International Journal of Plant & Soil Science

34(21): 795-808, 2022; Article no.IJPSS.89979
ISSN: 2320-7035

Sub-soil Properties as Influenced by Long-Term Manuring and their Relationship with Yield and Sustainability of a Rice-Rice Production System in Eastern India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2022/v34i2131334

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/89979

Original Research Article

Received 14 May 2022
Accepted 22 July 2022
Published 27 July 2022

ABSTRACT

Investigation was made to study the impact of long-term fertilizer and manure application on the sub-soil properties of an acidic *Inceptisol* under continuous rice-rice cropping system. For this purpose, a long-term fertilizer experiment commenced from 2005-06, *rabi* season in the Central Farm of Odisha University of Agriculture and Technology (OUAT), Bhubaneswar under aegis of ICAR, New Delhi was used. The experiment had 12 manurial treatments whose impact has been assessed after 20 cropping cycles. The initial soil was acidic (pH 5.8) with low soil organic carbon (4.3 g kg $^{-1}$) and CEC of 3.75 cmol (p^+) kg^{-1}. After 20 cropping cycles there was decrease in surface soil pH in all the fertilized treatments by 0.16 - 0.96 units except high yielding FYM amended treatments (NPK+FYM and NPK+FYM+lime) that resisted the drop. The pH, however increased to alkaline level (7.72-8.44) down the layers irrespective of treatments. More accumulation of salt was found at 60-75 cm layer with highest (0.418 dSm^{-1}) recorded in 100% NPK + FYM+lime treatment. The soil organic carbon (SOC) content increased in all the fertilized treatments in the surface layer

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and with depth it decreased sharply from 15-30 cm to 30-45 cm layer. The high yielding NPK+FYM treatment had highest content of SOC in all the layers. Among the parameters studied, SOC of all the layers, pH & EC of 15-30 cm layer could explain maximum variation in both yield and sustainability. Lower layer properties particularly of 15-30 cm layer had strong correlation with the surface layer. The SOC of layers up to 75 cm could explain 64.1 - 85.8% variation in productivity and 53.0 to 78.7 % variation in sustainability. The pH and EC of 15-30 cm layer also explained 75.6 and 47.9 % variation in productivity and 75.4 and 62.3 % in sustainability, respectively. Thus, lower layers also contribute to soil fertility of surface layer and in turn the productivity and sustainability of wet land rice-rice cropping system in sub -tropical ecosystem.

Keywords: Long-term manuring; rice-rice system; sub-soil properties; productivity; sustainability.

1. INTRODUCTION

For the development of sustainable food production system, maintenance and management of soil fertility is important. Rice-rice is one of the intensively cultivated production systems [1] in Eastern India. In the past few years, the yield of the system in most of the cases has either been stagnated or declined and it has happened mostly due to reduced and unmatched supply of nutrients by the soil to plants [2]. Deterioration of soil quality with poor nutrient supply capacity is a major constraint to sustainable productivity of such system. Imbalance use of chemical fertilizers alone tends to decline soil quality and fertility over a period of years with given inputs. Number of long-term manurial experiments has been used to monitor changes in soil status and nutrient dynamics in rice-based production systems [3]. The most logical way to manage long-term fertility and productivity of soil is integrated use of inorganic and organic sources of plant nutrients [4]. From an agricultural point of view, the subsoil also deserves close attention because it also influences the properties of surface soil and plant growth. Continuous cropping and management practices also influence the subsoil properties [5]. Sub-soil characterization is necessary for establishing relationship with the properties of top soil and nutrient uptake. Sub soil properties vary with the cropping system and climatic situation. The information on subsoil characterization in intensively rice cultivated soil under long-term continuous manuring is scanty in India. Very few researches have been carried out up to 45 cm only. The present investigation aimed at studying i. the long-term impact of different fertilizer nutrients, FYM and lime on various important soil properties such as pH, electrical conductivity and soil organic carbon of deeper soil layers up to 75 cm and ii. studying the contribution of lower layer properties to surface soil fertility, productivity and sustainability of rice-rice production system using a 10-year-old Long-term fertilizer experiment with 12 different manurial treatments.

2. MATERIALS AND METHODS

2.1 Experimental Site

The study was conducted during *kharif*, 2015 and *rabi*, 2015-16 in the ongoing experimental field of All India Coordinated Research Project (AICRP) on Long-Term Fertilizer Experiment (LTFE) of ICAR at OUAT, Bhubaneswar, India (20°17′ N, 85°49′ E and 30 m above mean sea level). The location of the experimental site is characterized as sub-humid sub-tropical climate with *rabi* season from October to June and *kharif* season from July to September. The average annual rain fall is 1453 mm and the mean maximum and minimum temperatures are 31.40^o C and 21.10^o C, respectively. The experimental soil is a pale yellow (10YR6/8), lateritic *Inceptisol*. The initial soil properties of 0-15cm layer were sandy loam texture with clay 17%, silt 12% and sand 71%, bulk density 1.55 gcm^{-3}, cation exchange capacity 3.75 cmol (p$^+$) kg^{-1}, pH 5.8, electrical conductivity 0.12 dSm^{-1}, organic carbon 4.3 g kg^{-1}, available N (Alkaline $KMnO_4$)187, available P (Olsen's)19.4 and available K (NH_4OAc) 43.4 kgha^{-1}, respectively. The DTPA extractable Fe, Mn, Zn and Cu were 33.0, 7.53, 1.80 and 3.15 mg kg^{-1}, respectively. Exchangeable cations Ca and Mg were 2.25 cmol (p$^+$) kg^{-1}and 0.65cmol (p$^+$) kg^{-1}. The hot water-soluble boron was 0.46 mg kg^{-1}. The twelve treatments with four replications in a randomized block design were as follows:

2.2 Experiment Details

The experiment consisted of 12 treatments; T_1-100% PK, T_2 - 100% NPK, T_3- 150%NPK, T_4-100%NPK+Zn, T_5-100%NPK+ FYM, T_6-100%NPK+Lime+FYM, T_7-100%NPK+B+Zn, T_8-100%NPK+S+Zn, T_9-100%N, T_{10}-100%NP, T_{11}-

100%NPK+Lime and T_{12}- Control, where 100% NPK correspond to 80-40-60 kg of N, P_2O_5 and K_2O ha^{-1}. The experiment was laid out in randomized block design (RBD) with four replications. Rice cultivar Swarna (MTU 7029) was grown in *kharif* season and Lalat in *rabi* season of every year. Twenty-five days old rice seedlings were transplanted at a spacing of 20 cm × 10 cm with 2-3 seedlings per hill to puddled field in both the seasons. Nitrogen (N) was applied in three splits i.e. 25% at puddling as basal, 50% topdressing at 18 days after transplanting and 25% topdressing at panicle initiation stage. Entire dose of phosphorus (P) was applied during puddling as basal and potassium (K) was applied in two splits, 50% at puddling as basal and 50% topdressing at panicle initiation (PI) stage. Entire FYM (5 t ha^{-1} $season^{-1}$) was applied at the time of puddling. FYM has been added @ 5 t ha^{-1} in each season in T_5 and T_6. Lime @ 1 t ha^{-1} in each season has been applied in T_6 and T_{11} at the time of land preparation. Zn has been applied as Zinc oxide @ 0.4% solution seedling root dipping in T_4, T_7 and T_8. Borax was foliar sprayed twice as a source of boron @0.25% solution in T_7. Gypsum was applied to supply sulphur @ 30 kg ha^{-1} in T_8. Necessary uniform intercultural, water management and plant protection measures were undertaken in general until the crop was matured for harvesting. Before harvest of crop grain yield was monitored through crop cutting.

2.3 Soil Sample Collection, Processing and Analysis

Individual soil samples from each plot were collected from surface downwards up to 75 cm depth at an interval of 15 cm i.e.,0-15, 15-30, 30-45, 45-60 and 60-75 cm after harvest of rice crop in the year 2015 through profile digging. Immediately after collection, the soil samples were air dried, ground and passed through a 2 mm sieve and analyzed for pH, EC, soil organic C. The pH was determined in 1:2.5 soil: water ratio with the help of a glass electrode on microprocessor-based pH meter [6]. Electrical conductivity of the soil was measured in 1:2.5 soil: water suspension at 25^0C with digital microprocessor-based conductivity meter [7]. The organic carbon content in the soil was determined by following the modified Walkley and Black [8] method as described by Jackson [6]. Particle size distribution was determined with the help of ASTM No.1 152H-Type standard hydrometer with Bouyoucous scale in g L^{-1} as per the procedure given by Piper [9].

2.4 Statistical Analysis

The experiment has been laid out in Randomized Complete Block Design with 12 treatments and 4 replications. Analysis of variance has been conducted to test the overall significance of difference between the treatments.

Null hypothesis, H_0: all the treatment means are identical

Alternate Hypothesis, H_1: at least one pair of treatment mean differ significantly.

Test statistics for the treatment, $F=\frac{TMS}{EMS}$

If the p value of F is <0.05, then F is considered to be significant and H_0 is rejected.

If F is found to be significant, then Least Significance Difference (LSD) test is conducted (at α=0.05) to test the significance of difference between each pair of treatment [10].

Simple linear regression analysis of was carried out between yield and sustainability with basic soil properties using the data analysis tool of MS Excel.

3. RESULTS AND DISCUSSION

3.1 Soil pH

The data in respect of the pH at surface and sub-surface depth of soil as influenced by long-term application of different fertilizers, manures and amendment combinations is presented in Table 1. After 10 years or 20 cropping cycles, the pH was found to decline in all the fertilized treatments except the treatments that received FYM and/ or lime in addition to NPK. These amendments resisted the pH drop and maintained the pH slightly above the initial pH. The soil pH at surface layer thus varied significantly.

Among the treatments lowest pH of 4.84 was registered under 100 % N treatment while the highest pH of 5.96 was recorded in 100% NPK +Lime, which was at par with 100% NPK + FYM and 100% NPK+ FYM + lime. Thus, integration of FYM with recommended dose of fertilizers either alone or inclusion of lime had significantly higher pH than 100% NPK and control. In the sub-soil the pH of all the treatments found to increase up to 60 cm (Fig .1); the reason for higher pH in subsoil as compared to surface soil might be attributed to higher amounts of clay as well as basic cations in lower layers [11]. Similar observation was also made by Thakur et al [12]; Sime [13]; Sharma [14] and Bhatt [15] from long-term fertilized plots.

3.2 Electrical Conductivity

Data presented in Table 2 depicts that application of nutrients through fertilizer alone and along with FYM had non-significant influence on soil EC at surface as well as sub-soil after harvest of 20th crop cycle.

The lowest electrical conductivity was recorded in control in both surface and sub-surface soil while the highest electrical conductivity was recorded with the treatment NPK+FYM+ lime plot. Addition of fertilizer increased accumulation of salt in soil which contributed to increase in electrical conductivity of soil [4]. The reason for relatively higher soluble salt contents observed in the FYM treated fertilizers could be attributed to the release of basic cations from the materials and subsequent formation of some of the soluble salts of those ions. The present study was in conformity with the results of Bhriguvamshi [16] and Ahmed [17]. The electrical conductivity value increased in all treatments due to continuous fertilizer use under intensive cropping [13]. Highest salt accumulation was observed in the bottom most layer (60-75 cm) (Fig. 2).

3.3 Soil Organic Carbon

An application of inorganic fertilizer at varying levels alone or in combination with FYM had significant influence on change in soil organic carbon content after continuous rice-rice cropping system for 10 years (Table 3 and Fig. 3).

Table 1. Effect of long-term manurial practices on soil reaction at different depths after 20 cropping cycles of rice

Treatments		pH				
		Soil depth (cm)				
		0-15	15-30	30-45	45-60	60-75
T-1	100% PK	5.44	6.51	8.08	8.28	8.17
T-2	100% NPK	5.54	6.70	7.65	8.18	8.01
T-3	150% NPK	5.62	6.74	7.58	7.72	7.43
T-4	100% NPK + Zn	5.64	6.81	7.39	8.13	7.51
T-5	100% NPK +FYM	5.86	7.12	8.05	8.16	7.97
T-6	100% NPK +lime +FYM	5.92	7.26	8.23	8.34	8.01
T-7	100% NPK +B +Zn	5.50	6.62	7.73	8.00	7.36
T-8	100% NPK S+ Zn	5.42	6.64	8.24	8.44	8.06
T-9	100%N	4.84	6.56	7.78	8.12	7.54
T-10	100% NP	5.11	6.65	7.80	8.15	7.39
T-11	100 % NPK +Lime	5.96	7.16	8.25	8.39	7.99
T-12	Control	5.42	6.01	7.87	7.79	7.76
$CD_{(0.05)}$		0.34	0.46	0.40	0.26	0.21

Initial (0-15 cm): 5.80

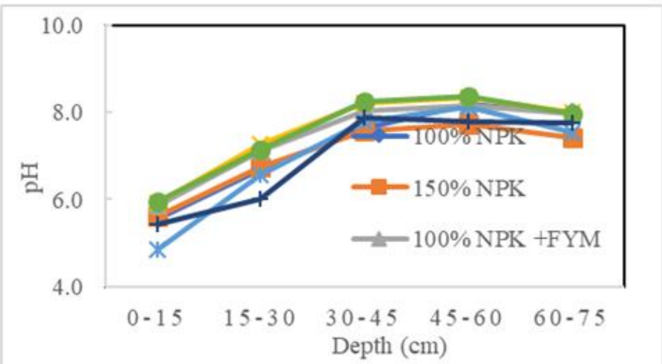


Fig. 1. Effect of long-term manurial practices on soil reaction at different depths under rice-rice intensive cropping system

Table 2. Effect of long-term manurial practices on soil electrical conductivity at different depths after 20 cropping cycles of rice

Treatments		Electrical conductivity (d S m^{-1}) Soil depth (cm)				
		0-15	15-30	30-45	45-60	60-75
T-1	100% PK	0.108	0.088	0.133	0.158	0.293
T-2	100% NPK	0.133	0.128	0.148	0.168	0.323
T-3	150% NPK	0.138	0.132	0.145	0.168	0.333
T-4	100% NPK + Zn	0.115	0.112	0.138	0.155	0.340
T-5	100% NPK +FYM	0.205	0.147	0.168	0.185	0.358
T-6	100% NPK +lime +FYM	0.208	0.178	0.178	0.198	0.418
T-7	100% NPK +B +Zn	0.155	0.138	0.143	0.145	0.350
T-8	100% NPK S+ Zn	0.180	0.150	0.165	0.208	0.365
T-9	100%N	0.138	0.123	0.143	0.185	0.275
T-10	100% NP	0.120	0.098	0.118	0.160	0.240
T-11	100 % NPK +Lime	0.125	0.118	0.150	0.165	0.263
T-12	Control	0.093	0.088	0.138	0.143	0.150
CD $_{(0.05)}$		0.03	0.02	0.04	0.04	0.08

Initial (0-15 cm): 0.12

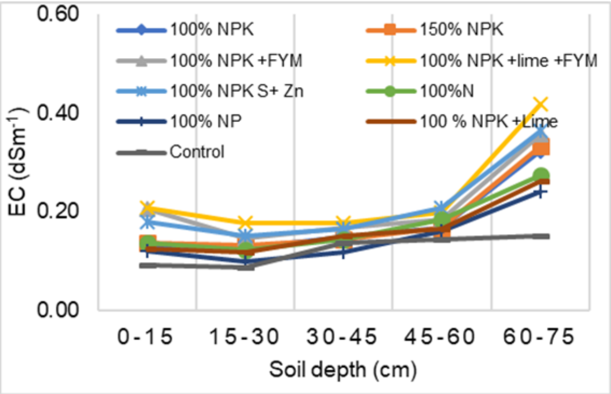


Fig. 2. Effect of long-term manurial practices on electrical conductivity at different depths under rice-rice intensive cropping system

Table 3. Effect of long-term manurial practices on soil organic carbon content at different depths after 20 cropping cycles of rice

Treatments		SOC (g kg^{-1}) Soil depth (cm)				
		0-15	15-30	30-45	45-60	60-75
T-1	100% PK	4.20	3.93	1.22	1.13	0.68
T-2	100% NPK	4.67	4.27	1.28	1.11	0.8
T-3	150% NPK	5.05	4.35	1.32	1.18	0.98
T-4	100% NPK + Zn	4.92	4.52	1.49	1.19	0.85
T-5	100% NPK +FYM	6.29	5.77	2.12	2.08	1.5
T-6	100% NPK +lime +FYM	6.05	5.47	2.07	1.76	1.21
T-7	100% NPK +B +Zn	4.97	4.54	1.56	1.23	0.87
T-8	100% NPK S+ Zn	5.21	4.83	1.7	1.56	1.02
T-9	100%N	4.22	3.67	1.06	0.92	0.7
T-10	100% NP	4.47	3.89	1.14	0.98	0.77
T-11	100 % NPK +Lime	5.86	5.38	1.76	1.55	1.15
T-12	Control	3.12	2.69	0.92	0.86	0.62
CD $_{(0.05)}$		0.57	0.48	0.20	0.17	0.11

Initial (0-15 cm) 4.3

In the surface soil it varied from 3.12 to 6.29 g kg^{-1}. Non-application of fertilizer/FYM significantly decreased soil organic carbon content in control both in the surface and sub-surface soil layers, whereas, substantial build-up in the organic carbon content occurred under NPK+FYM, NPK+lime +FYM and NPK+lime treatments. The increase in SOC content under integrated use of fertilizers and organic manure treatments might have been due to direct incorporation of organic matter, better root growth and more plant residue addition resulting in increased soil organic carbon content. These results are in conformity with the finding of Singh et al*.* [18]; Jadhao et al*.* [19]; Ravankar et al. [20] ; Mishra et al*.* [21] who reported the enhanced soil organic carbon status after ten years of continuous rice-wheat cropping under varying fertilizer and manure treatment in *Mollisols* at Pantnagar. The maximum increase in soil organic carbon content was observed with integrated use of inorganic fertilizers (N+P+K) and organic manure in rice-wheat cropping system in long-term experiment [22,23]. With depth the content decreased slightly up to second layer & sharply in the third layer. Shah et al. [24] also reported lower SOC values in the sub-soil layers (40-60, 60-80 and 80-100 cm) compared to top soil. This reduction may be due to roots in the Ap sub superficial horizon (Shahbaz et al., 2017). This depth-dependent decrease in total SOC might also be attributable to the increased SOC mineralization and SOC output due to continuous tillage [25,26] management at the experimental site.

3.4 Clay Content

The clay content in the profile varied from 6.7 to 35.8% (Table 4). The clay content increased with increase in depth in the profile. Similar trend was also reported in the long-term fertilizer experiment under rice-rice cropping system in an acidic laterite soil [27].

3.5 Correlation between Basic Soil Properties for Different Depths

Relationship among pH, EC, SOC and clay content of various layers is presented in terms of correlation coefficient in Table 5 & 6. Results showed that pH of 15-30 cm has significant correlation with EC (r=0.616*) but pH of first 3 layers have significant correlation with SOC (r=0.699*, 0.935** & 0.500*).

3.6 Relationship of Lower Layer with Surface Soil

The relationship of lower layer with surface layer for different parameters has been carried out by linear regression equation (Table 7). From the results it is found that the pH, EC and clay content of 2nd layer, 15-30 cm have significant correlation with surface layer (r=0.662*, 0.899* & 0.626*). However, lower layers beyond 30 cm depth have very poor correlation with surface layer for these three properties.

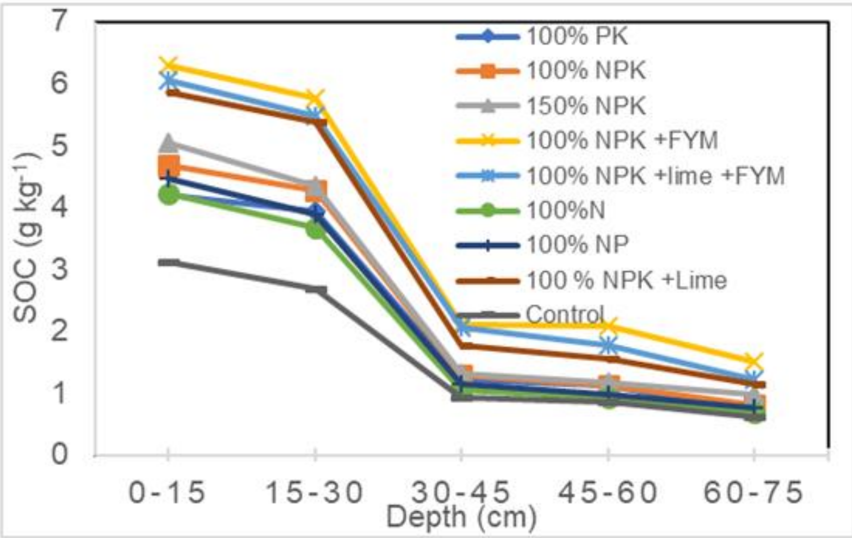


Fig. 3. Effect of long-term manurial practices on SOC at different depths under rice-rice intensive cropping system

Table 4. Effect of long-term manurial practices on clay content at different depths under rice-rice intensive cropping system

Treatments		Clay (%)				
		Soil depth (cm)				
		0-15	15-30	30-45	45-60	60-75
T-1	100% PK	9.9	18.1	28.6	35.2	35.8
T-2	100% NPK	10.9	16.3	19.8	25.4	33.6
T-3	150% NPK	9.2	19.1	20.7	23.8	28.9
T-4	100% NPK + Zn	8.3	11.1	20.2	31.8	34.2
T-5	100% NPK +FYM	6.7	9.3	19.3	24.4	28.6
T-6	100% NPK +lime +FYM	9.4	12.8	18.8	25.4	31.6
T-7	100% NPK +B +Zn	8.4	16.4	24.3	30.4	35.3
T-8	100% NPK S+ Zn	7.4	16.2	29.6	35.9	34.6
T-9	100%N	8.6	8.1	21.0	23.8	28.5
T-10	100% NP	6.9	11.7	17.3	29.4	34.3
T-11	100 % NPK +Lime	8.9	11.0	13.2	23.3	33.2
T-12	Control	7.6	15.3	15.6	22.6	31.5
$CD_{(0.05)}$		1.97	2.25	3.31	5.71	6.58

Initial (0-15 cm): 17

Table 5. Correlation between basic soil properties (pH and EC) for different depths

Depths	pH					EC				
	0-15 cm	15-30 cm	30-45 cm	45-60 cm	60-75 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm	60-75 cm
pH	-	-	-	-	-	0.096	0.616*	0.161	0.387	-0.032
SOC	0.699*	0.935**	0.500*	0.490	0.317	0.582*	0.738*	0.341	0.329	0.343
EC	-	-	-	-	-	-	-	-	-	-
Clay	0.590*	-0.254	0.087	0.426	0.141	0.110	0.060	0.228	0.187	0.101

Table 6. Correlation between basic soil properties (SOC and clay content) for different depths

Depths	SOC					Clay				
	0-15 cm	15-30 cm	30-45 cm	45-60 cm	60-75 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm	60-75 cm
pH	-	-	-	-	-	-	-	-	-	-
SOC	-	-	-	-	-	0.575*	-0.062	0.0067	-0.022	-0.434
EC	-	-	-	-	-	-	-	-	-	-
Clay	-	-	-	-	-	-	-	-	-	-

The relationship with clay content is significant only in top layer (r=0.590). SOC and clay have significant correlation only with surface layer (r= 0.575*) but very poor correlation in bottom layers.*
*** significant at 0.01 level * significant at 0.05 level*

Table 7. Relationship of basic soil properties of lower depths with surface layer in terms of correlation coefficient (r)

Bottom layers (15-75 cm)	pH	EC	SOC	Clay
	Surface layer (0-15 cm)			
15-30 cm	0.662*	0.899**	0.992**	0.626*
30-45 cm	0.318	0.407	0.944**	-0.006
45-60 cm	0.205	0.571	0.906**	-0.262
60-75 cm	0.430	0.564	0.932**	-0.360

*** significant at 0.01 level * significant at 0.05 level*

The SOC content decreased with depth. In contrast to pH and EC, the SOC content of all the bottom layers up to 75 cm had strong correlation (r =0.992**, 0.944**, 0.906** & 0.932**) with the SOC of surface layer with surface layer.

3.7 Grain Yield

The fertilizer treatments comprising fertilizer alone or combination with FYM/soil amendment had significant effect on grain yield of rice (Table 8) in both *rabi* and *kharif* season. Perusal of results in grain yield revealed that there was a significant variation among the treatments. In both the seasons studied, *kharif*, 2015 & *rabi*, 2015-16, the highest grain yield was recorded in the treatment 100%NPK+FYM which was at par with 100%NPK+FYM+lime. This may be attributed to better utilization of applied nutrients through the activities of greater population of soil micro-organisms which caused more nutrient transformation and also release of nutrients from organic sources that influenced more nutrient availability to the crop plants as well as the potential for higher production. Moreover, organic manures also supply growth promoting substances like enzymes and hormones [28]. Similar results were reported by Kandeshwari et al. [29]. Hence, integrated use of organic and inorganic fertilizers can make important contribution for increasing and sustaining rice production. This was also evidenced by studies of Jayajothi and Nalliah Durai Raj [30] and Nayak et al. [31].

Super optimal dose of NPK i.e. 150% NPK produced significantly higher yield (46.6 q ha^{-1} in *kharif* season & 48.3 q ha^{-1} in *rabi* season) than recommended dose i.e. 100% NPK (41.80 q ha^{-1} in *kharif* season & 31.9 q ha^{-1} in *rabi* season). The lowest grain yield (21.95 q ha^{-1} in *kharif* season & 15.3 q ha^{-1} in *rabi* season) was recorded in control. Application of Zn, Zn +S and Zn + B did not have any significant effect on grain yield.

3.8 Effect of Soil pH, SOC & Clay Content of Bottom Layers on Grain Yield

Effect of important soil properties studied in this investigation has been presented in regression graphs (Fig. 4 a-d).

Values/content of pH, EC, SOC and clay in different layers was found to contribute differentially to variation in grain yield: content of SOC of all the 5 layers (0-15 cm, 15-30 cm, 30-45 cm, 45-60 cm and 60-75 cm) could significantly explain the variation in grain yield (R^2=0.858, 0.795, 0.706, 0.641 & 0.753). It is due to strong correlation of bottom layer. The percent variation in yield explained by the SOC content thus ranged from 64.1 to 85.8 per cent with highest recorded in surface layer that decreased with depth. In contrast, pH, EC and clay content of all the layers failed to explain much variation in grain yield under the present situation of study. However, the results reveal that only the second layer (15-30 cm) salt concentration and pH could explain the variation in grain yield. The variation due to pH & EC of 2nd layer amounts to 75.9 & 62.3%, respectively. Clay content of top layer only contributes to the 33.9% variation in yield.

Table 8. Effect of long-term manurial practices on yield of rice after twenty cycles under rice-rice cropping system

Treatments		Kharif season Grain yield (q ha^{-1})	Rabi season Grain yield (q ha^{-1})	System yield (q ha^{-1})	Sustainable Yield Index (SYI) of the system
T-1	100% PK	32.80	25.3	58.1	0.43
T-2	100% NPK	41.80	31.9	73.7	0.45
T-3	150% NPK	46.60	48.3	94.9	0.47
T-4	100% NPK + Zn	45.05	32.3	77.3	0.45
T-5	100% NPK +FYM	51.58	52.5	104.1	0.54
T-6	100% NPK +lime +FYM	49.15	51.7	100.8	0.53
T-7	100% NPK +B +Zn	45.45	32	77.5	0.46
T-8	100% NPK S+ Zn	45.38	33	78.4	0.44
T-9	100%N	35.50	23.9	59.4	0.38
T-10	100% NP	40.90	28.8	69.7	0.41
T-11	100 % NPK +Lime	43.60	35.9	79.5	0.45
T-12	Control	21.95	15.3	37.3	0.20
	CD $_{(0.05)}$	4.83	5.28	3.37	-

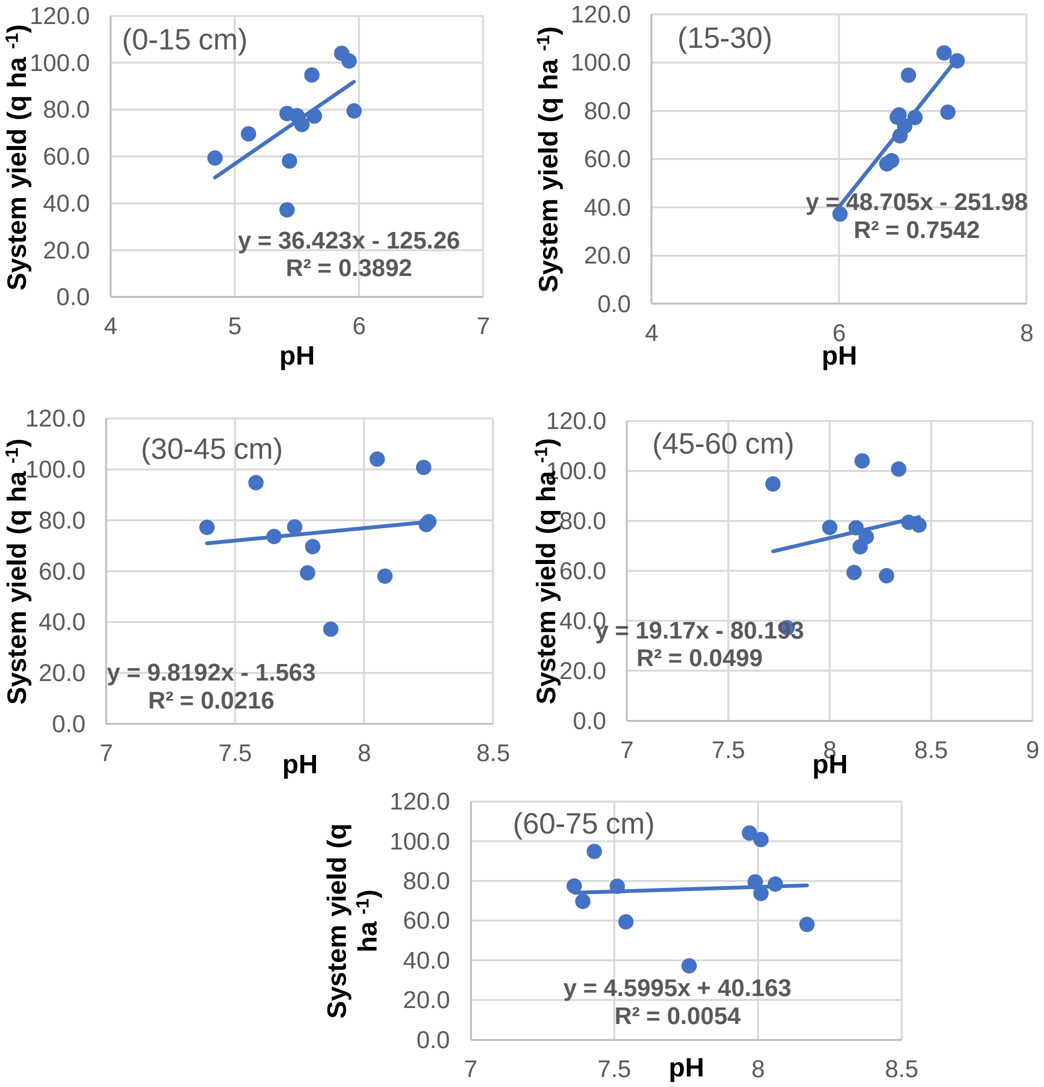
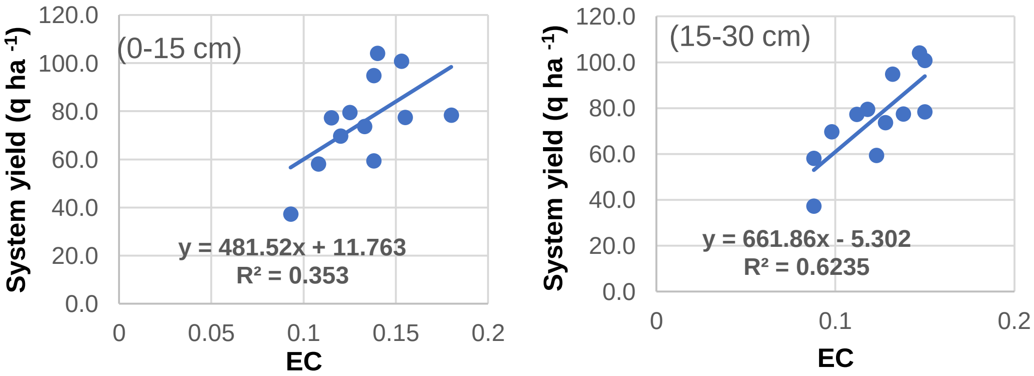


Fig. 4. (a) Contribution of pH towards explaining variability in system yield



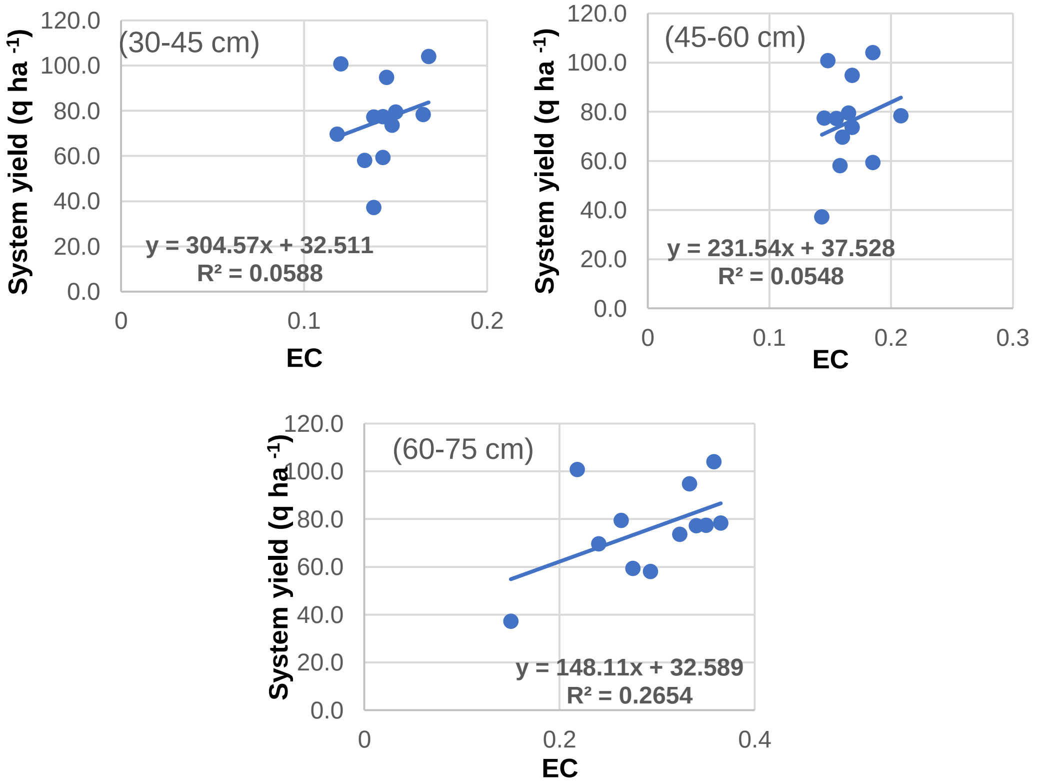
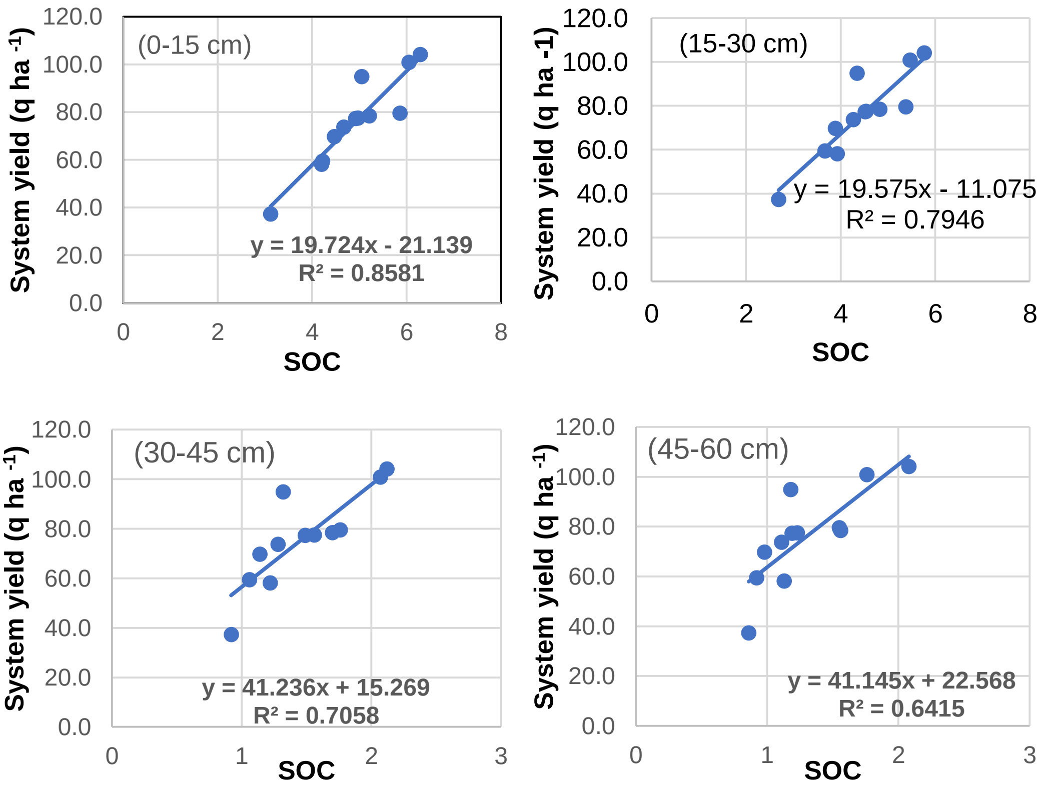


Fig. 4. (b) Contribution of EC towards explaining variability in system yield



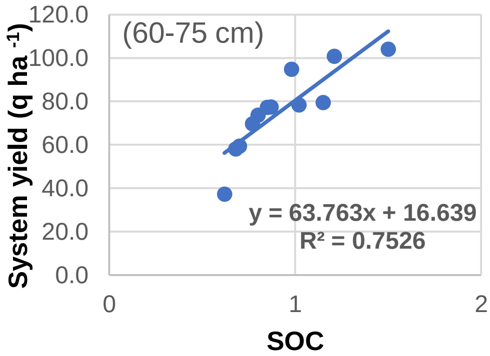


Fig. 4. (c) Contribution of SOC towards explaining variability in system yield

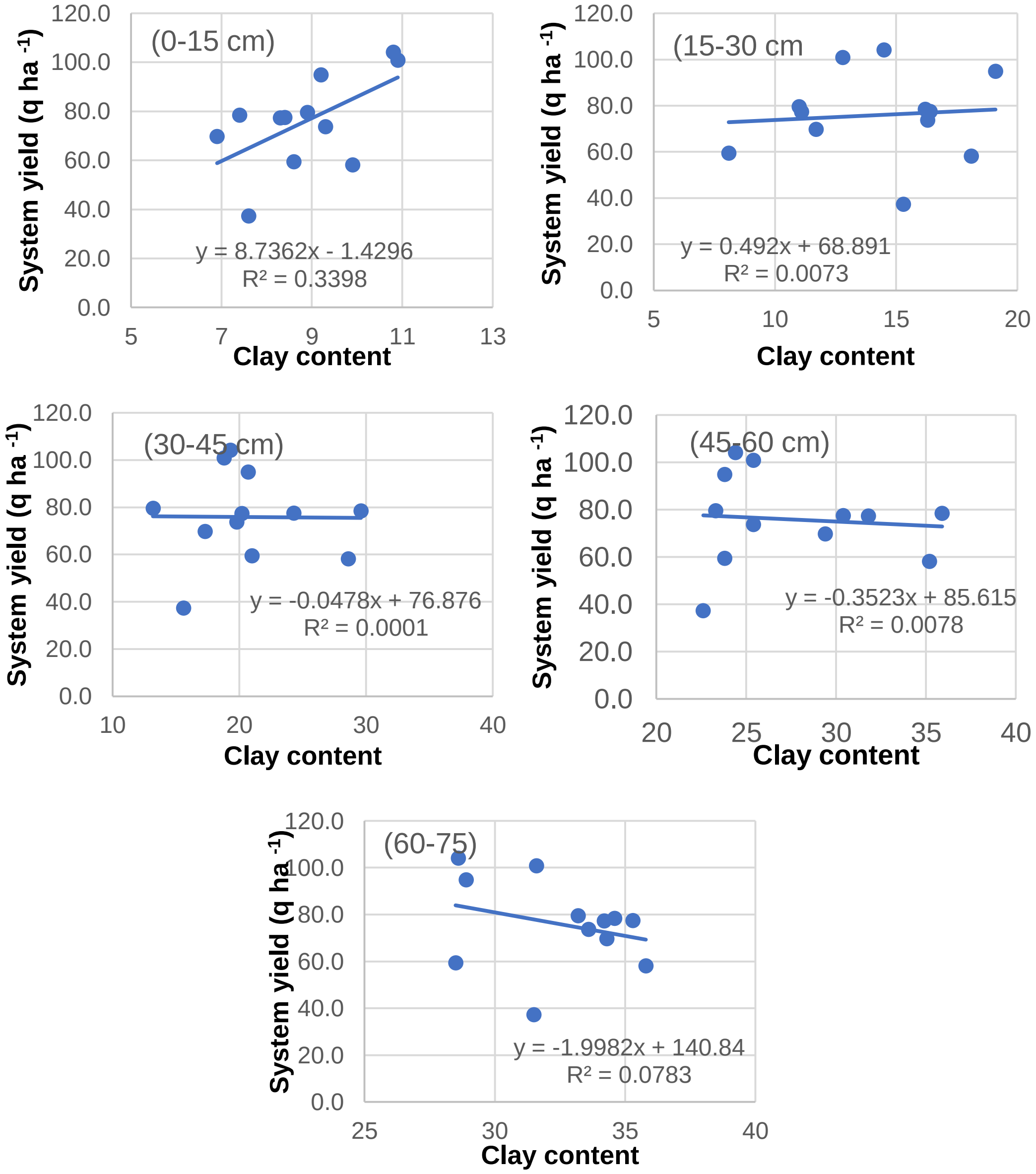


Fig. 4. (d) Contribution of clay content towards explaining variability in system yield

Table 9. Extent of variation in sustainability explained by the basic soil characteristics for different layers

Layers (cm)	Coefficient of variance (R^2)			
	Sustainability			
	SOC	pH	EC	Clay
0-15	0.787	0.261	0.336	0.388
15-30	0.785	0.756	0.479	0.004
30-45	0.619	0.025	0.033	0.039
45-60	0.530	0.191	0.060	0.024
60-75	0.530	0.029	0.403	0.001

3.9 Effect of Soil pH, SOC & Clay Content of Bottom Layers to Sustainability

Similar to grain yield all the 4 parameters such as: SOC, pH, EC and Clay also had significant effect on yield sustainability. The SOC content of all the 5 layers has strong relationship with sustainability with highest explained by top soil. The SOC could explain 53.0 to 78.7 % variation in sustainability (Table 9). The per cent variation in sustainability due to pH ranged between 2.92 to 75.6 per cent with highest variation explained by the pH of 15-30 cm. similarly the EC of different layers could explain 3.3 to 47.9% variation in sustainability with highest measured in 15-30 cm layer followed by 60-75 cm layer. On the other hand, clay content of surface layer explained maximum variation of 38.8% contribution. Contribution of Clay content of lower layers are insignificant.

4. CONCLUSION

Long-term use of inorganic fertilizers and organic manure (FYM) found superior to sole application of inorganic fertilizers to sustain the crop productivity and maintain soil fertility. Application of chemical fertilizers alone caused decrease in pH. But its integration with FYM and / or lime resisted the drop in pH. There was significant increase in pH with depth, but followed the same trend as the surface layer with respect to the effect of treatments. More accumulation of salt was found at 60-75 cm layer with highest recorded in 100% NPK + FYM treatment. With 20 cropping cycles the soil organic carbon content of all fertilized plots of surface layer increased by 0.17 to 2.09 g kg^{-1} with highest recorded in FYM amended treatment. With depth, the content decreased slightly up to second layer & sharply in the third layer. The treatments did not have any significant effect on surface soil clay content which showed an increasing trend with depth irrespective of treatments. The FYM amended plot had lower clay content in the lower layers which might be due to retention of clay in aggregates in the surface layer. The SOC content of all the layers however had significant correlation with the grain yield. SOC could explain 64.1 to 85.8% variation in grain yield. But on the other hand, pH and EC only of 2nd layer explained more variation than surface layer. Among the parameters studied, SOC of all the layers, pH & EC of 15-30 cm could explain maximum variation in both yield and sustainability. Lower layer properties also governed the soil fertility of surface layer and in turn the productivity and sustainability of wet land rice-rice cropping system in sub -tropical ecosystem.

ACKNOWLEDGEMENTS

The authors highly acknowledge the use of experimental field of AICRP on LTFE (ICAR) at Bhubaneswar and support of Department of Soil Science and Agricultural Chemistry, OUAT and Krishi Vigyan Kendra (ICAR), Kandhamal, OUAT for undertaking the laboratory analysis required for the study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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