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Effect of Integrated Nutrients Management on Growth, Yield, Nutrient Uptake and Soil Properties in Direct Seeded Rice (*Oryza sativa* L.) Crop in the Acidic Soils of Nagaland

Seyiekevino Tsükrü, P. K. Singh, Kevineituo Bier, Manoj Dutta, Jurisandhya Bordoloi, Damitre Lytan, Aibapynsuk Khongwar, Lanamika Kjam

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ABSTRACT

Two-year field experimentation was carried out under a Randomized Block Design replicated thrice consisting of fifteen treatments in total to investigate the influence of INM treatment combinations using FYM, vermicompost, biofertilizers like *Azospirillum* on crop growth, yield, nutrient uptake and soil properties. Careful observation from the growth indices confirmed that T_8 recorded significantly the highest in terms of plant height (cm), number of tillers plant^{-1}, CGR. Yield attributes were also confirmed to have found highest with treatment T_8, respectively. Nutrient uptake both in grain and straw were also observed to have enhanced with T_8 and organic source included treatments. Soil properties like pH, electrical conductivity, organic carbon, and available NPK were also found to have improved significantly with T_8 over the course of investigation.

Keywords Rice, Growth, Yield, Nutrient uptake, Soil properties.

Seyiekevino Tsükrü[1], P. K. Singh[2]*, Kevineituo Bier[3], Manoj Dutta[4], Jurisandhya Bordoloi[5], Damitre Lytan[6], Aibapynsuk Khongwar[7], Lanamika Kjam[8]

[1]PhD Scholar
Department of Soil Science, School of Agricultural Sciences (SAS), Nagaland University, Nagaland 797106, India

[2]Professor, HoD, [3]Assistant Professor, [5]Associate Professor
[2,3,5]Dept of Soil Science, SAS, Nagaland University, India

[4]Professor,
Dept of Soil and Water Conservation, SAS, Nagaland University, India

[6]Guest Faculty, Department of Entomology, SAS, Nagaland University, India

[7]Young Professional-I, ICAR RC for NEH Region, Umiam, India
[8]Senior Research Fellow, ICAR Umiam, India

Email: pksingh@nagalanduniversity.ac.in
*Corresponding author

INTRODUCTION

The global food security is intensively reliant on the agricultural sector which is considered and expected to provide food, nutritional and energy security to the growing population (Batabyal *et al.* 2024). Rice crop is the world's third most- produced agricultural crop behind sugarcane and maize. It is cultivated both in *kharif* and *rabi* season in India. In *kharif* season, the area sown with rice rose from 38,919 thousand hectares in 2019 to 41,195.80 thousand hectares in 2023, with fluctuations in between. This data provided an insight into the trends and variations in rice crop cultivation in India over the specified years and showed an insight of nation's agricultural landscape and production capacity (Infomerics Economic Research 2023). This growth may be ascribed to various factors including improved agricultural practices, increased use of technology, and government support for the farming sector. With the introduction of Green revolutions in the 1960s, the productivity of grains particularly rice and wheat crop rose in its production with the inclusion of high yielding varieties and inorganic fertilizers to address the growing demand of the booming population in the country. Over the years this led to improper and unbalanced use of inorganic fertilizers without sufficient knowledge to increase the productivity of crops thus neglecting the ill-effects of chemical fertilizers on soil health in the long run. There was also negligence in the use of organic sources like animal manures, FYM, vermicompost etc as it was not well promoted then. In India, nearly 92.97 M ha of land suffers from various degrees of soil acidity and impaired soil fertility. Also, it was reported that 34.5% of the cultivated lands are acidic in reaction (Maji *et al.* 2012). The excessive reliance on inorganic fertilizers in the long run can aggravate the already existing soil problem causing deterioration in the soil health and sustainability. Continuous application of inorganic fertilizers without soil test can also contribute to increase in soil acidity. Nitrogenous fertilizers increase soil acidity although it had played a great role in increasing crop yields, thereby raising the possibility of the number of basic cations being removed. Therefore, maintenance of soil fertility and soil health by following balanced use of inorganic fertilizers along with incorporation of organic sources which holds the potential to improve and sustain the soil physico-chemical and biological properties at the same time increase the productivity of the crop. Management of soil acidity with proper amendments and addition of required nutrients are important to achieve higher yield of crops (Rautaray *et al.* 2003). Recently more findings have emphasized the significant role of integrated soil fertility management involving combination of microbial inoculants, organic and inorganic fertilizers in elevating the productivity and improving soil health and sustainability of the environment in the long run (Devi *et al*. 2013). Studies have shown that residual effect of compost and manures applications significantly increased EC, soil pH levels, plant-available P and NO_3-N concentrations (Eghball *et al*. 2004). Insufficient application of one nutrient causes the loss or the imbalance of the other nutrients, where researchers have reported that an insufficient application of K fertilizer increases the leaching losses of basic cations like Ca^{2+}, Mg^{2+} . Hence, there is a substantial need in maintenance of soil fertility for long term sustainable of crop productivity. In view of the above, the objective of the present study was to investigate the effect of different integrated nutrient management treatments on growth, yield and nutrient uptake of the crop while also examining the effect of the treatments on soil properties.

MATERIALS AND METHODS

The study was conducted in the experimental farm of School of Agricultural Sciences, Nagaland University, Medziphema Campus during the *kharif* seasons, 2021 and 2022. The soil of the experimental plot was characterized by well drained and sandy clay loam texture. Soil pH 4.25, 0.04 dSm^{-1}EC, 1.41 g cm^{-3} bulk density, 15.2 g kg^{-1} organic carbon. The value of available NPK were 256.42, 9.05, 96.60, respectively. A total of fifteen treatments were studied in this experiment which was laid out in Randomized Block Design replicated thrice. Different treatments were of the following combinations, T_1 - Control, T_2 - 100% NPK, T_3 - 50% NPK, T_4 - SSNM (109:30:46 NPK), T_5 - 100% NPK + Zn, T_6 - 100% NPK + S, T_7 - 100% NPK +Zn + S, T_8 - 100% NPK +Zn +S+FYM @ 5t ha^{-1}, T_9 -100% NPK+Liming @LR, T_{10} - 50% NPK + *Azospirillum,* T_{11} - 50% NPK + 50% N-FYM, T_{12} - 50% NPK + 50% N- VC, T_{13} - 50% NPK + 25% N-FYM + 25% N-VC, T_{14} - FYM @ 10 t ha^{-1}, T_{15} - FYM @ 10 t ha^{-1} + Liming @ LR. Five plants from each plot were randomly selected and tagged for recording the plant height at different growth stages at 45, 90 DAS and at harvest. The number of tillers $plant^{-1}$, CGR were recorded from each plot at 45 and 90 DAS. The composite soil sample was collected from experimental field (0-15 cm depth) before initiating the experiment. The collected soil samples were air dried, crushed, sieved to pass through 2 mm sieve. Soil available nitrogen by Alkaline permanganate method (Subbiah and Asija 1965), available phosphorus by Bray and Kurtz method (1945), available potassium by Ammonium acetate method (Jackson 1973). The powdered grain and straw samples were analyzed for N, P and K content. Digestion for N: Half a gram powdered sample was digested with concentrated H_2SO_4 in the presence of digestion mixture ($CuSO_4$ + K_2SO_4) till the digest gave clear bluish color. The digested sample was further diluted carefully with distilled water to known volume. Then a known volume of aliquot was transferred to distillation unit (Micro kjedahl – apparatus) and liberated ammonia was trapped in boric acid containing mixed indicator. Later it was titrated against standard H_2SO_4 and the amount of ammonia liberated was estimated in the form of nitrogen. Digestion of plant sample for P and K: Half a gram powdered sample was pre-digested with concentrated HNO_3 overnight. Further pre-digested sample was treated with di- acid (HNO_3: $HCLO_4$ in the ratio of 10:4) mixture and kept on the hot plate for digestion till colourless thread-like structures was obtained. After complete digestion precipitate was dissolved in 6 N HCL and transferred to the 100 ml volumetric flask through Whatman No. 42 filter paper and finally the volume of extract was made to 100 ml with double distilled water and preserved for further analysis. The uptake of different nutrients was separately carried out in grain and straw samples thereby multiplying nutrient content in grain and straw samples with their corresponding yield data.

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Yield (kg ha}^{-1}\text{)} \times \text{ Nutrient content (\%)}}{100}$$

Statistical analysis: The data related to each character were analyzed statistically by applying the techniques of variance and the significance of different source of variation was tested by 'F' test (Cochran and Cox 1957).

RESULTS AND DISCUSSION

It was observed that plant height increased from 43.61 to 72.08 cm, 70.23 to 111.41 cm and 86.01 to 134.46 cm at 45, 90 DAS and harvest, respectively as indicated in Table 1.The significant increase in the plant height can be attributed to the application of nutrients required for the growth and development of the plant at different stages of crop development. Application of T_8 (100% NPK +Zn +S + FYM @ 5t ha^{-1}) proved to have significantly enhanced plant height over the control (T_1) at all the stages of plant growth. It did not only have a significant difference with control (T_1) but also demonstrated to be significantly higher over all the other treatments which gives an explanation that although sole balanced inorganic fertilizer application enhanced the plant growth but in combination with organic manure FYM had better superlative effect on the plant height. The highest number of tillers plant^{-1} shown in Table 1, i.e., 5.57 at 45 DAS, 7.63 at 90 DAS, respectively were recorded with treatment T_8 (100% NPK +Zn +S + FYM @ 5t ha^{-1}) while the low-

Table 1. Influence of different treatments on growth and yield in direct seeded rice (pooled value).

Treatments	Plant height (cm) 45 DAS	90 DAS	At harvest	Number of tillers plant^{-1} 45 DAS	90 DAS	CGR (g m^{-2} day^{-1}) 0- 45 DAS	45-90 DAS	Number of panicle m^{-2}	Number of grains panicle^{-1}	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T_1	43.61	70.23	86.01	3.30	4.57	2.24	5.09	17.17	89.53	2238.83	4330.00
T_2	54.04	85.49	98.88	4.10	5.83	2.67	6.43	24.67	101.63	3297.75	5001.33
T_3	51.67	83.21	97.23	3.97	5.63	2.33	6.02	22.33	98.47	3075.87	4861.67
T_4	63.44	98.13	116.58	4.75	6.95	3.33	6.56	27.33	116.47	3808.95	5601.67
T_5	62.37	100.74	123.29	4.83	7.10	3.52	6.65	27.67	116.43	4097.02	5826.67
T_6	60.85	92.91	109.87	4.43	6.50	2.96	6.62	25.83	112.23	3620.98	5353.17
T_7	66.55	103.70	128.11	4.90	7.22	3.73	6.87	28.50	121.13	4506.68	5971.67
T_8	72.08	111.41	134.46	5.57	7.63	3.86	7.07	30.33	127.73	4853.73	6275.33
T_9	61.95	97.10	120.90	4.77	7.07	3.47	6.67	27.33	114.63	3960.42	5623.50
T_{10}	55.79	88.55	101.70	4.30	5.92	2.80	6.32	23.67	103.70	3296.50	5266.00
T_{11}	61.19	96.07	114.17	4.70	6.82	3.25	6.51	26.33	112.37	3750.82	5496.83
T_{12}	59.40	93.95	105.93	4.50	6.43	2.92	6.52	25.17	109.98	3529.82	5276.67
T_{13}	67.00	102.38	126.51	4.93	7.10	3.59	6.85	28.83	112.87	4343.30	5849.50
T_{14}	56.35	91.64	104.27	4.40	6.90	2.89	6.49	24.50	105.07	3489.02	5094.33
T_{15}	58.39	94.28	110.62	4.60	6.63	3.24	6.57	26.83	111.23	3333.57	4829.17
SEm±	0.56	1.03	1.41	0.11	0.10	0.02	0.01	1.15	1.63	41.55	33.11
CD (p=0.05)	1.59	2.92	3.99	0.32	0.28	0.07	0.03	3.26	4.61	117.70	93.80

est was recorded with control plot T_1 with values 3.30 at 45 DAS and 4.57 at 90 DAS, respectively. This was followed by integrated treatment T_{13} which recorded 4.93 and 7.10 at both stages of plant growth. This corroborates with the findings of Mirza *et al.* (2005) who reported that productive per hill were increased by the application of FYM along with different macro and micronutrients. Increase in the number of tillers plant^{-1} at both stages of plant growth could be attributed to the fact that as sufficient nutrient was applied in the treatments it resulted in ample nutrients in the soil available pool which was ultimately taken up by the plant increased the production of more tillers from the shoot nodes and in progression as primary, secondary and tertiary tillers. Results of different treatments on crop growth rate at 45 and 90 DAS have been presented in the Table 1. As indicated in the data Table 1, application of 100% NPK + Zn + S + FYM @ 5t ha^{-1} significantly affected the crop growth rate at both stages of plant growth. It was evident that the highest CGR for 0-45 DAS was recorded from T_8 with a data of 3.86 g m^{-2} day^{-1}. Similarly, at 45-90 DAS T_8 also recorded highest with a data of 7.07 g m^{-2} day^{-1}, respectively. The lowest crop growth rate at 0-45 DAS was observed in control treatment T_1 with data 2.24 g m^{-2} day^{-1}, similarly at 45-90 DAS T_1 also recorded lowest among all the treatments with a value of 5.09 g m^{-2} day^{-1}. Enhanced performance with T_8 in respect to crop growth rate could be explained by greater released and supply of nutrients in varied proportions and times from the combined used of organic manure FYM and chemical fertilizer along with application of zinc and sulfur as basal doses, thus improving the uptake of nutrients at its peak time. The above results on the effect of different proportions of chemical fertilizers and organic sources on influencing growth attributes of rice were also reported by Rama *et al.* (2020) and Behera *et al.* (2021).

Data from the comparative study of the treatments showed that treatment T_8 (100% NPK +Zn +S + FYM @ 5t ha^{-1}) performed better among all other treatments as it recorded significantly the highest number of panicles with a data of 30.33. While the minimum number of panicles was recorded with the control treatment T_1 with a data of 17.17. From the Table 1, it was observed that application of T_8 recorded an increase of about 76.64% over control T_1, 22.94% over T_2 (100% NPK) alone. Critical evaluation also revealed that statistically, treatments T_4 (27.33), T_5 (29.67), T_7 (29.00) and T_{13} (28.83) were at par with treatment T_8. The better performance of treatment T_8 as compared to other treatments under study proved that when nutrients were provided in ample amount with inorganic source and merging with organic sources which encourages a slow and continuous release of nutrients throughout the growth stages of the crop that enabled assimilation of sufficient photosynthetic products which in turn increased dry matter resulting in a greater number of panicles. This finding is in conformity with Apon *et al.* (2018) who reported the highest number of panicles with treatment 100% RDF+ FYM @ 5t ha^{-1}. Among all the treatments under study, treatment T_8 proved to have recorded significantly the highest number of grains panicle^{-1} with a data of 127.73 over the control treatment T_1 with a value of 89.53. Treatment T_7 recorded the second highest with value of 121.13 during the course of investigation. The control plot which did not received any external source of nutrients proved to yield the lowest number of grains panicle^{-1} with a value of 89.53. The favorable synthesis of growth promoting synthesis constituents in plant system owing to better supply of nutrients might have resulted in higher number of grains panicle^{-1}. More number of grains panicle^{-1} might also be due to better translocation of carbohydrates from source to sink (Shalini *et al.* 2017). Grain yield was found to have increased with the application of various treatments where treatment T_8 recorded about 4853.73 kg ha^{-1} which gave an increase of about 116.79 % over the control plot T_1 which recorded a data of 2238.83 kg ha^{-1}. It was followed by treatment T_7 (100% NPK +Zn +S) with a value of 4506.68 kg ha^{-1} and T_{13} (50% NPK + 25% N-FYM + 25% N-VC) with a value 4343.30 kg ha^{-1}. Further evaluation of the data in Table 1 reflected that among the treatments, T_8 had an increase of 7.70 % and 11.75 % over treatments T_7 and T_{13}, respectively. Increasing grain yield might be due to nitrogen application through inorganic and organic source enhancing the dry matter production, crop growth rate, promoting elongation of internodes and activity of growth hormones like gibberellins (Singh *et al.* 2000). FYM being a store house of both macro and micro nutrients which might have enhanced and improved the efficiency in utilization of both applied and native nutrients at a faster rate thus enhancing the yield components of rice crop. The favorable influence of applied zinc on yield may be due to its catalytic or stimulatory effect on most of the physiological and metabolic process of plants (Mandal *et al.* 2009). The stimulating effect of applied S in the synthesis of chloroplast protein might have resulted in the greater photosynthetic efficiency, which then increased the yield (Khampuang *et al.* 2023). Data from Table 1 also revealed that treatment T_8 performed significantly better than all the treatments with a highest straw yield of about 6275.3 kg ha^{-1} while the lowest was recorded in the control treatment T_1 with 4330.00 kg ha^{-1}, respectively. Treatment T_8 recorded about 44.92% over control T_1. With treatment T_8 recording significantly the highest, this was followed by treatments T_7 with value of 5971.67 kg ha^{-1} and T_{13} with value 5849.50 kg ha^{-1}, and showed that treatment T_8 recorded an increase of about 5.08% over T_7 and 7.27% over T_{13}, respectively. The increment in yield with treatment T_8 over other treatments can be due to the beneficial effects of organic manures on straw and grain yield probably due to additional supply of plant nutrients as well as improvement in physical and chemical properties of soil and thus elucidates that integrated nutrient management proved more superior than alone application of chemical fertilizer or biofertilizers and manures. These are in concordance with the findings of Nath *et al.* (2015) and Kumar *et al.* (2018).

The maximum N uptake by grain and straw was recorded in T_8 - 100% NPK +Zn +S + FYM @ 5t ha^{-1} with 57.97 kg ha^{-1} in grain and 32.29 kg ha^{-1} in straw, respectively as shown in Table 2. While the minimum value was recorded in control treatment T_1 with value of 20.78 kg ha^{-1} N uptake in grain and a value 18.76 kg ha^{-1} for N uptake in straw, respectively. Critical examination of the pooled value showed that grain N uptake in plots receiving treatment T_8 was enhanced by 178.97% over control T_1 and 9.56% over treatment T_7, 14.72% over T_{13} while in straw N uptake 72.12% over control T_1, 4.76% over T_7 and 10.81% over T_{13} with the application of treatment T_8. Higher assimilation of nutrient in plant tissue as well as biomass production attributed to increase nutrient uptake as abundance of nutrients were made available to the plants through both inorganic and organic sources. Sahu *et al.* (2020) also reported that combined application of inorganic fertilizers along with organic manures encouraged N uptake as compared to inorganic fertilizers alone. The uptake of phosphorus in rice crop with different treatments under study revealed that maximum P uptake of in grain was observed in treatment T_8, with a value of 14.49 kg ha^{-1}, while minimum was recorded with control T_1 with a value of 3.69 kg ha^{-1} respectively. A critical examination of the data in Table 2 indicated treatment T_8 was followed by T_7 (12.56 kg ha^{-1}), T_{13} (11.74 kg ha^{-1}), it also recorded an enhancement of P

Table 2. Influence of different treatments N, P and K uptake in grain and straw in direct seeded rice (pooled data).

Treatments	N uptake (kg ha^{-1})		P uptake (kg ha^{-1})		K uptake (kg ha^{-1})	
	Grain	Straw	Grain	Straw	Grain	Straw
T_1	20.78	18.76	3.69	2.92	6.81	45.02
T_2	35.17	22.19	7.53	3.66	11.56	55.79
T_3	30.49	21.16	6.77	3.48	10.34	53.44
T_4	43.55	26.85	9.53	4.47	15.41	70.19
T_5	47.34	28.60	10.51	4.80	17.36	74.70
T_6	42.00	24.74	8.43	4.11	14.26	64.20
T_7	52.91	30.82	12.56	5.04	19.01	78.16
T_8	57.97	32.29	14.49	5.38	21.52	83.16
T_9	45.75	27.31	10.38	4.57	16.37	71.29
T_{10}	35.87	23.48	7.23	3.86	11.76	59.87
T_{11}	42.54	26.10	9.19	4.33	14.76	67.61
T_{12}	39.77	24.10	8.13	3.99	12.92	62.19
T_{13}	50.53	29.14	11.74	4.89	18.23	75.94
T_{14}	39.21	22.85	7.92	3.80	12.93	58.77
T_{15}	37.79	22.50	8.06	3.76	12.59	58.71
SEm±	0.56	0.27	0.21	0.03	0.30	0.40
CD (p=0.05)	1.58	0.77	0.59	0.09	0.86	1.14

Table 3. Influence of different treatments on soil properties (pooled data).

Treatments	pH	Electrical conductivity (dSm^{-1})	Organic carbon ($g\ kg^{-1}$)	Available nitrogen ($kg\ ha^{-1}$)	Available phosphorus ($kg\ ha^{-1}$)	Available potassium ($kg\ ha^{-1}$)
T_1	4.50	0.03	14.55	245.78	8.28	96.27
T_2	4.73	0.04	16.17	261.31	10.70	99.67
T_3	4.76	0.03	15.78	257.43	9.32	98.01
T_4	4.73	0.03	18.05	272.17	14.14	108.54
T_5	4.66	0.04	18.33	263.60	15.19	112.51
T_6	4.73	0.04	17.55	266.23	12.97	106.72
T_7	4.85	0.03	18.72	281.83	17.98	113.27
T_8	4.75	0.04	18.95	286.19	18.18	117.10
T_9	4.86	0.04	18.20	277.47	14.57	110.64
T_{10}	4.83	0.03	17.47	258.04	11.68	101.63
T_{11}	4.86	0.04	17.54	273.91	13.46	108.21
T_{12}	4.87	0.03	17.68	261.69	12.70	106.46
T_{13}	4.85	0.03	18.88	279.91	17.31	112.53
T_{14}	4.70	0.04	18.72	277.51	12.28	104.08
T_{15}	4.81	0.04	18.82	279.19	13.27	107.01
SEm±	0.08	0.003	0.13	1.10	0.08	0.58
CD (p=0.05)	NS	NS	0.37	3.13	0.23	1.65

uptake with about 292.68% over control, 15.36% over T_7 and 23.42% over T_{13} respectively. Similarly, the P uptake in straw was also recorded maximum with treatment T_8 that recorded highest with 5.38 kg ha^{-1} among all the other treatments under study. Further evaluation in the Table 2 data showed that treatment T_8 phosphorus uptake in straw was enhanced by 84.24% over control T_1, 6.74% over T_7 and 10.02% over T_{13} respectively. Application of FYM and NPK along with other secondary nutrients like sulfur and calcium and micronutrients like zinc also proved to have enhanced the nutrient content as compared to other treatments due to the availability of nutrients in optimum amount through inorganic and organic sources in the available nutrient pool leading to development of root biomass and surface ultimately encouraging more uptake of nutrients by the plant roots. Similar findings on increased concentration of P in grain and straw due to increased nutrient level and integration with organic sources have also been reported by Bora *et al.* (2018) and Latha *et al.* (2019). The highest potassium uptake in grain and straw was reported with the treatment T_8 a value recorded about 21.52 kg ha^{-1} and 83.16 kg ha^{-1} respectively. Whereas the minimum uptake in grain and straw was recorded in control T_1 with 6.81 kg ha^{-1} and 45.02 kg ha^{-1} respectively. A critical examination of potassium uptake in grain from Table 2, revealed that T_8 was significantly the highest which was followed by T_7 and T_{13} respectively while it was found that T_7 was at par with T_{13}. Further evaluation of the data, it reflected that application of T_8 enhanced the potassium uptake in grain by 216.00% over control T_1, similarly also showed a similar trend of increment in potassium uptake in straw with about 84.71% over control T_1, 6.93% over T_7, 9.50% over T_{13} respectively. The increased in uptake of potassium as documented by Biswas *et al.* (2020) that with integrated approach it showed better growth of roots due to ample amount of nutrients from the soil thus resulted in a better nutrient uptake by the plants.

The perusal data on pH as affected by the various treatments in direct seeded rice revealed that application of inorganic and organic sources of nutrients through different treatments did not show any significant effect during both the years of experimentation which has presented in Table 3. However, with the data obtained it disclosed that pH varied from 4.50 to 4.87 showing a slight increase in soil pH from control plot which had no nutrient application. Treatments which had organic source and lime treated plots displayed a higher pH as compared to those treatments which had no nutrient source or inorganic fertilizer alone. Besides lime which is known for raising pH for acidic soils, the slight raise in soil pH in other treatments may be attributed due to the presence of organic sources like FYM, vermicompost and Azospirillum which decreases the activity of exchangeable Al^{3+} ions in soil solution due to chelation effect of organic molecules and in addition promotes the release of basic cations like K^+, Ca^{2+}, Mg^{2+} and Na^+ in soil (Patra *et al.* 2020). Data revealed that soil electrical conductivity was proved to be non-significant as the different treatments could not show any statistical difference and the value varied from 0.03 to 0.04 (dSm^{-1}). Evaluation of data from Table 3 delineated that application of T_8 increased the organic carbon by 30.24% over control T_1. It was also observed that treatments which received organic manures recorded much higher organic carbon compare to sole recommended dose of fertilizers and no nutrient application in control. Treatment T_8 recorded the highest which was followed by T_{13}, T_{15}, T_{14} and T_7 which were at par with T_8. The above treatments recorded an increase in organic carbon of about 29.75%, 29.34%, 28.65% and 28.65% respectively over control T_1. The significantly greater organic carbon in the fertilized plots over control might be due to the greater yield associated with greater amount of root residues and stubbles of the crop added to the soil. Jena and Pattanayak (2021) also recorded a gradual improvement in soil organic carbon stock under INM with application of treatment 100% NPK + FYM or Vermicompost with the advancement in year which could be possibly due to addition of organic manures and crop residues and carbon input excess due to decomposition. The data obtained as shown in Table 3 revealed that application of treatment T_8- 100% NPK +Zn +S + FYM @ 5t ha^{-1} recorded the highest available nitrogen with the value 286.19 kg ha^{-1}. While the lowest was obtained from control T_1 with a value of 245.78 kg ha^{-1} respectively. With further evaluation it was observed that T_8 was followed by T_7 which was at par with T_{13} (281.02 kg ha^{-1}), T_{14} (279.78 kg ha^{-1}), and T_{15} (280.60 kg ha^{-1}). Application of treatment T_8 100% NPK +Zn +S + FYM @ 5t ha^{-1} increased the soil available nitrogen to the tune of about 16.70% over control respectively. It can be observed in this study that providing a balanced nutrition to the soil through both organic and inorganic sources increased the available nitrogen content of the soil whereas a reduction in any of the nutrient resulted in a lower value due to the imbalanced nutrient management. Upadhyay and Vishwakarma (2014) also observed that available nitrogen content was higher by providing balanced nutrition to the soil through organic and inorganic source under rice-wheat cropping sequence while the lower content was noted with insufficient nutrient application. NPK dose 100% also proved to have higher build-up of available nitrogen in soil as compared to 50% NPK. This was in conformity with the findings of Kumar *et al.* (2010) and Subehia and Sepehya (2012) who reported that substitution of nitrogen at higher rate produced significantly higher nitrogen in soil than the lower dose of respective source. The available phosphorus content in soil varied from 8.28 kg ha^{-1} in control to 18.18 kg ha^{-1} in plots which received 100% NPK +Zn +S + FYM @ 5t ha^{-1} followed by 100% NPK +Zn +S through inorganics as displayed in Table 3. There was an increase in available phosphorus contents over its initial value of 8.28 kg ha^{-1} in all the treatments where phosphorus addition and nutrients in organics form was made (T_2 to T_{15}). Amongst all the nutrients added T_8 recorded the highest available phosphorus (18.18 kg ha^{-1}) thereby showing the superiority of inorganics along with FYM over sole application of inorganics or organics source and other integrated nutrient source tried. It was revealed that treatment T_8 increased the soil available phosphorus to an extent of 119.56% over control T_1. Build-up of phosphorus in treatment T_8 with comparison to control and other treatments may be due to the application of inorganic fertilizers along with FYM that led to a possible release of organic acids during decomposition which in turn helped in the release of phosphorus through solubilizing action of native phosphorus in soil (Sharma and Subehia 2014). Organic fertilization also stimulates the activities of soil microorganisms and phosphatase, accelerating the rate of mineralization (Song *et al.* 2022). The available potassium in soil after cultivation was significantly influenced by application of different treatments. It varied from 96.27 kg ha^{-1} in control to 117.10 kg ha^{-1} under T_8 as displayed in Table 3. The highest increase to a tune of about 21.63% in soil available potassium content over control was observed under T_8, where 100% of NPK with sulfur and zinc along with integration of FYM was included in the treatment combination. This was followed by treatment T_7 (113.27 kg ha^{-1}), T_{13} (112.53 kg ha^{-1}), T_5 (112.51 kg ha^{-1}) and T_9 (110.64 kg ha^{-1}) which had comparatively higher build-up of soil available potassium content in soil. Further evaluation revealed that amongst the treatments T_8 proved to have a superlative effect on soil potassium content as T_8 increased the soil available potassium to an extent of 3.38% over T_7, 4.06% over T_{13}, 4.08% over T_5 and 5.83% over T_9 respectively. The higher availability of potassium with FYM may be ascribed to the reduction in potassium fixation and release of potassium due to the interaction of organic matter with clay (Pant *et al.* 2017) and as organic fertilization stimulates/improves the microbial conversion and activity of organic potassium into inorganic potassium (Yu *et al*. 2023). Shahid *et al.* (2015) observed that available potassium was highest in NK+FYM followed by NPK+FYM treatment, demonstrating the role of chemical fertilizers and organic manure in the supplementation of K in the soil while also suggesting the continuous addition of potassium which would improve the soil available potassium supply. With further evaluation of the data from Table 3, treatment T_{13} (50% NPK + 25% N-FYM + 25% N-VC) recorded a lower value compared to T_8 even though it had organic sources in its components which might due to the exclusion of S from the fertilizer dose. Pant *et al*. (2017) reported that exclusion of either phosphorus and potassium or sulfur from the fertilizer dose reduced the K availability.

CONCLUSION

On the basis of the results recorded, evaluated and discussion given above, it can be thus concluded that as compared to control and other combination of treatments, treatment T_8 -100% NPK +Zn +S + FYM @ 5t ha^{-1} is competent enough for enhancing the growth, yield, nutrient uptake of rice crop and also has the promising potential to sustain the soil health and productivity in the long run as it was found to have significantly outperformed other treatments under study in terms of the soil nutrients status.

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