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Impact of long-term integrated nutrient management on crop productivity and sustainability under cereal-vegetables-pulses cropping system in an acid upland *Inceptisols*

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Abstract
The long term (10 years) effect of various integrated nutrient management practices under cereal-vegetables-pulses cropping system on crop productivity and sustainability is being studied in an acid upland *Inceptisols* of Bhubaneswar. The results revealed that the integrated application of 100% NPK (STD) with organics (FYM/vermicompost), biofertilizers and lime resulted in higher biomass yield, maize equivalent yield (MEY), relative agronomic efficiency (RAE). The 10 years pooled data indicated that MEY response due to fertilizers was 64.8 per cent, organics 60.3 per cent, biofertilizers 14 per cent and lime 18.4 per cent. The control and sole STD treatments were not sustainable (lower SYI). However, highest SYI of 0.54 was observed in STD + VC /FYM + Lime + Biofertilizers treatment indicating sustainability of the complete integrated treatments.

Keywords: Long term experiment, integrated nutrient management, crop productivity, sustainable yield index

Introduction
Achieving food security for a rapidly expanding population would necessitate intensifying food production on existing crop lands through enhanced nutrient input and recycling. Continuous and intensive cropping without adequate restorative practices may pose threats to the sustainability of agriculture. Sustaining the production has become a major concern in agriculture in many parts of India especially in acid soil region. Issues of agricultural sustainability are related to soil quality. Adoption of nutrient management practices involving the integration of organic and inorganic fertilizers is the best viable alternative to make the production system more sustainable and profitable (Sarkar *et al*., 2020) [1].

Crop production in acidic soils are 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) [9]. As soil acidity has negative impact on the production of staple food crops, management of such soils is important to enhance crop productivity for achieving food security.

Long term fertilizer experiments are invariably a potential tool for knowing the crop yields and yield trends. They are used to assess sustainability of system, potential carrying capacity of soil and predicting soil productivity (Reddy *et al*., 2006) [3].

Inadequate and imbalanced fertilizer use and emergence of multiple nutrient deficiencies are the major factors responsible for the low productivity of the crops (Tiwari, 2002) [4]. Therefore, to maintain crop productivity balanced use of nutrients is important. Under this circumstances, integration of chemical and organic sources and their management have shown promising results not only in sustaining the productivity but have also proved to be effective in maintaining soil health and enhancing nutrient use efficiency (Thakur *et al*., 2011) [5]. 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) [6].

No information is available on long term impacts of INM practices on crop productivity and sustainability of cereals–vegetables-pulses cropping system in acid inceptisols of Odisha. Therefore, the present investigation was undertaken to assess long term impacts of INM practices on crop yield and sustainability of cereal-vegetable-pulse cropping system.

Materials and Methods

The present study is a part of an ongoing long term experiment under All India Network Project on Soil Biodiversity and Biofertilizers with cereal (ragi/ maize)-vegetables (cabbage/ cauliflower/ knolkhol)-pulses (greengram/ blackgram/cowpea) cropping system which was started during 2010 at College of Agriculture, Bhubaneswar (OUAT). Experimental site is located at 20°15' N latitude and 85°28' E longitude at an altitude of 25.9 m above mean sea level. It comes under East and South Eastern Coastal Plain Agro-climatic zone of Odisha and hot sub-humid eco-region with red and lateritic soils agro-ecological region (AEZ No.12) and sub-region 12.2 of India. The soil of experimental site belongs to order *Inceptisols* having loamy sand texture and comes under sub-group *Vertic Ustochrept*. The initial soil was having pHw (1:2.5) 5.14, EC. 0.03 dSm^{-1}, organic carbon 3.91 g kg^{-1} soil and available N, P and K were 207, 37 and 85 kg ha^{-1} respectively.

There were 08 treatments replicated three times in Randomized Block Design. The 100% NPK dose is based on soil test values. The treatments were viz., T_1 – control, T_2- STD (100% NPK), T_3 – STD + F (100% NPK + FYM), T_4 – STD + VC (100% NPK + vermicompost), T_5 – STD + F + BFs (100% NPK + FYM + Biofertilizers), T_6 – STD + VC + BFs (100% NPK + vermicompost + biofertilizers), T_7 – STD + F + L + BFs (100% NPK + FYM + Lime + BFs) and T_8 – STD + VC + L + BFs (100% NPK + vermicompost + lime + biofertilizers).

The dose of FYM was 5 t ha^{-1} for maize, ragi and vegetables and 2.5 t ha^{-1} for pulses; vermicompost @ 2.5 t ha^{-1} for maize, ragi and vegetables and 1.25 t ha^{-1} for pulses. For non-leguminous crops *Azotobacter* + *Azospirillum* + PSB @ 4 kg ha^{-1} each inoculated to pre-limed (5%) vermicompost/ FYM in 1:25 ratio and incubated for 07 days at 30% moisture and for leguminous crops seed inoculation with *Rhizobium* @ 50 g /kg seed and treatment with sodium molybdate @ 10 g/25 kg seeds. The dose of lime for dicot crops was 0.2 LR (woodruff buffer method) to pH 6.5 and for monocot crops it was 0.1 LR. Standard agronomic practices were followed for all the crops. Fourteen crops were grown during 1st 5 years (2010-14) and 15 crops during 2nd 5 years (2015-19).

For comprehensive comparison, the economic yield of the crops was converted to Maize Equivalent Yield (MEY) and was derived by using the following formula: MEY = $\frac{Y_c P_c}{P_m}$,

where MEY = maize equivalent yield, Y_c = yield of particular crop, P_c = market price of particular crop, P_m = market price of maize crop. Sustainable yield index (SYI) is a quantitative measure to assess sustainability of an agricultural practice. SYI of individual treatment was computed using the following equation (Singh *et al*., 1990) [7]: SYI = $\frac{A - Y}{y_{\max}}$,

Where, A = mean yield of a particular treatment, Y = standard deviation of a particular treatment, Y_{max} = maximum yield obtained of a particular treatment over the years.

Relative agronomic efficiency (RAE) (%) of different treatment was calculated based on MEY and dry biomass yield using the formula,

$$\text{RAE (\%)} = \frac{\text{Yield of treatment - Yield in control}}{\text{Yield in standard treatment - Yield in control}} \times 100$$

Where STD + F was considered as standard treatment.

Experimental data were subjected to analysis of variance (ANOVA) (Gomez and Gomez, 1984). To compare the treatment means, least significant difference (LSD 0.05) test was used.

Results and Discussion

Effect of long term use of INM practices on dry matter production

The data regarding the dry matter production during 10 years of experimentation under INM treatments are presented in Table 1. The data of 1st 5 years (2010-14) revealed that the average dry biomass production of 14 crops varied between 5.37 t ha^{-1} $year^{-1}$ in the integrated treatment of STD + vermicompost + Lime + Biofertilizers. There was significant variation in biomass production due to use of different inputs. Application of soil test dose of inorganic fertilizers alone and integration of STD with organics (F/VC), organics with BFs and more specifically with organics, biofertilizers and lime in acid soil increased the biomass yield by 82, 130, 157 and 187 per cent compared to control yield, respectively.

Table 1: Influence of long term (10 years) INM practices in cereal-vegetable-pulse cropping system on total dry matter production in acid *Inceptisols*

Treatments	Dry matter (t ha^{-1} $year^{-1}$)			
	Average of 1st 5 years (2010-14	Average of 2nd 5 years (2015-19)	Loss/gain (%) over 1st 5 years	10 years pooled (Average)
Control	5.37	4.16	23	4.77
STD	9.77	5.85	40	7.81 (-32.5)*
STD + F	12.11	10.73	11	11.42
STD +VC	12.55	10.87	13	11.71
STD + F + BFs	13.51	11.75	13	12.63
STD + VC + BFs	14.06	11.90	15	12.93 (+10.5)*
STD + F + L + BFs	15.36	14.49	6	14.93
STD + VC + L + BFs	15.49	14.64	6	15.07 (+29.7)
LSD (P = 0.05)	0.39	0.61	-	0.48
CV (%)	6.0	7.0	-	6.0

During 2nd 5 years of cropping (2015-19) the average dry matter production of crops decreased, where it varied between 4.16 and 14.64 t ha^{-1} $year^{-1}$. The reduction in biomass production ranged from 6 to 40 per cent over 1st 5 years. The lowest reduction was recorded with lime integrated treatments and highest with STD alone. The influences of FYM and vermicompost were not significant when used alone with STD or with BFs or lime with BFs.

The 10 years pooled average dry matter production under the influence of INM practices varied significantly between 4.77 and 15.07 t ha^{-1} $year^{-1}$, lowest with control and highest with STD + VC + L + BFs integrated treatment. There was no significant difference between FYM and vermicompost in influencing dry matter production. However, compared to the performance of STD + organics, the performance of STD alone was 32.5 per cent less, integration of biofertilizers was 10.5 per cent more and integration of biofertilizers and lime was 29.7 per cent more. The higher dry matter production under STD + VC /FYM + lime + BFs treatments may be ascribed to better nutrient supply through incorporation of organics along with conducive physical environment leading to better root activity and higher nutrient uptake which resulted in better plant growth. The results are in agreement with Srinivasa Rao (2011).

Effect of long term INM practices on economic yield production

The data related to economic yield of 29 crops grown during the period 2010 to 2019 (10 years) was converted into their maize equivalent yields and reported in Table 2.

During 1st 5 years of cropping, the economic yield (MEY) under the influence of eight different treatments varied significantly between 3.63 and 12.88 t ha^{-1} $year^{-1}$, lowest with control treatment and highest with integrated treatment of STD, FYM, BFs and lime. The influence of FYM and vermicompost was statistically at par.

Table 2: Influence of long term INM practices on economic productivity in cereal- vegetable-pulse cropping system in acid *Inceptisols*

Treatments	Economic productivity (t $ha^{-1}year^{-1}$)			
	1st 5 years	2nd 5 years	Loss/ gain (%) over 1st 5 years	10 years pooled(average)
Control	3.63	3.58	(-)1.4	3.61
STD	7.64	4.26	(-)44.3	5.95
STD + F	9.81	9.12	(-)7.0	9.47
STD +VC	9.99	9.23	(-)7.6	9.61
STD + F + BFs	11.29	10.26	(-)9.1	10.78
STD + VC + BFs	11.52	10.38	(-)9.9	10.95
STD + F + L + BFs	12.88	12.98	(+)0.8	12.93
STD + VC + L + BFs	12.77	12.86	(+)0.7	12.82
LSD (P = 0.05)	0.47	0.45	-	0.43
CV (%)	6.0	7.0	-	6.0

During 2nd 5 years of cropping (2015-19), the average MEY varied significantly between 3.58 and 12.98 t ha^{-1} $year^{-1}$, lowest with control and highest with STD + FYM + Lime + BFs treatment. Compared to 1st 5 years of cropping, there was decrease in economic yield in the 2nd 5 years except in combined application of STD, organics, biofertilizers and lime where there was increase in production up to 0.8 per cent. In rest of the lime unintegrated treatments, the economic yield decreased with maximum of 44.3 per cent with sole STD treatment.

The ten years pooled maize equivalent yields under the influence of INM practices varied significantly between 3.61 and 12.93 t ha^{-1}. The performance of FYM and vermicompost did not differ significantly, though their lone integration with STD treatment increased the production by 59 per cent (FYM) and 62 per cent (VC), respectively. The yield response due to fertilizers was 64.8 per cent, organics 60.3 per cent, biofertilizers 14 per cent and lime 18. 4 per cent. The higher yield in complete integrated treatments with STD, organics, lime and biofertilizers may be due to sustained nutrient supply and better utilization of applied nutrients through improved microbial activity that involved nutrient transformations. Similar results of superiority of long term INM treatments on crop productivity was also reported by Shafi *et al.* (2018) [17], Richakumari *et al.* (2017) [14], Bhatt *et al.* (2017) [12]. Integrated use of balanced inorganic fertilizers (NPK) in combination with lime, FYM and biofertilizers sustained higher crop productivity (Saha *et al.*, 2010) [13].

Effect of long term INM practices on relative agronomic efficiency: Considering the efficiency of STD + FYM as 100, the relative agronomic efficiency of other treatments for total dry matter and economic yield have been calculated and presented in Table 3.

Table 3: Relative agronomic efficiency of different treatments in total biomass and economic productions in cereal-vegetables-pulses cropping system

Treatments	Relative agronomic efficiency (RAE) (%)					
	During 1st 5 years		During 2nd 5 years		10 years average	
	A*	B**	A	B	A	B
STD	63	65	27	12	45	40
STD + F	100	100	100	100	100	100
STD +VC	102	103	103	102	103	102
STD + F + BFs	123	124	118	121	121	122
STD + VC + BFs	131	128	120	123	130	125
STD + F + L + BFs	158	150	164	170	161	159
STD + VC + L + BFs	160	148	168	168	164	157

A*: RAE based on total biomass production
B**: RAE based on economic production

The data indicated that the performance (RAE) of treatments for dry matter production followed the order: STD (63) < STD + F (100) < STD + VC (102) < STD + F + BFs (123) < STD + VC + BFs (131) < STD + F + L + BFs (158) < STD + VC + L + BFs (160) during 1st 5 years of production phase. The relative agronomic efficiency differed to a considerable extent during 2nd 5 years of production phase. The performance of STD treatment decreased maximum (from 63 to 27). There was small decrease with BFs integrated treatments. However, for lime integrated treatments, the RAE increased. The treatments followed similar order as in the 1st phase

The 10 years average RAE values for dry matter production followed the order: STD (45) < STD + F (100) < STD + VC (103) < STD + F + BFS (121) < STD + VC + BFs (130) < STD + F + L + BFs (161) < STD + VC + L + BFs (164).

The RAE for the production of economic yield varied between 65 and 150. Various treatments followed the order: STD (65) < STD + F (100) < STD + VC (103) < STD + F + BFs (124) < STD + VC + BFs (128) < STD + VC + L + BFs (148) < STD + F + L + BFs (150) during 1st 5 years phase of crop production. During 2nd phase the RAE values decreased for STD treatment (from 65 to 12) and increased for STD + FYM /VC + L + BFs treatments. The 10 years average RAE for economic yield of different treatments followed the order: STD (40) < STD + F (100) < STD + VC (102) < STD + F + BFs (122) < STD + VC + BFs (125) < STD + VC + L + BFs (157) < STD + F + L + BFs (159).

Effect of long term INM practices on sustainable yield index (SYI)

The data related to SYI of various treatments for dry matter and economic matter productions have been presented in Table 4.

Table 4: Sustainable yield index of INM treatments for total biomass and economic production

Treatments	Sustainable yield index	
	Total biomass production	Economic production
Control	0.21	0.16
STD	0.26	0.22
STD + F	0.45	0.37
STD +VC	0.46	0.38
STD + F + BFs	0.53	0.44
STD + VC + BFs	0.54	0.44
STD + F + L + BFs	0.66	0.54
STD + VC + L + BFs	0.68	0.54

The SYI is a useful tool to assess overall yield sustainability of system. For dry matter production, the calculated SYI of various treatments ranged from 0.21 to 0.68, lowest with control which increased with the use of inorganic fertilizers (STD 0.26), almost doubled with integrated use of organic (F/VC), increased by 17 per cent with the integrated use of biofertilizers and another 24 per cent with liming of acid soil. Greater value of SYI in integrated treatments may be due to good crop response for organics and inorganic fertilizers applied.

For economic matter production, the SYI values varied widely between 0.16 and 0.54. The index value was lowest with non use of agro inputs, thereafter increased to 0.22 for use of only chemical fertilizers based on soil test. Highest SYI of 0.54 was observed in treatments receiving STD + F/VC + L + BFs indicating sustainable crop production. In contrary, 100% NPK (STD) treatment was unsustainable (Khan *et al*., 2017) [15]. Similar results of higher SYI in INM treatments compared to sole inorganic or organic or control treatment were also reported by Silpa *et al*. (2021) [10], Bangre *et al*. (2020) [11] and Abid *et al*. (2020) [16].

Conclusion

Long term (10 years) integrated use of STD with organics (FYM/vermicompost), biofertilizers and liming of acid soils gave higher maize equivalent yield, biomass yield and RAE compared to sole STD or other integrated treatments with organics and biofertilizers. The productivity due to sole use of inorganic fertilizers is not sustainable (lower SYI). However, complete integrated treatment showed higher SYI value and sustainability in crop production under cereal-vegetables-pulses cropping system.

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