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Uptake of nutrients by BR 22 rice plants at two growth stages driven by locally made organic amendments

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Abstract

An on-site experiment was done at the Aman season to evaluate the potential differences in nutrient supply by five different organic amendments (OAs) to BR 22 rice following a completely randomized block design (CRBD). The OAs were incorporated in the subplots at 0, 5, and 10 t ha^{-1}. The amendments were observed to have varied significantly ($p < 0.05$) in supplying the mineral nutrition of rice plants both in the maximum tillering and harvesting stages. With respect to N and P, the treatment of rice straw plus cow dung compost of 1:4 at its higher dose (T_5) was found to have the most potential to enhance these nutrients accumulation in shoots at the maximum tillering stage at 21.05 and 7.0 g kg^{-1} N and P, respectively. Whereas, TC (T_9) was detected with the highest K contents (39.95 g kg^{-1}) in shoots at the tillering stage followed by RH (T_{13}) and SD compost (T_{11}). As per the secondary nutrients, TC (T_9) manifested the highest S, compost mixture (T_5) for Ca, and treatment (T_{13}) accounted for the highest Mg uptake in the rice plant. Moreover, the findings showed that OAs significantly augmented the contents of micronutrients Zn, Fe, and Mn in rice plants over the control. In most instances, the nutrient content declined as the plants turned towards maturity.

Introduction

Rice, being the third-most widely consumed cereal grain, positions itself as the top staple food across the globe(1), including Bangladesh, and is becoming 'Rice is life' as it provides 76% of caloric value and 66% of the protein contents(2). As a result, around 78% of net cultivable land in this country, corresponding to an area of 11.55 million hectares, is used for rice cultivation year-round(3,4). In this line, although production here has increased threefold since independence(5), the amount still lags significantly behind China and Japan(6). The reasons behind this can be manifold, but fundamentally, those of microclimates, crop management, and fertilization affect mineral nutrient supply throughout the life cycle of rice plants.

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Again, the macro- and micro-nutrients play multi functions in plants including rice. For example, nitrogen and phosphorous are critical for crops as they affect growth, yield, and crop quality. However, their availability is restricted by soil conditions such as acidity and alkalinity. Potassium, needed for structural stability, vigour, disease resistance, and root development, is limited due to fixation and release characteristics under variable soil conditions. In addition, sulfur generally improves rice height, leaf number, dry matter production, and yield. Moreover, calcium is for the maintenance of structure and functions of cell walls and membranes(7); magnesium is for photosynthesis, activating enzyme, and the synthesis of nucleic acid and proteins(8); zinc is an essential but deficient micronutrient in the soil worldwide(9); iron deficiency frequently occurs upland soils that are high in pH and well aerated(10); manganese is essential in several metabolic functions such as photosynthesis, respiration, ATP synthesis, proteins, lipids, and activation of hormones(11). The demand for nutrients is fulfilled by inorganic fertilizers that cause physical, chemical, and biological degradations of soil and ultimately soil health in most cases. Considering the negative impacts of inorganic fertilizers with their high prices and associated climate change, OAs are prioritized as a nutritional source for plants with concomitant improvement in soil health(12). Because of low level of nutrient status, it is wise to use them along with chemical fertilizers where organic substances enhance microbial actions, the net efficiency of nutrient uptake, and the presence of indigenous nutrients to crops for easy uptake(13) to maintain optimum soil health that ultimately improves crop output in an intensive cropping system.

Applying composts and farm yard manure improves soil structure through soil aggregate stability, humification, and microbial action(14). It also decreases bulk density in surface and sub-surface soils(15), increasing water-holding capacity in soils by increasing organic carbon(16). Additionally, the application of composts and manure significantly increases total N content(17), improves phosphorus nutrition for plants and microbes, increases K concentration threefold(18) and other macro and micronutrients are also positively increased by consecutive application of composts(19). The present research is conducted to investigate the uptake of the above mentioned essential nutrients by the BR 22 rice plant under different locally made organic amendments application in two growth stages.

Materials and Methods

An experimental field was prepared at Mithapukur (GPS: 24°03′27″N, 91°18′32″E), in Madhabpur Upazila of Habiganj district, Bangladesh. This site belongs to the Old Meghna Estuarine Floodplain(20), with clay loam texture, and poorly drained clay loam subsoil where initial soils available N, P, K, S, Ca, Mg, Zn, Fe and Mn vales are 39.38, 20.38, 34.68, 316.44, 3.54, and 1.90 mg kg$^{-1,}$ respectively and exchangeable K, Ca and Mg are 0.18, 4.71, and 1.98 cmol$_c$ kg^{-1}, respectively. The field was ploughed to prepare and mix the previously added OAs into the soil. Treatments are T_1 = Control (-OAs), T_2 = 5 tons vermicompost ha^{-1} (V_5), T_3 = 10 tons vermicompost ha^{-1} (V_{10}), T_4 = 5 tons rice straw plus cow dung at 1:4 compost ha^{-1} (1RS:4CD_5), T_5 = 10 tons rice straw plus cow dung at 1:4 compost ha^{-1} (1RS:4CD_{10}), T_6 = 5 tons rice straw plus cow dung at 1:2 compost ha^{-1} (1RS:2CD_5), T_7 = 10 tons rice straw plus cow dung at 1:2 compost ha^{-1} (1RS:2CD_{10}), T_8 = 5 tons TC ha^{-1} (TC_5), T_9 = 10 tons tricho-compost ha^{-1} (TC_{10}), T_{10} = 5 tons saw dust compost ha^{-1} (SD_5), T_{11} = 10 tons saw dust compost ha^{-1} (SD_{10}), T_{12} = 5 tons RH compost ha^{-1} (RH_5) and T_{13} = 10 tons rice husk compost ha^{-1} (RH_{10}). The chemical composition of these amendments is given in Table 1.

Table 1. The composition and nutrients contents of the selected organic amendments

Organic amendments	Rice straw plus cow dung of 1:2 compost	Rice straw plus cow dung of 1:4 compost	Sawdust compost	Rice husk compost	Vermicompost	Tricho-compost
Total N (%)	2.51	2.19	1.92	1.05	2.55	2.76
Total P (%)	0.73	0.40	0.21	0.29	0.54	0.92
Total K (%)	0.49	0.41	0.28	0.20	0.50	0.72
Total S (%)	1.15	1.09	0.17	0.14	1.48	1.17
Total Ca (mg kg^{-1})	958	748	1107	954	1047	1225
Total Mg (mg kg^{-1})	229	491	388	224	310.83	522.08

Thirteen treatments were applied before ploughing, consisting of vermicompost, tricho-compost, rice straw plus cow dung, rice husk and sawdust composts at 5 and 10 t ha^{-1}. Following the fertilizer recommendation set by Bangladesh Agricultural Research Council, 120 kg Urea at two separate doses, 60 kg TSP, and 40 kg MoP were also applied per hector as basal doses. The experiment followed a CRBD replicated three times. The treatments containing composts were incorporated into all plots. The main plots were divided into 13 subplots each with (2m × 2m) size. To address the probable contamination issue among sub-blocks, 15 cm spacing with an additional 10 cm thick earthen boundary was maintained. For irrigation purposes, a drain (25 cm) was dug between the blocks. After all the preparation, BR 22 seedlings obtained from the local farmers were transplanted in 6 rows, at a rate of 3 seedlings in a hill, with hill-hill distance of 15 cm, and row-row distance of 20 cm, respectively. In addition to two irrigations, thinning, and weeding were part of the cultural practices. At the sampling stage, at maximum tillering and harvesting, reserve the first and final rows for guarding purposes, the vegetative part of the plants from two randomly selected rows in every subplot was sampled from 1 cm above ground height. Then the plants were washed, dried, pulverised, ground, and finally stored for nutrient analyses. Powdered plant sample of 0.5 g from each preserved sample was digested employing a 2:1 mixture of HNO_3 and $HClO_4$ on a hotplate, following the method outlined by Jackson[21]. After cooling, the digests were filtered, diluted, and preserved in dry plastic bottles as a stock solution for further determination of P, K, S, Zn, Ca, Mg, Fe and Mn. Total Phosphorus from plant samples was determined calorimetrically by a PG spectrophotometer at 430 nm wavelength following the development of a yellow color in the digest using vanadomolybdate[22]. Total sulfur in the digested samples was quantified based on the turbidity formed by suspended barium sulfate, stabilized using Tween-80. The turbidity was measured at a wavelength of 420 nm using a HACH DR 5000 spectrophotometer[23]. Total potassium in shoots was determined by Flame Photometer, and total Zn, Ca, Mg, Fe and Mn by a PerkinElmer PinAAcle 500 Flame Atomic Absorption Spectrometer.

Conversely, total N in the shoots was quantified using the Micro-Kjeldahl method, involving H_2SO_4 digestion followed by steam distillation with 40% NaOH. The ammonia liberated was trapped in 4% boric acid and quantified through titrimetric analysis[21]. Microsoft Excel and Minitab 20 were employed for conducting statistical analysis and visualizing the data.

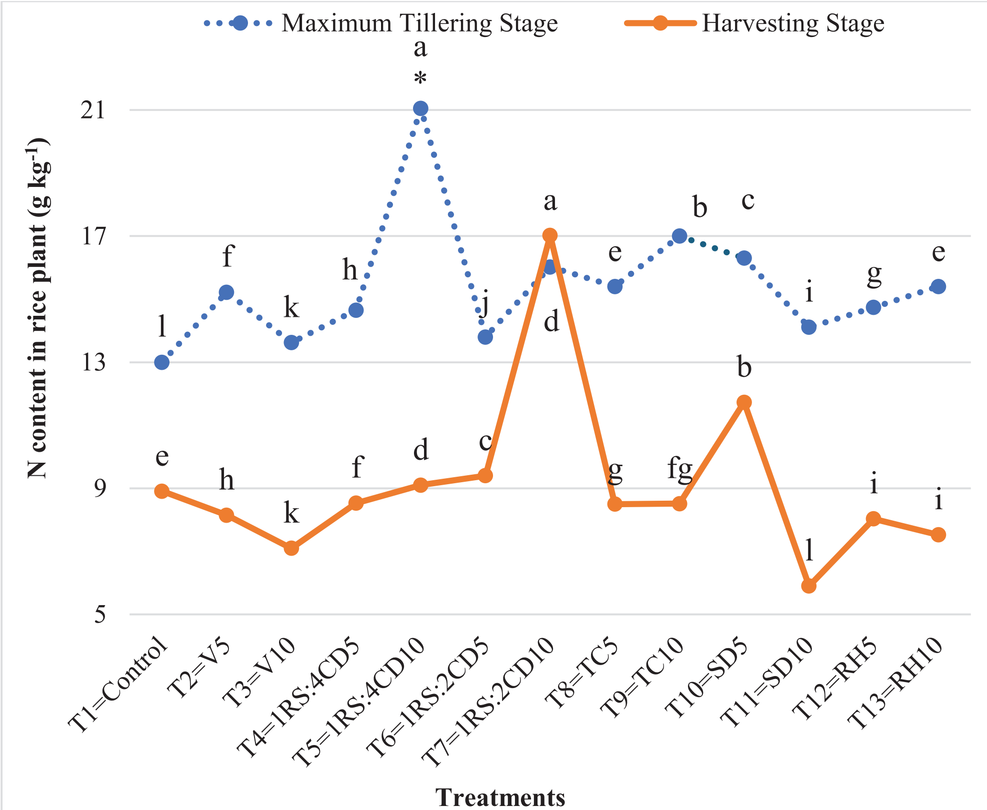
Results and Discussion

Nitrogen

The amount of total N in shoots of BR 22 rice plant differed significantly ($p < 0.05$) due to the application of varying doses of several locally available OAs in the studied maximum tillering and harvesting stages, possibly attributable to differences in the rate of mineralization of OAs (Fig. 1).

In maximum tillering, the most significant amount of nitrogen (21.05 g kg^{-1}) was obtained in rice plants grown in soil with RS and CD (1:4) compost was used at 10 tons per hectare (T_5). Among the other treatments, the increased N content was determined in 10 tons TC ha^{-1} (T_9: 17.00 g kg^{-1}) > 5 tons SD compost ha^{-1} (T_{10}: 16.30 g kg^{-1}) > 10 tons RS plus CD (1:2) compost ha^{-1} (T_7: 16.02 g kg^{-1}) > 10 tons RH compost and 5 tons VC ha^{-1} (T_2: 15.40 g kg^{-1}). The control, which received no OAs, had the lowest nitrogen content at 13 g kg^{-1}

Whereas, the amount of total nitrogen was determined lower in harvesting stage than that of the maximum tillering stage, except for the 10 tons RS plus CD (1:2) compost ha^{-1} (T_7: 17.02 g kg^{-1}), which might be due to the decrement of N as a result of grain formation. However, in the harvested shoots of rice, the maximum N content (17.02 g kg^{-1}) was marked out in T_7 (10 tons RS plus CD (1:2) compost ha^{-1}) followed by 5 tons SD compost ha^{-1} (T_{10}: 11.73 g kg^{-1}) > 5 tons RS plus CD (1:2) compost ha^{-1} (T_6: 9.40 g kg^{-1}) > 10 tons RS plus CD (1:4) compost ha^{-1} (T_5: 9.10 g kg^{-1}). The minimum N content (5.90 g kg^{-1}) was found in the shoots of SD at 10 t ha^{-1} (T_{11}).



* Means assigned with various letters are significantly dissimilar at the level of 5% in Tukey's HSD test, applied independently for each sampling stage.

Fig. 1. Effects of OAs on N content (g kg^{-1}) in rice plants.

The observed differences in total nitrogen among the treatments at two growth stages indicate a significant influence of OAs on nutrient dynamics and the uptake of BR 22 rice. The minimum nitrogen content in T_1 (control) revealed the role of OAs input in nitrogen availability in the soil due to improve nutrients release, microbial activity and overall soil fertility[(24)]. Notably, the reduction in total nitrogen content from the maximum tillering stage to the harvesting stage in most treatments may be attributed to the physiological redistribution of nitrogen from the shoots to the developing grain during the grain filling period[(25)]. This trend also aligns with the inverse yield nitrogen law provided by Mitscherlich[(26)].

Phosphorous

Significant positive effects ($p < 0.05$) of OAs on total phosphorus were observed at both the maximum tillering and harvesting stages of shoots (Fig. 2).

The least amount of P was found in the control plot (T_1: 2.12 g kg^{-1}), which didn't receive OAs during the maximum tillering stage. Across the treatments, the total P levels ranged from 2.12 to 7.00 g kg^{-1} in shoots of the BR 22 rice cultivar in this growth stage of rice. The maximum P content (7.00 g kg^{-1}) was found in treatment where soils was amended with 10 tons RS plus CD (1:4) compost ha^{-1} (T_5) followed by the soils treated with 5 tons RH compost ha^{-1} (T_{12}: 6.71 g kg^{-1}) > 10 tons TC ha^{-1} (T_9: 5.92 g kg^{-1}) > 10 tons VC ha^{-1} (T_3: 4.06 g kg^{-1}).

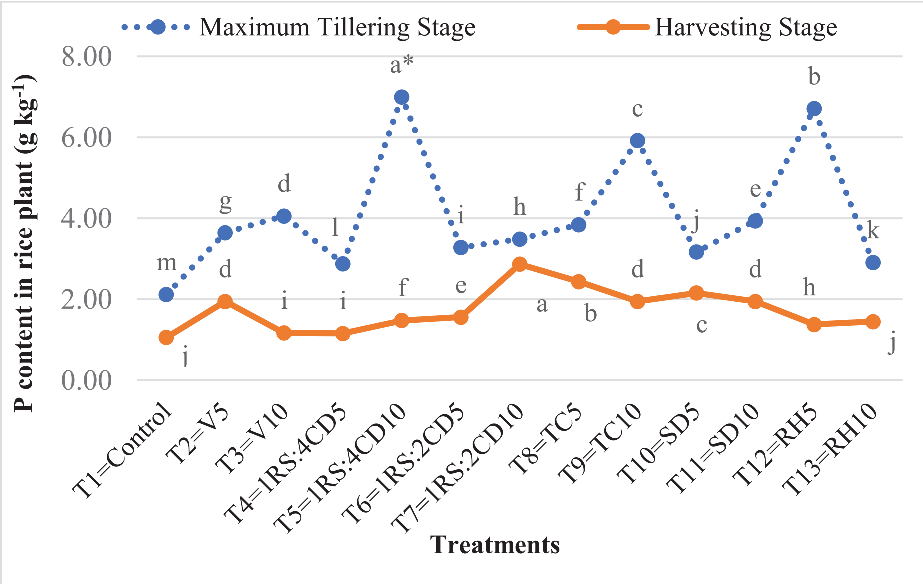


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Fig. 2. Effects of OAs on P content (g kg^{-1}) in rice plants.

At the harvesting stage, the total phosphorus content in shoots was lower than that observed in the maximum tillering stage, as anticipated. Among the harvested shoots of different treatments, the treatment T_7 (10 tons RS plus CD (1:2) compost ha^{-1}) was found to be contained more total P (2.87 g kg^{-1}) followed by 5 tons TC ha^{-1} (T_8: 2.44 g kg^{-1}) > 5 tons SD compost ha^{-1} (T_{10}: 2.16 g kg^{-1}). The treatment that didn't receive any organic amendment carried the least amount of total P (1.06 g kg^{-1}) in its shoots of the BR 22 rice variety.

The above result reflects the pivotal role of OAs in improving phosphorus (P) availability and uptake. In both growth stages, the lowest P content in the shoots of the control plot (T_1), where no OAs were added, highlights that the native P unavailability in untreated soils might be due to fixation by Fe-Al oxide and low solubility. In contrast, T_5 exhibited higher P content, as cow dung might release readily available P, and rice straw might contribute to microbial activity while facilitating the mineralization of bound P. Other treatments also recorded higher P levels, possibly due to multiple factors such as the formation of organic acids from the decomposition of applied composts, which solubilized bound P, and the microbial movement of P[27]. As expected, a reduction in total P concentration in shoots was observed at the harvesting stage, possibly due to the translocation of P from the vegetative parts to the grains[25].

Potassium

The current data suggest that amending soils with organic materials can increase the total potassium content in the shoots of BR 22 rice. Significant ($p < 0.05$) increases in total potassium levels were observed in the shoots at both the maximum tillering and harvesting stages due to the application of various doses of locally available OAs (Fig. 3).

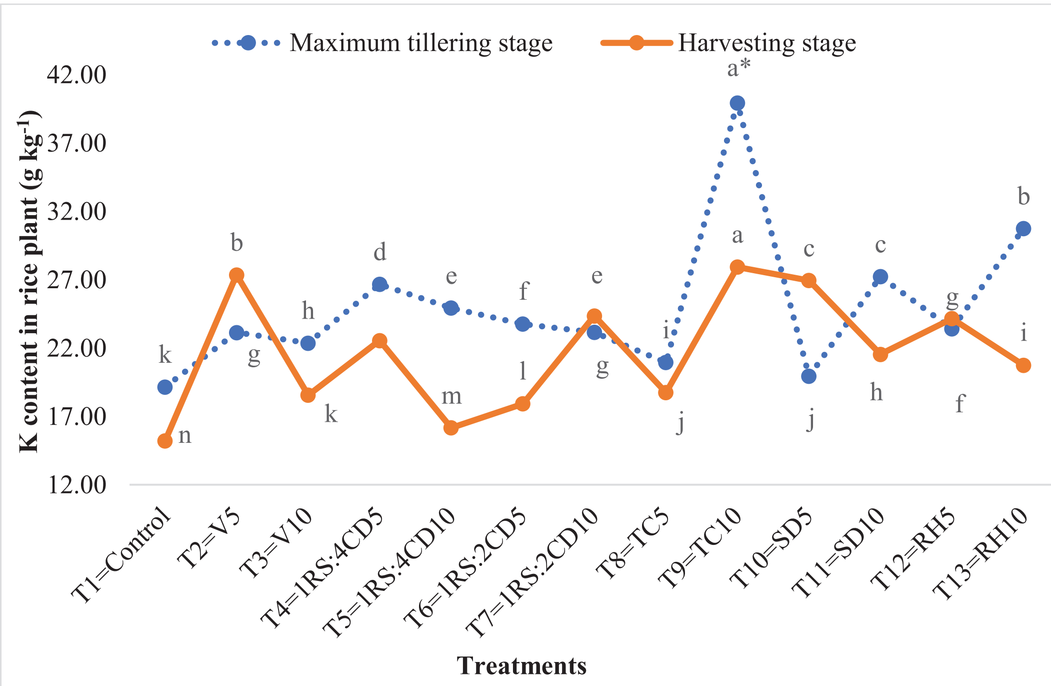

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Fig. 3. Effects of OAs on K content (g kg^{-1}) in rice plants.

The 10 tons TC ha^{-1} exerted better endorsement of total K content (T_9: 39.95 g kg^{-1}) in the shoots of this rice over the other treatments, followed by10 tons RH compost ha^{-1} (T_{13}: 30.75 g kg^{-1}) in the highest tillering time. The 10 tons SD compost ha^{-1} (T_{11}: 27.24 g kg^{-1}) and 5 tons RS plus CD (1:4) compost ha^{-1} (T_4: 26.67 g kg^{-1}) also had enhanced K content after the aforesaid treatments. The other treatments also contained more K than the control plot (T_1: 19.16 g kg^{-1}).

The TC at 10 t ha^{-1} also had the highest total K content (T_9: 27.94 g kg^{-1}) in its shoots in the harvesting stage followed by VC at 5 t ha^{-1} (T_3: 27.36 g kg^{-1}), SD compost at 10 t ha^{-1} (T_{10}:

26.95 g kg^{-1}). Potassium was found least (15.23 g kg^{-1}) in the shoots of control that didn't receive any OAs.

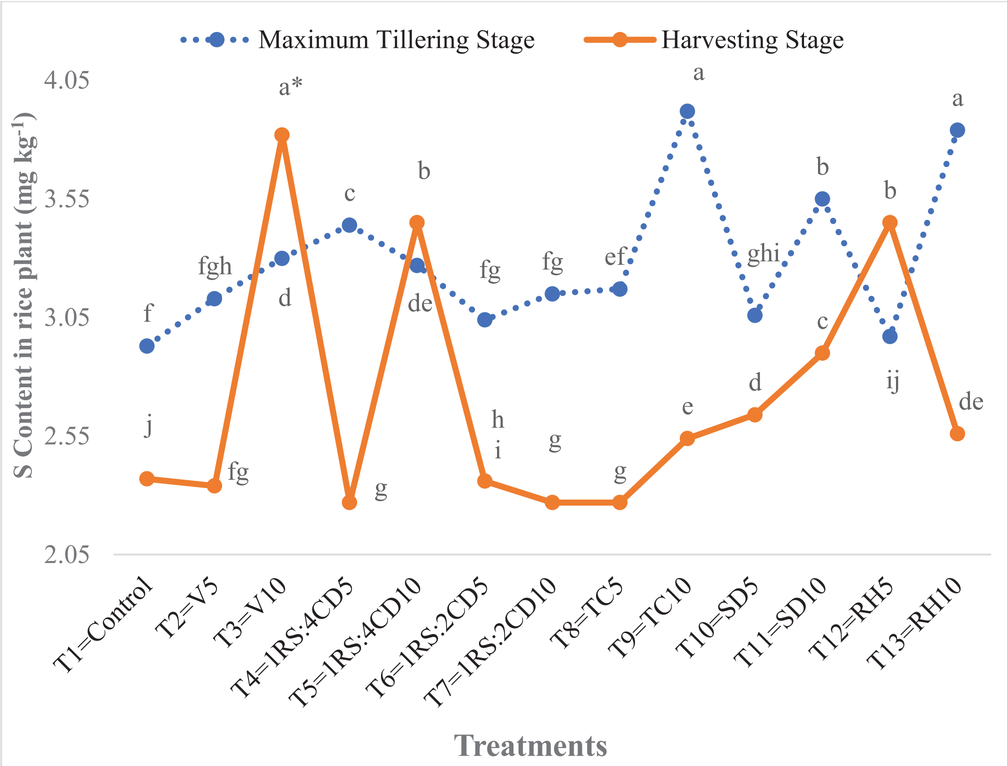
The highest K content in shoots in both stages was recorded in T_7, which might be due to its rich nutrient profile, low C:N ratio, and faster mineralization and release of nutrients[28]. Other treatments also increased K content than that of the control through enhancement of CEC, improved microbial activity and nutrient release. Unlike N and P, K is a soluble and mobile nutrient and hence its increment and translocations in amended soils are also facilitated by the soil physical and biological conditions of the soil than that of the control.

Sulphur

This study assessed the effect of OAs on S uptake by the BR 22 rice variety where S content in the shoots of BR 22 rice was significantly affected ($p < 0.05$) by the varying doses of locally available OAs (Fig. 4).

In the maximum tillering stage, the shoots from the treatment of 10 tons TC ha^{-1} had the maximum S content (T_9: 3.92 mg kg^{-1}), followed by 10 tons SD compost ha^{-1} (T_{11}: 3.55 mg kg^{-1}), then 5 tons RS plus CD (1:4) compost ha^{-1} (T_4: 3.44 mg kg^{-1}), and finally VC at 10 t ha^{-1} (T_3: 3.30 mg kg^{-1}). At this growth stage of rice, the shoots of BR 22 had the least S content (2.93 mg kg^{-1}) from the control plot without OAs, although it was statistically similar to 5 tons RH compost ha^{-1} (T_{12}: 2.97 mg kg^{-1}).

The shoots of rice plants from the soil amended with VC at 10 t ha-1 (T_3) had an elevated S content (3.82 mg kg^{-1}) compared to the other doses of OAs in the harvesting stage. Among the other treatments, the total sulphur content was found to be the same (3.45 mg kg^{-1}) and the 2nd highest in both RH compost at 5 t ha^{-1} (T_{12}) and RS plus CD of 1:4 compost at 10 t ha^{-1} (T_5). The statistically same but almost similar least amount of S content were determined in the shoots of rice from the treatments of VC at 5 t ha^{-1} (T_2: 2.34 mg kg^{-1}), RS plus CD of 1:4 compost at 5 t ha^{-1} (T_4: 2.27 mg kg^{-1}), RS plus CD of 1:2 compost at 5 and 10 t ha^{-1} (T_6 and T_7: 2.36 and 2.27 mg kg^{-1}) and TC at 5 t ha^{-1} (T_8: 2.27 mg kg^{-1}: Fig. 4).



* Means assigned with various letters are significantly dissimilar at the level of 5% in Tukey's HSD test, applied independently for each sampling stage.

Fig. 4. Effects of OAs on S content (mg kg^{-1}) in rice plants.

At maximum tillering state, TC of 10 t ha^{-1}, which showed the highest uptake and accumulation of S among all the treatments, might be due to the improved S availability that facilitates efficient S uptake, as *Trichoderma* sp. present in this compost enhances nutrient mineralization and root development of immobile S(29). The higher concentration of S in other organic amendment-treated shoots confirms the role of these amendments in improving soil health and better nutrient cycling.

Calcium

The effects of the locally available OAs on Ca accumulation in the shoots of BR 22 rice at two different growth stages were determined, and they were shown to differ significantly ($p < 0.05$: Fig. 5). The maximum accumulation of Ca (3.81 g kg^{-1}) in the tissue of the BR 22 rice was achieved using locally available 10 tons RS plus CD (1:4) compost ha^{-1} (T_5), followed by 10 tons SD compost ha^{-1} (T_{11}: 3.42 g kg^{-1}) during the maximum tillering stage.

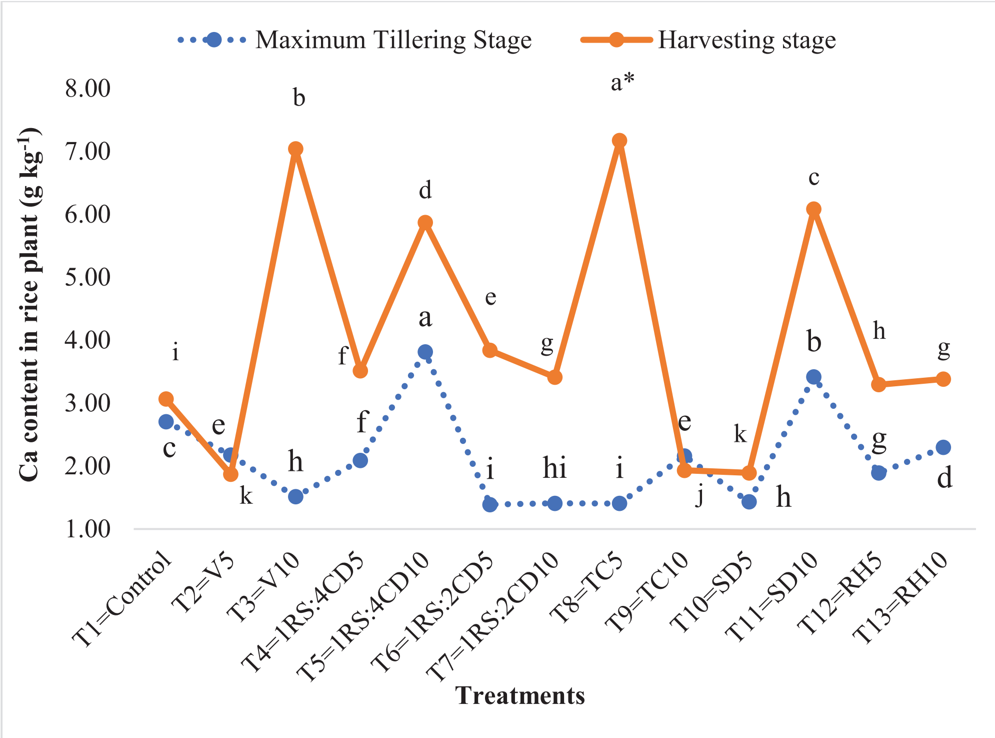


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Fig. 5. Effects of OAs on Ca content (g kg^{-1}) in rice plants.

Conversely, at the harvesting stage, the greatest amount of Ca accumulation (7.17 g kg^{-1}) was found in the shoots of rice from the soils treated with 5 tons TC ha^{-1} (T_8) followed by 10 tons VC (T_3: 7.04 g kg^{-1}) and 10 tons SD compost (T_{11}: 6.07 g kg^{-1}) ha^{-1}, respectively.

During maximum tillering, the highest amount of Ca concentration in shoots of BR 22 rice was found using RS plus CD at a 1 : 4 ratio, followed closely by SD compost. The ability to gradually decompose these materials might prolong Ca uptake at the early vegetative stage. Again, at the harvesting stage, TC-treated soils provided maximum Ca concentration in their shoots, followed by VC, which might indicate their capability of sustained nutrient release, fulfilled the grain filling stage, as they are specially valued for microbial activity, which improved the bioavailability and uptake by roots. In control plots relatively low Ca accumulation indirectly support the integration of OAs into nutrient management practices in rice system.

Magnesium

The Mg content in the shoots of BR 22 rice was observed, and it was found that the harvesting stage shoots contained more Mg than the shoots of the maximum tillering stage, as expected. Similar to Ca accumulation, Mg content was found to be significant ($p < 0.05$) with different doses of OAs in both growth stages of rice (Fig. 6).

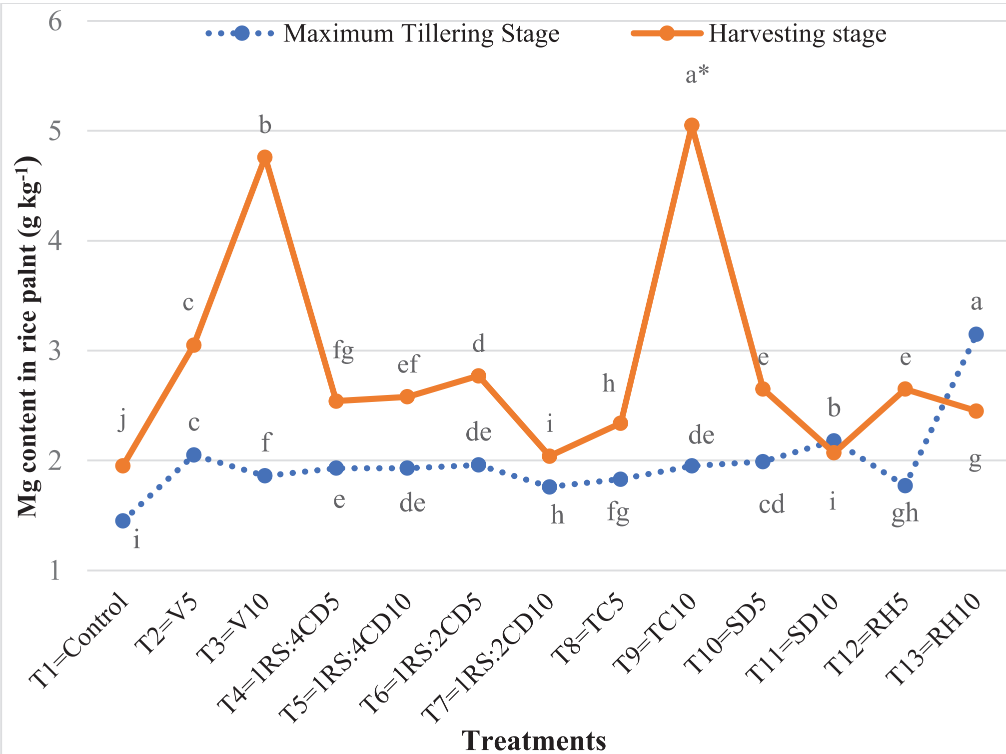

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Fig. 6. Effects of OAs on Mg content (g kg^{-1}) in rice plants.

In the maximum tillering time, RH compost at 10 t ha^{-1} (T_{13}) was identified as the single most effective amendment, predominantly enhancing Mg content in the shoots of the BR 22 rice cultivar, in which the highest Mg content of 3.15 g kg^{-1} was found. Other treatments also found to have significantly ($p < 0.05$) higher Mg accumulation in its shoots than that of control plot where the lowest amount of Mg (1.45 g kg^{-1}) was detected in this stage of rice growth.

TC applied at 10 t ha^{-1} (T_9) endorsed a maximum and statistically superior Mg accumulation (5.05 g kg^{-1}) in the tissue of BR 22 rice during the harvesting stage. VC at 10 t ha^{-1} (T_3: 4.76 g kg^{-1}) was found with 2^{nd} highest Mg accumulation followed by VC 5 t ha^{-1}

(T_2: 3.05 g kg^{-1}) at this stage. Whereas, the least amount of Mg accumulation (1.95 g kg^{-1}) was found in the shoots of BR 22 rice from the control plot (T_1).

The control plot consistently showed the lowest Mg accumulation in both growth stages, emphasizing the need to integrate OAs in rice production. At the maximum tillering stage, slowly decomposed RH compost contributed to higher Mg accumulation, likely due to its steady release of Mg, which matches the early-stage nutrient demand. However, TC followed by VC demonstrated the highest Mg uptake, as they are known to enhance microbial activity and soil structure.

Zinc

The enhanced Zn uptake and consequent assimilation in the tissues of BR 22 rice tended to occur due to the different doses of OAs. The Zn content in the shoots was also found to significantly ($p < 0.05$) vary positively with the locally available OAs applied during both sampling growth stages of rice (Fig. 7).

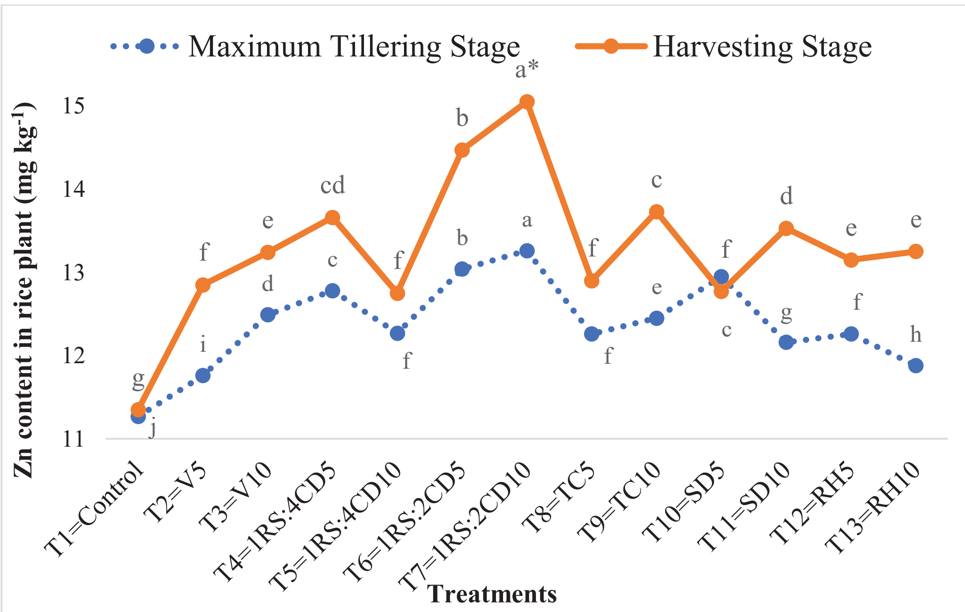

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Fig. 7. Effects of OAs on Zn content (mg kg^{-1}) in rice plants.

RS plus CD (1 : 2) compost at 10 and 5 t ha^{-1} (T_7 and T_6) were evaluated better over the rest of the treatments on Zn uptake on their tissue. Zinc content was found 13.26 and 13.04 mg kg^{-1} in their shoots by the aforesaid treatments, respectively. The other treatments also determined with significantly ($p < 0.05$) higher Zn contents in their shoots than that of control where the least Zn content was observed in the shoots of control plot (11.27 mg kg^{-1}).

Similar to maximum tillering, the shoots of BR 22 from the treatments RS plus CD of 1:2 compost at 10 t ha^{-1} and 5 t ha^{-1} (T_7: 15.05 mg kg^{-1} and T_6: 14.47 mg kg^{-1}) were ranked 1st and 2nd regarding to the Zn accumulation during the harvesting stage. All the organically treated shoot had more Zn content than that of control (1.35 mg kg^{-1}).

In both the stages of growth, the higher Zi accumulation was found in organic amendment soil than that of control might be due to the abilities of Chelate formation by these OAs that improve Zn availability and finally root absorption.

Iron

Iron deficiency is commonly observed in upland soils with high pH and aerobic conditions. Conversely, iron toxicity poses a significant challenge to lowland rice production. The toxicity of iron is linked to the reduced soil conditions in submerged or flooded soils, which increase the concentration and uptake of Fe^{2+}[10]. Thus, the concentrations of Fe in the shoots of BR 22 were observed in the present study with different doses of OAs under field conditions. It was found that the concentrations of Fe differed significantly ($p < 0.05$) in the shoots of BR 22 rice with selected different doses of OAs (Fig. 8).

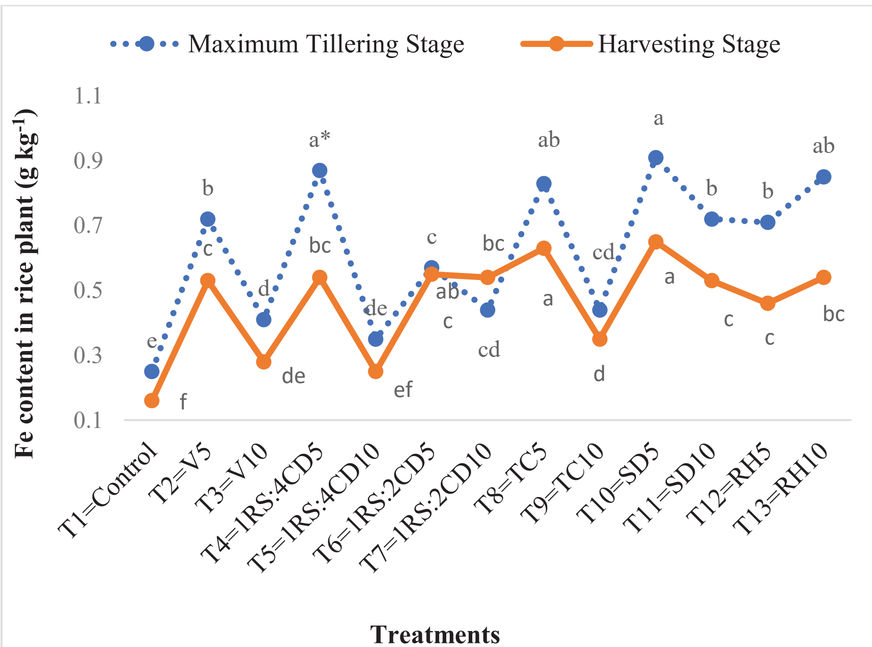

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Fig. 8. Effects of OAs on Fe content (g kg^{-1}) in rice plants.

In maximum tillering stage, it was found that the shoots from the lower doses (5 t ha^{-1}) of locally available OAs contained more Fe accumulation than those of higher doses (10 t ha^{-1}).

The reason might be the development of Fe toxicity associated with higher doses that hinder Fe uptake. However, the soil amended with SD compost at 5 t ha^{-1} (T_{10}) was found highest Fe content of 0.91 g kg^{-1} in its shoots but the concentration was statistically identical with RS plus CD of 1 : 4 compost at 5 t ha^{-1} (T_4: 0.87 g kg^{-1}). Other treatments also determined with significantly ($p < 0.05$) higher total Fe accumulation than that of control plot (T_1: 0.25 g kg^{-1}).

Iron accumulation in rice shoots was found to range within 0.16 to 0.65 g kg^{-1} at harvesting stage. Similar to maximum tillering, 5 tons SD compost ha^{-1} (T_{10}: 0.65 g kg^{-1}) ranked 1st and the control plot (T_1: 0.16 g kg^{-1}) ranked last regarding Fe accumulation in rice plant during harvesting. The significantly ($p < 0.05$) higher concentration was also demonstrated in other treatments of locally available OAs.

The toxicity of Fe commonly occurs in lowland rice systems, primarily under submerged or waterlogged conditions where the soils are in a reduced state. In these conditions, Fe^{3+} is reduced to Fe^{2+}, increasing its solubility and bioavailability, which can lead to concentrations that are detrimental to rice growth[30]. Symptoms of Fe toxicity in rice, such as leaf browning and discoloration of roots[31], were not observed in the present study, where organic amendment played a significant role in regulating the availability of Fe by modifying redox potential, microbial activity, and nutrient dynamics. These processes may account for the highest Fe concentration in shoots at both growth stages. This study revealed that applying OAs addresses not only Fe deficiency but also mitigates its toxicity to plants.

Manganese

Significant ($p < 0.05$) variations in Mn concentration in the rice shoots of the tested variety of rice were observed for different doses of OAs (Fig. 9).

The highest amount of Mn (37.35 mg kg^{-1}) was obtained from the RS plus CD of 1:4 compost at 5 t ha^{-1} (T_4) followed by SD compost at 5 t ha^{-1} (T_{10}: 36.28 mg kg^{-1}) > RS plus CD of 1:2 compost at 10 t ha^{-1} (T_7: 32.75 mg kg^{-1}) > VC at 10 t ha^{-1} (T_3: 29.36 mg kg^{-1}) in the maximum tillering stage. Whereas, treatment without OAs had lowest Mn accumulation of 13.84 mg kg^{-1} in its shoots.

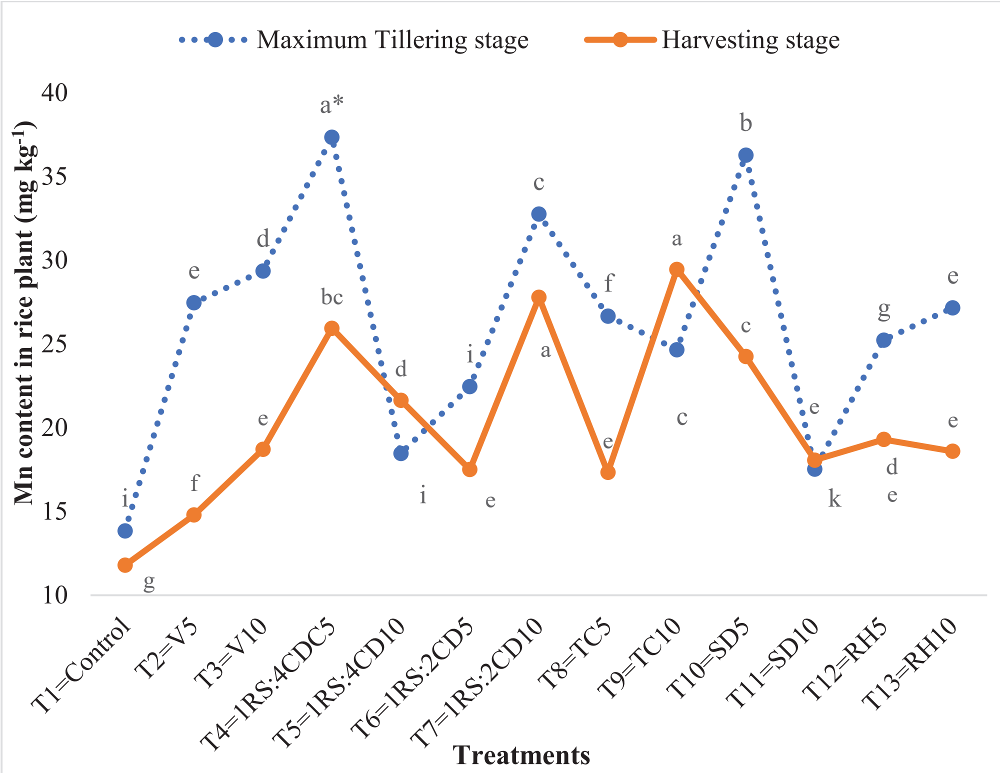

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Fig. 9. Effects of OAs on Mn content (g kg^{-1}) in rice plants.

In harvesting time, the shoots from the soil treated with 10 t TC ha^{-1} (T_9) was determined with maximum Mn content (29.46 mg kg^{-1}) in the tissue of BR 22. However, statistically identical Mn content was measured in RS plus CD of 1:4 at 10 t ha^{-1} (T_7: 27.28 mg kg^{-1}). Whereas, no OAs exerted a suppression on Mn content (T_1: 11.78 mg kg^{-1}).

At highest tillering stage, the highest Mn was found in soils treated with RS plus CD compost at 1:4 ratio aligned with previous study of Riaz(11) suggest that organic amendment improves micronutrient availability through enhanced microbial activity, CEC and reducing Mn fixation. Again, in harvesting stage, top Mn concentration was found in TC at 10 t ha^{-1} that indicates OA vary regarding nutrient release pattern and decomposition rate where OAs chelate Mn to make it more plant available form.

It might be concluded that VC, tricho-compost, rice straw, cow dung, and sawdust (OAs) had significant positive effects on the mineral nutrition of BR 22 rice plants at maximum tillering and post-harvest stages.

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