the bindings of P from the soil, and also increased K and S contents. Organic matter showed strong positive correlation with soil pH (0.99***) and total nitrogen (0.83**). It revealed that increased and decreased of pH and total nitrogen depends on organic matter contents.

Functional relationship between grain the yield with deferent soil characteristics: A strong positive linear linkage was detected between the grain yields with all the identified soil properties (Fig. 3). However, a considerable association was identified between the grain yield with P, K and S contents (R^2=0.69, 0.85 and 0.67, respectively). The regression equation can be determined to investigate the yield response of rice with contrasting soil properties. The equations indicate that rice yield can be increased at the rate of 1.43, 38.37, 0.37, 66.5 and 0.88 t ha^{-1} with an increase of 1% organic matter, 1% total nitrogen, 1 ppm P, 1 meq K/100g soil and 1 ppm S, respectively. The R^2 values of 0.59, 0.50, 0.40, 0.69, 0.85 and 0.67 from the equations indicate that rice yield can be explained as 59%, 50%, 40%, 69%, 85% and 67% by the respective function.

Table 2. Effects of VC and P on the growth and yield contributing characters of BRRI dhan28.

Treatments	Plant height (cm)	No. of leaves hill^{-1}	No. of effective tillers hill^{-1}	Panicle length (cm)	No. of grains panicle^{-1}	No. of filled grains panicle^{-1}	1000-grain weight (g)
T_1	81.17 b	55.43 b	11.20 c	20.89b	113.23 c	90.51c	23.17 b
T_2	85.33 a	66.43 a	15.27 ab	22.72a	119.89 b	106.24 b	24.50 ab
T_3	86.83 a	67.87 a	18.07 a	22.91a	135.65 a	1231.65 a	25.89 a
T_4	85.93 a	66.97 a	17.63 a	22.87a	122.75ab	114.02ab	24.20 ab
T_5	84.73 ab	63.13ab	15.10 ab	22.54a	120.43 b	111.12ab	24.08 ab
T_6	84.60 ab	63.23ab	14.57 b	21.07b	115.21 c	98.52c	23.96b
LSD	**5.116**	**15.20**	**3.176**	**1.199**	**26.56**	**24.03**	**1.955**
CV (%)	**3.31**	**13.11**	**11.78**	**2.97**	**9.82**	**11.89**	**4.33**

Values in the column with identical letter(s) do not substantially differ at the 5% level of probability; T_1: $VC_{0\%}P_{0\%}$ (Control treatment), T_2: $VC_{100\%}$ $P_{0\%}$ (VC @ 6 t ha^{-1} + P @ 0 kg ha^{-1}), T_3: $VC_{75\%}P_{25\%}$ (VC @ 4.5 t ha^{-1} + P @ 22.5 kg ha^{-1}), T_4: $VC_{50\%}P_{50\%}$ (VC @ 3 t ha^{-1} + P @ 45 kg ha^{-1}), T_5: $VC_{25\%}P_{75\%}$ (VC @ 1.5 t ha^{-1} + P @ 67.5 kg ha^{-1}), and T_6: $VC_{0\%}P_{100\%}$ (VC @ 6 t ha^{-1} + P @ 0 kg ha^{-1}); LSD = Least significant difference; CV = Coefficient of variance

Table 3. Effect of VC and P on the yield components of BRRI dhan28.

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})
T_1	3.95 c	4.58 b	8.53 c
T_2	4.91 b	5.11 ab	10.02 ab
T_3	5.68 a	5.98 a	11.66 a
T_4	5.36 ab	5.53 a	10.89 a
T_5	5.23 ab	5.45 a	10.68 a
T_6	4.81 b	4.93 b	9.74 b
LSD	**1.082**	**1.277**	**1.950**
CV (%)	**11.73**	**14.50**	**10.80**

Values in the column with identical letter(s) do not substantially differ at the 5% level of probability; T_1: $VC_{0\%}$ $P_{0\%}$ (Control treatment), T_2: $VC_{100\%}$ $P_{0\%}$ (VC @ 6 t ha^{-1} + P @ 0 kg ha^{-1}), T_3: $VC_{75\%}P_{25\%}$ (VC @ 4.5 t ha^{-1} + P @ 22.5 kg ha^{-1}), T_4: $VC_{50\%}$ $P_{50\%}$ (VC @ 3 t ha^{-1} + P @ 45 kg ha^{-1}), T_5: $VC_{25\%}P_{75\%}$ (VC @ 1.5 t ha^{-1} + TSP @ 67.5 kg ha^{-1}), and T_6: $VC_{0\%}P_{100\%}$ (VC @ 6 t ha^{-1} + P @ 0 kg ha^{-1}); LSD = Least significant difference; CV = Coefficient of variance

Table 4. Effect of VC and P on post-harvest soil properties.

Treatments	pH	Organic matter (%)	Total N (%)	Available P (ppm)	Exchangeable K (me/100 g soil)	Available S (ppm)
T_1	5.57 b	1.35 b	0.070 b	13.60 b	0.07	11.23
T_2	6.59 a	1.76 a	0.084 a	15.25 ab	0.08	12.13
T_3	6.57a	1.74 a	0.085 a	16.22 a	0.09	12.38
T_4	6.55 a	1.71 a	0.084 a	16.12 a	0.08	12.37
T_5	6.54 a	1.67 a	0.072 b	16.08 a	0.08	11.89
T_6	5.54 b	1.24 b	0.070 b	16.02 a	0.08	12.05
LSD	0.564	0.325	0.058	4.188	0.058(NS)	4.055(NS)
CV %	4.72	10.60	17.05	14.81	24.37	18.56

Values in the column with identical letter(s) do not substantially differ at the 5% level of probability; NS = non-significant; T_1: $VC_{0\%}$ $P_{0\%}$ (Control treatment), T_2: $VC_{100\%}$ $P_{0\%}$ (VC @ 6 t ha^{-1} + P @ 0 kg ha^{-1}), T_3: $VC_{75\%}$ $P_{25\%}$ (VC @ 4.5 t ha^{-1} + P @ 22.5 kg ha^{-1}), T_4: $VC_{50\%}$ $P_{50\%}$ (VC @ 3 t ha^{-1} + P @ 45 kg ha^{-1}), T_5: $VC_{25\%}$ $P_{75\%}$ (VC @ 1.5 t ha^{-1} + TSP @ 67.5 kg ha^{-1}), and T_6: $VC_{0\%}$ $P_{100\%}$ (VC @ 6 t ha^{-1} + P @ 0 kg ha^{-1}); LSD = Least significant difference; CV = Coefficient of variance

Table 5. Correlation of grain yield with different soil characteristics under various VC and P levels.

	pH	OM	TN	P	K	S	GY
pH	1						
OM	0.99***	1					
TN	0.79	0.83*	1				
P	0.54	0.41	0.39	1			
K	0.61	0.55	0.63	0.81*	1		
S	0.66	0.59	0.76	0.88*	0.85*	1	
GY	0.78	0.69	0.66	0.91**	0.91**	0.91**	1

*Significant at P=0.05; **Significant at P=0.01; ***Significant at P=0.001; OM=Organic matter (%); TN=Total N (%)

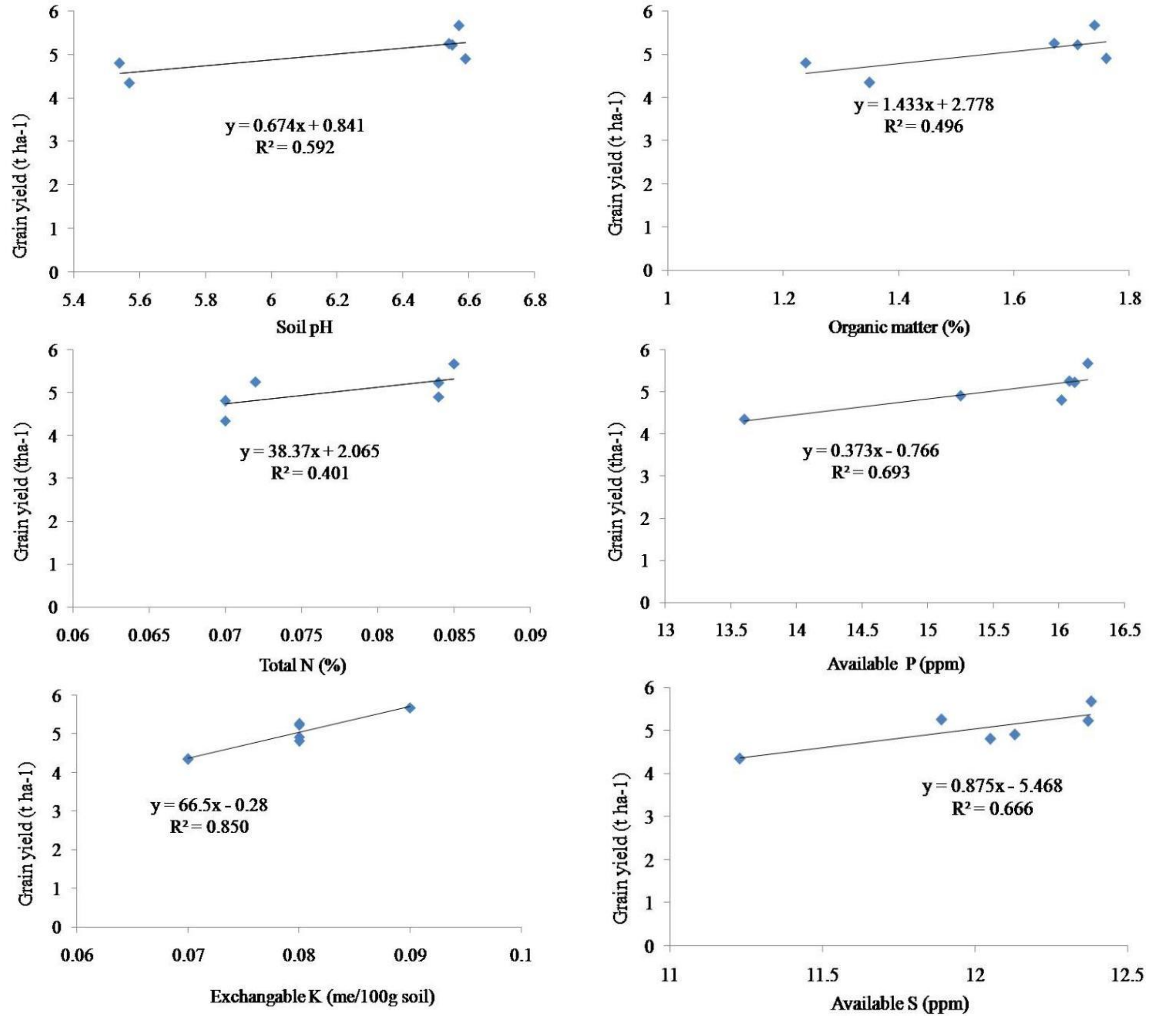

Fig. 3. Contribution of soil nutrients and other elements (bottom) on rice grain yield.

Conclusion

The integrated effect of VC and P significantly impacted the yield attributable characteristics and yield of rice (BRRI dhan28). Addition of VC @ 4.5 tonand P @ 22.5 kg ha^{-1} ($VC_{75\%}$ $P_{25\%}$) with RDF showed the maximum values of yield indices and yield which was statistical identical with VC @ 3 ton and P @ 45 kg ha^{-1} ($VC_{50\%}$ $P_{50\%}$). The post-harvest soil properties like pH, organic matter and the content of total nitrogen as well as available phosphorus significantly increased with the addition of VC and P. Potassium and sulfur content in post-harvested soil also increased with the addition of VC but not at a remarkable level, and VC contributed to improve soil properties. Positive correlation was opined between the grain yield and post-harvest soil properties, wherein strong and significant correlation was found with P, K and S. Application of VC (3-4.5 t ha^{-1}) saved 50-75% P from RDF to get equivalent or higher yield. Therefore, it can be recommended to use VC with reduced RDF to obtain desired yield as well as improving soil health for sustainable rice cultivation.

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