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System Productivity and Nutrient Recoveries as Influenced by Nine Years of Long-term INM Practices under Acidic *Inceptisols* of India

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ABSTRACT: The long term intensive cropping system in acid soil without proper soil management leads to unsustainable crop productivity. Therefore, integrated nutrient management with various combinations of inorganics, organics, bioinoculants, and amendments in acidic soils can be the most effective way to sustain soil health and increase in crop productivity. A long-term field experiment was conductedin an acid *Inceptisols* of Odisha, India since 2010 to assess the effect ofintegrated nutrient management practices on system productivity and nutrient recoveriesin a sweetcorn-knolkhol-blackgram cropping system at the end of 9th cropping cycle (2018-19). The highest yield was recorded in T8 (STD + VC + Lime + BF) followed by T7, T6, T5, T3, T4, T9, T2, and T1 in sweetcorn but in knolkhol and blackgram the yield sequence was T8>T7>T6>T5>T4>T3>T9>T1>T2. The total dry matter production of the cropping system was highest (13.44 t ha^{-1}) in T8 followed by T7 (13.28 t ha^{-1}), T6 (11.28 t ha^{-1}), T5 (11.07 t ha^{-1}), T4 (10.33 t ha^{-1}), T3 (10.19 t ha^{-1}), T9 (4.97 t ha^{-1}), T2 (4.64 t ha^{-1}) and lowest was in T1 (4.00 t ha^{-1}). The system N, P and K uptake was highest (195 kg ha^{-1}, 47 kg ha^{-1} and 196 kg ha^{-1}) and lowest was in T1 (38 kg ha^{-1}, 12 kg ha^{-1} and 36 kg ha^{-1}). The recovery of nutrients in only inorganic package was lowest (6 % N, 7% P, and 8% K) while the highest was in T8 (44 % N, 30 % P, and 86 % K).

Keywords: Sweetcorn-knolkhol-blackgram cropping system, productivity, nutrient uptake, nutrient recoveries, INM.

INTRODUCTION

Achieving food security for a burgeoning population ina country like India, higher food production on existing croplands through enhanced nutrient input and recycling is essential (Jena & Pattanayak 2021). Intensive and continuous cropping without proper soil management may lead to a threat to the sustainability of agriculture. In problematic soils like acidic conditions, sustainable production has become a major concern in India. The adoption of integrated nutrient management practices involving organic and inorganic fertilizers is the best approach to make the production system more sustainable and profitable (Sarkar *et al.,* 2020). Crop production in acidic soil is mainly inhibited due to aluminium and iron toxicity, P deficiency, declined microbial activity, low base saturation, and other acidity-induced nutritional and fertility problems (Kumar *et al.,* 2012; Pattanayak & Sarkar 2016).

The biofertilizer application with soil amelioration enhances the productivity of cropsby maintaining soil fertility (Khuntia *et al.,* 2022; Sethi *et al.,* 2021). The application of native strains also improves the bioavailability of essential nutrients in the soil. The inoculation of native rhizobium strain enhances the nodular properties, and N- availability and enhances the biological activity at the pulse rhizosphere (Sethi *et al.*, 2019b). The stress-tolerant native strains provide the ambient condition at the rhizosphere by producing exopolysaccharides to make the rhizosphere un-hydrated and produce phytohormones (Sethi *et al.*, 2019a; Subudhi *et al.*, 2020) and nutrient availability (Pattanayak & Sethi 2022). Nutrient management through agro-waste management is an eco-friendly approach (Pandit *et al.*, 2020). The application of in-situ crop residue management enhances the soil's physical, biological and chemical properties (Pattanayak & Sethi 2022). The application of organic inputs like farm yard manure and vermicompost increases soil quality. Application of vermicompost having a C:N ratio below 15 is desirable for agronomic use (Pandit *et al.*, 2020).

Long-term integrated nutrient management practices increase soil quality (Garnaik *et al.*, 2022; Swain *et al.*, 2021) and INM practice is a potential tool for knowing the crop yields and yield trends. They are used to assess the sustainability of the system, the potential carrying capacity of the soil, and to predict soil productivity (Reddy *et al.*, 2006). Inadequate and imbalanced fertilizer use and the emergence of multiple nutrient deficiencies are the major factors responsible for the low productivity of the crops (Tiwari, 2002). Therefore, to maintain crop productivity balanced use of nutrients is important. Under these circumstances, the integration of chemical and organic sources and their management have shown promising results not only in sustaining productivity but have also proved to be effective in maintaining soil health and enhancing nutrient use efficiency (Thakur *et al.*, 2011). When integrated nutrient management through chemical fertilizers and different organic sources are applied on a long-term basis, they show a beneficial impact on crop productivity (Swarup, 2010). Therefore, the present study was undertaken to study the long-term effect of integrated nutrient management practices on nutrient uptake, nutrient recovery, and system productivity of sweetcorn, knolkhol, and blackgram in an acid *Inceptisols*.

MATERIAL AND METHODS

The present field experiment was performed on the farmland of "AINP on Soil Biodiversity - Biofertilizers" inthe College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar (20.26°N latitude, 85.81°E longitude and 25.9 m above mean sea level) since 2010. However, observations were taken during 2018-19 (after nine years of experimentation) to study the effect of long-term integrated nutrient management on system productivity and nutrient recoveries of sweetcorn, knolkhol, and blackgram in a cereal-vegetable-pulse cropping system. The experimental area falls under a subhumid tropical climate. The mean annual rainfall was 1577 mm, and the mean maximum and minimum temperatures were 33.2 and 21.4°C, respectively.

The soils of the site belong to *Inceptisols* order with acidic soil reaction.The experiment was laid out in a randomized block design (RBD) having three replications with treatments consisting of T1 (control), T2 Soil Test Dose of fertilizer (**STD**), T3 (STD + FYM), T4 (STD + VC), T5 (STD + FYM + BF), T6 (STD + VC + BF), T7 (STD + FYM + Lime + BF), T8 (STD + VC + Lime + BF), and T9 (1/2 STD + BF). The soil test dose of fertilizer was given to the crops*viz*; 150:20:48 for sweetcorn, 125:38:63 for knolkhol, and 25:30:25 for blackgram in the form of $N:P_2O_5:K_2O$ kg ha^{-1}. Lime was applied @ 0.1 LR to sweetcorn and @0.2 LR to knolkhol and blackgram crop. Standard methods were adopted for the analysis of soil and organic inputs to fix the soil test dose of fertilizers (Page *et al*., 1982; Panda, 2019). Organic sources applied were farm yard manure (FYM) @ 5t ha^{-1} and vermicompost (VC) @ 2.5 t $ha^{-1}$to each crop. Biofertilizers (BF) like *Rhizobium* to Blackgram and *Azotobacter, Azospirillum,* and PSB (@1:1:1) to Knolkhol and Sweetcorn. The crop residues were incorporated into the soil after harvesting the economic yield potion of each crop. The total nutrients added to the cropping system in that cropping year are presented in Table 1.

Table 1: Total nutrients added to the Sweetcorn-Knolkhol-Blackgram cropping system.

Treatments	Total nutrients added (Kg ha^{-1}) to the cropping system		
	N	P	K
T1: Control	0	0	0
T2: STD	300	88	136
T3: STD + FYM	355	115	186
T4: STD + VC	355	115	186
T5: STD + FYM + BF	355	115	186
T6: STD + VC + BF	355	115	186
T7: STD + FYM + Lime + BF	355	115	186
T8: STD + VC + Lime + BF	355	115	186
T9: 1/2STD + BF	150	88	68

The economic yield was recorded by taking the fresh weight of sweetcorn, knolkhol, and sundry weight of blackgram (moisture 12%) and expressed in t ha^{-1}. The dry matter production was calculated by taking 100 g of each treatment on respective crops kept in an oven at 65°C till constant weight was recorded. The dry matter production was expressed in t ha^{-1}. The system uptake was calculated by adding each crop uptake and recovery was also calculated by taking each crop recovery. In each crop, uptake and recovery of each nutrient were calculated by using the formulae given below.

$$\text{Nutrient Uptake } (kg\ ha^{-1}) = \text{Drymatter Yield } (q\ ha^{-1}) \times \text{ Nutrient Concentration } (\%)$$

$$\text{Recovery } (\%) = \frac{\text{Yield in treated plot } (\text{kg ha}^{-1}) - \text{Yield in control plot } (\text{kg ha}^{-1})}{\text{Quantity of nutrient added to the treated plot } ((\text{kg ha}^{-1})}$$

The data were analyzed by using OPSTAT software developed by O.P. Sheoran, Chaudhary Charan Singh, Haryana Agricultural University, Hisar, Haryana, India (Sheoran *et al.,* 1998).

RESULT AND DISCUSSION

Influence of long-term INM practice on economic yield

The data relating to economic yield has been presented in Table 2. The sweetcorn yield varied between 2.93 t ha^{-1} to 8.93 t ha^{-1}. The lowest yield (2.93 t ha^{-1}) was estimated in control and the highest (8.93 t ha^{-1}) was estimated in the package where soil test-based fertilizer was applied with vermicompost, lime, and biofertilizers. The sequence of yield followed as T8>T7>T6>T5>T3>T4>T2>T9>T1. The knolkhol yield varied between 1.64 t ha^{-1} and 24.21 t ha^{-1}. The highest yield (24.21 t ha^{-1}) was recorded in T8 (STD + VC + Lime + BF) followed by T7 (23.64 t ha^{-1}), T6 (18.71 t ha^{-1}), T5 (18.35 t ha^{-1}), T4 (13.78 t ha^{-1}), T3

(13.24 t ha^{-1}), T9 (4.2 t ha^{-1}), T1 (1.89 t ha^{-1}) and T2 (1.64 t ha^{-1}).

The blackgram yield ranged from 0.20 t ha^{-1} to 0.89 t ha^{-1}. The highest yield (0.89 t ha^{-1}) of blackgram was estimated in the package where the soil test dose of fertilizers was added with 2.5 t ha^{-1} vermicompost, lime, and biofertilizers (T8) followed by T7, T6, T5, T4, T3, T9, T1 and lowest was recorded in the package where only chemical fertilizers were added (T2). The yield reduction in the treatment (T2) may be due to the long-term addition of only chemical fertilizers to the acid soil creating further acidification to such a range where sensitive crops like blackgram and knolkhol didn't sustain their yield. The sweetcorn equivalent yield was highest (14.78) in T8 followed by T7, T6, T5, T4, T3, T9, T2, and the lowest was in T1 treatment. The yield of all three crops was higher in the vermicompost applied packages than in FYM applied packages.

The lime application enhances 23-25 per cent, 29 per cent, and 33per cent higher yield in sweetcorn, knolkhol,and blackgram, respectively, with integrated packages than without lime integrated packages. This positive response in the limed package was due to neutralizing soil acidity (Pattanayak & Sarkar 2016) and enhancing the bioavailability of plant nutrients (Priyadarshini *et al.*, 2017; Sethi *et al.,* 2017). The biofertilizer application with lime in acid soil also enhanced the yield it was due to the creation of a congenial rhizospheric environment for the growth of inoculated microbes (Sethi *et al.*, 2017, 2021). Integrated nutrient management enhanced the yield of all three crops. The similar findings of INM enhanced the yield of coriander(Priyadarshini *et al.*, 2017), sweetcorn (Prusty, Dash *et al.*, 2022; Prusty Swain, *et al.,* 2022), finger millet (Swain *et al.,* 2021), Fenugreek (Husain *et al.,* 2022), Papaya (Reena *et al.,* 2022) and cereal -vegetable-pulse cropping system (Jena & Pattanayak 2021).

Table 2: Influence of long-term INM practice on economic yield (t ha^{-1}).

Treatments	Sweetcorn	Knolkhol	Blackgram	SEY
T1: Control	2.93	1.89	0.20	3.27
T2: STD**	3.71	1.64	0.13	4.10
T3: STD + FYM	6.28	13.24	0.46	8.97
T4: STD + VC	6.24	13.78	0.50	9.20
T5: STD + FYM + BF	6.76	18.35	0.64	10.95
T6: STD + VC + BF	7.10	18.71	0.67	11.97
T7: STD + FYM + Lime + BF	8.43	23.64	0.85	13.74
T8: STD + VC + Lime + BF	8.93	24.21	0.89	14.78
T9: 1/2 STD + BF	3.50	4.20	0.33	5.20
LSD (P=0.05)	1.06	2.51	0.09	-

*SEY: Sweetcorn Equivalent Yield; STD**: Soil Test Dose of Fertilizer

Influence of INM practice on dry matter production. The dry matter production of crops in cropping sequence has been presented in Table 3. The dry matter production of sweetcorn was more than knolkhol and blackgram. In sweetcorn, the highest dry matter (6.74 t ha^{-1}) was recorded in an integrated nutrient management practice where a soil test dose of fertilizerwas applied with vermicompost, lime, and biofertilizer followed by STD + FYM + Lime + BF (6.68 t ha^{-1}), STD + VC + BF (5.41 t ha^{-1}), STD + FYM + BF (5.33 t ha^{-1}), STD + VC (5.24t ha^{-1}), STD + FYM (5.14 t ha^{-1}), STD (2.67 t ha^{-1}), 1/2 STD + BF (2.54 t ha^{-1}), and lowest was recorded in control (1.91 t ha^{-1}). The dry-matter production in knolkhol was lesser in comparison to sweetcorn and blackgram. The dry matter of knolkhol was highest in T8 (3.17 t ha^{-1}) followed by T7 (3.11 t ha^{-1}), T6 (2.64 t ha^{-1}), T5 (2.49 t ha^{-1}), T4 (2.22 t ha^{-1}), T3 (2.19 t ha^{-1}), T9 (0.61 t ha^{-1}), T1 (0.52 t ha^{-1}) and lowest was in T2 (0.37 t ha^{-1}). The blackgram drymatter varied between 1.57 t ha^{-1} and 3.53 t ha^{-1}.

The highest dry matter production was recorded in integrated packages with soil management package followed by without management package, without biofertilizer inoculation, sub-optimal dose of NPK with biofertilizer, control, and only soil test dose of fertilizer. The total dry matter production of the cropping system was highest (13.44 t ha^{-1}) in T8 followed by T7 (13.28 t ha^{-1}), T6 (11.28 t ha^{-1}), T5 (11.07 t ha^{-1}), T4 (10.33 t ha^{-1}), T3 (10.19 t ha^{-1}), T9 (4.97 t ha^{-1}), T2 (4.64 t ha^{-1}) and lowest was in T1 (4.00 t ha^{-1}). The dry matter production in the integrated package was due to the application of adequate nutrients during the crop growth period. Similar findings have been reported by(Jena & Pattanayak, 2021; Khadadiya *et al.*, 2020).

Table 3: Influence of long-term INM practice on systemtotal dry matter production (t ha^{-1}).

Treatments	Sweetcorn	Knolkhol	Blackgram	Total
T1: Control	1.91	0.52	1.57	4.00
T2: STD	2.67	0.37	1.60	4.64
T3: STD + FYM	5.14	2.19	2.85	10.19
T4: STD + VC	5.24	2.22	2.87	10.33
T5: STD + FYM + BF	5.33	2.49	3.24	11.07
T6: STD + VC + BF	5.41	2.64	3.27	11.28
T7: STD + FYM + Lime + BF	6.68	3.11	3.48	13.28
T8: STD + VC + Lime + BF	6.74	3.17	3.53	13.44
T9: 1/2 STD + BF	2.54	0.61	1.81	4.97
LSD (P=0.05)	0.76	0.35	0.46	-

Influence of long-term INM practices on system nutrient uptake (kg ha^{-1}) and recoveries (%). The data relating to system nutrient uptake has been presented in Table 4. The system N uptake was highest (195 kg ha^{-1}) in the package where STD + VC + Lime + BF (T8) followed by STD + FYM + Lime + BF(194 kg ha^{-1}), STD + VC + BF (140 kg ha^{-1}), STD + FYM + BF (154 kg ha^{-1}), STD + VC (116 kg ha^{-1}), STD + FYM (123 kg ha^{-1}), 1/2 STD + BF (64 kg ha^{-1}), STD (58 kg ha^{-1}), and lowest was in control (38 kg ha^{-1}). The phosphorus uptake by the cropping system varied between 12 kg ha^{-1} and 47 kg ha^{-1}.The highest (47 kg ha^{-1}) phosphorus uptake was estimated in T8 followed by T7 (42 kg ha^{-1}), T6 and T5 (39 kg ha^{-1}), T4 (35 kg ha^{-1}), T3 (32 kg ha^{-1}), T2 and T9 (18 kg ha^{-1}) and lowest (12 kg ha^{-1}) was estimated in control. The potassium uptake ranged from 36 kg ha^{-1} to 196 kg ha^{-1}. The highest was in T8 (196 kg ha^{-1}) followed by T7 (183 kg ha^{-1}), T6 (159 kg ha^{-1}), T5 (154 kg ha^{-1}), T4 (139 kg ha^{-1}), T3 (138 kg ha^{-1}), T9 (64 kg ha^{-1}), T2 (46 kg ha^{-1}) and lowest (36 kg ha^{-1}) was in control.

The application of organic manures along with inorganic fertilizers significantly (p=0.05) increased the NPK uptake in the system. The application of biofertilizers with organics and inorganics influenced the uptake of N, P, and K significantly (p=0.05). Likewise, the amelioration of acid soil with the integration of all the components increased the nutrient uptake in the system. A similar finding was reported by (Swain *et al.,* 2021) in finger milletand (Prusty, Swain, *et al.,* 2022) in sweetcorn. The influence of long-term INM practice on N, P, and K recovery has been presented in Fig 1. The recovery of nutrients in the only inorganic package was lowest (6 % N, 7% P, and 8% K) and the highest was in T8 (44 % N, 30 % P, and 86 % K). The recovery of nitrogen, phosphorus, and potassium was more in ameliorated package followed by inorganics + organics + biofertilizers package, inorganics + organics, ½ inorganics + biofertilizers and the lowest was in only inorganic added package.

Table 4: Influence of long-term INM practice on system nutrient uptake (kg ha^{-1}).

Treatments	System uptake (kg ha^{-1})		
	N	P	K
T1: Control	38	12	36
T2: STD	58	18	46
T3: STD + FYM	133	32	138
T4: STD + VC	126	35	139
T5: STD + FYM + BF	154	39	154
T6: STD + VC + BF	140	39	159
T7: STD + FYM + Lime + BF	194	42	183
T8: STD + VC + Lime + BF	195	47	196
T9: 1/2 STD + BF	64	18	64
LSD (P=0.05)	19.2	4.9	17.7

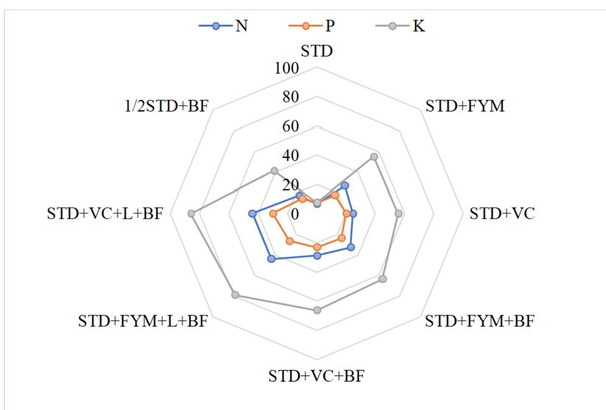

Fig. 1. Influence of long-term INM practices on system nutrient recoveries (%).

CONCLUSION

The long-term integrated nutrient management practices after nine years of field experimentation resulted in higher economic yield, system total dry matter production, nutrient uptake, and recoveries. The soil management through liming of problematic soil like acid soil improved the economic yield, dry matter production, nutrient uptake, and recovery in comparison to the non-application of lime package. The efficiency of biofertilizer with liming was more in comparison to non-liming packages. The study showed that integrated nutrient management with various combinations of inorganics, organics, amendments, and microbial inoculants in problematic acid soils resulted in the most effective way of increasing system productivity under a cereal-vegetable-pulse cropping system.

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Conflict of Interest. None.

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