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

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 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.

Key words: [Long-term manuring, sub-soil, pH, EC, SOC, productivity, sustainability, rice-rice]

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 terms 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 study aimed at determining the impact of long-term manuring on some basic sub soil properties vis a vis surface soil and their relationship with crop yield and its sustainability in both rabi & kharif season.

2. MATERIAL 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, available N (Alkaline $KMnO_4$)187, available P (Olsen's)19.4 and available K (NH_4OAc)43.4 kg/ha, respectively. The DTPA extractable Fe, Mn, Zn and Cu were 33.0, 7.53, 1.80 and 3.15 mg/kg, respectively. Exchangeable cations Ca and Mg were 2.25cmol (p^{+}) kg^{-1}and 0.65cmol (p^{+}) kg^{-1}. The hot water-soluble boron was 0.46 mg/kg. 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 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^{0}C 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.

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						

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.

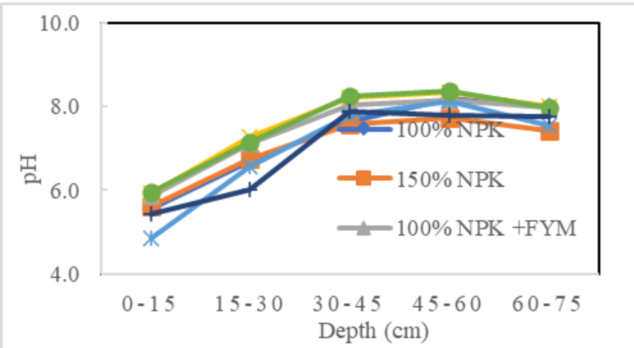

Fig.1 Effect of long-term manurial practices on soil reaction at different depths under rice-rice intensive

3.2. Electrical Conductivity

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

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				

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).

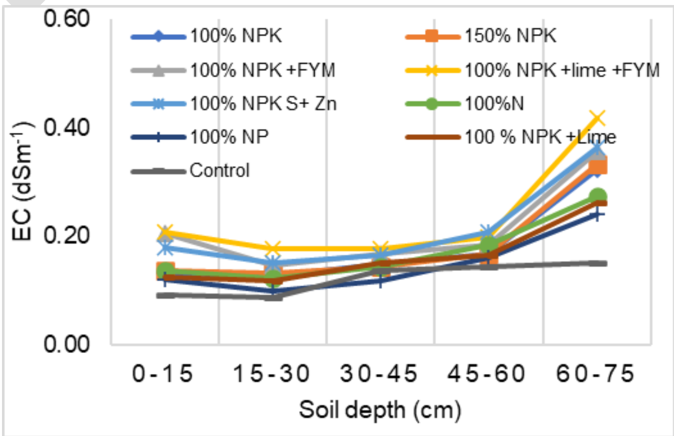

Fig.2 Effect of long-term manurial practices on electrical conductivity at different depths under rice-rice intensive cropping system

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 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] and 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]. With depth the content decreased slightly up to second layer & sharply in the third layer.

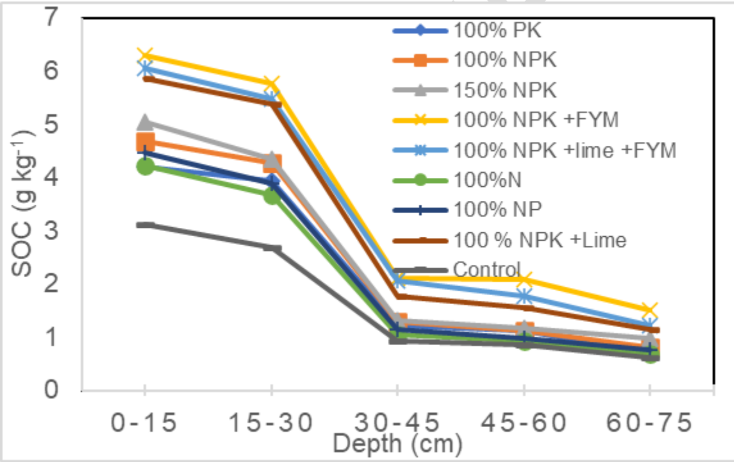

Fig.3 Effect of long-term manurial practices on SOC at different depths under rice-rice intensive cropping system

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 [23].

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		

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*).

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*

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.

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 [24]. Similar results were reported by Kandeshwari *et al*. [25]. 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 [26] and Nayak et al. [27].

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	-

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 2^{nd} layer amounts to 75.9 & 62.3%, respectively. Clay content of top layer only contributes to the 33.9% variation in yield.

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. Contribution of pH and EC to sustainability was more from the 2nd layer (15-30 cm) than other layers. Clay content only of surface layer contributed more (38.8) to yield variation than the bottom layers.

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

Layers (cm)	Sustainability (R^2)			
	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

2 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 remained same 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 cycle 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 significant correlation with the grain yield. SOC could explain 64.1 to 85.8 % variation in grain yield, highest. But on the other hand, pH and EC only of 2nd layer explained more higher 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.

Reference

1. [1] Mohanty S, Nayak AK, Kumar A, Tripathi R, Shahid M, Bhattacharyya P, Raja R, Panda BB. Carbon and nitrogen mineralization kinetics in soil of rice-rice system under long term application of chemical fertilizers and farmyard manure. *European Journal of Soil Biology*. 2013; 58 :113-121.
2. [2] Majhi P, Rout KK, Nanda G, Singh M. Soil quality for rice productivity under long-term fertilizer and manure application. *Communication in Soil Science and Plant Analysis*. 2019 ;50(11) :1330-43.
3. [3] Shivhare S, Rout KK, Mandal M, Samanta PK, Majhi P, Phonglosa A, Nayak R, Gupta AK. Thirteen Year Long Term Fertilization Effect on Soil Phosphorus Fractions of an Acid *Inceptisol* and their contribution to phosphorus uptake by a double crop of rice under sub-tropical climate. *International Journal of Plant & Soil Science*. 2022; 34 (18) : 7-25.
4. [4] Bhatt MK, Labanya R Joshi HC, Pareek N, Chandra KP Raverkar R. Long-term effects of inorganic fertilizers and FYM on soil chemical properties and yields of wheat under rice-wheat cropping system. *ENVIS Bulletin Himalayan Ecology*. 2017; 25 : 28-35.
5. [5] Winters E and Simonson RW. The subsoil, *Advances in Agronomy*. 1951; Vol.III.
6. [6] Jackson ML. Preentice Hall of India Pvt. Ltd., New Delhi.1967, 498-506.
7. [7] Bover CA, Wilcox LA. Soluble salts. In: Method of soil analysis. Part-2, Chemical and microbiological properties. *Agronomy Monograph*. ASA and SSSA, Madison, Wisconsin, USA. 1965; 433-451.
8. [8] Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*. 1934; 37 (1): 29-38.
9. [9] Piper CS. Soil and plant analysis: a laboratory manual of methods for the examination of soils and the determination of the inorganic constituents of plants. Adelaide: Univ. of Adelaide-A monography from the Waite Agricultural research Institute, Univ. of Adelaide, SA. 1945; 368.
10. [10] Gomez KA Gomez A A. Statistical Procedures for Agricultural Research, 2nd ed. Wiley - Interscience, New York. 1984
11. [11] Divya M, Jagadesh BR, Srinivasa DK, Yogesh S. Effect of long-term soil fertilizer application on forms and distribution of potassium in soil under rice-cowpea cropping system. *An Asian Journal of Soil Science.* 2016; 11(1) : 9-19.
12. [12] Thakur R, Sawarkar SD, Kauraw DL, Singh M. Effect of inorganic and organic sources on nutrients availability in a *Vertisol*. *Agropedology.* 2010; 20 (1) : 53-59.
13. [13] Sime T. Long term effect of fertilizers and manures on the availability and uptake of calcium, magnesium and sulphur by wheat in a *Mollisol*. Thesis, Master of Science in Agriculture (Soil Science), G.B.P.U.A. & T. Pantnagar. 2001; 5-19.
14. [14] Sharma M. Long term effect of fertilizers and manure on some physical properties of soil and nutrient uptake by wheat. Thesis, Master of Science in Agriculture (Soil Science), G. B. P. U. A. & T, Pantnagar. 2004; 15-20.
15. [15] Bhatt B. Effect of long-term fertilizer application in rice-wheat system on crop productivity and soil. Ph. D. Thesis submitted to G.B.P.U.A. & T., Pantnagar, India. 2012; 135-145.
16. [16] Bhriguvamshi SR. Long term effect of high doses of FYM on soil properties in crop yield. *J. Indian Soc. Soil Sci*. 1988; 36: 784-786.
17. [17] Ahmed Nasir Nasarath. Effect of long-term fertilizer application on soil physical properties, available nutrients, micro nutrients and uptake of nutrients, M.Sc. (Ag.) Thesis, University of Agricultural Sciences, Bangalore, Karnataka, India. 2010.
18. [18] Singh NP, Sachan RS, Pandey PC, Bisht PS. Effect of a decade long-term fertilizer and manure application on fertility and productivity of rice-wheat system in a *Mollisols*. *Journal of Indian Society of Soil Science*. 1999; 47(1) : 72-80.
19. [19] Jadhao SD, Mali DV, Kharche VK,Singh M, Bhoyar SM, Kadu PR, Wanjari RH, Sonune BA. Impact of continuous manuring and fertilization on changes in soil quality under sorghum-wheat sequence on a *Vertisols*. *Journal of the Indian society of Soil science*. 2019; 67 (1) : 55-64.
20. [20] Ravankar HN, Gajbhiye NN, Sarap PA. Effect of organic manures and inorganic fertilizers on yield and availability of nutrients under sorghum- wheat sequence. *Indian Journal of Agriculture Research*, 2005; 39 : 142-145.
21. [21] Mishra B, Sharma A, Singh SK, Prasad J, Singh BP. Influence of continuous application of amendments to maize-wheat cropping system on dynamics of soil microbial biomassin

Alfisol of Jharkhand. *Journal of the Indian Society of Soil Science*. 2008; 56: 71-75.
22. [22] Beri V, Sidhu BS, Bahl GS, Bhat AK. Nitrogen and phosphorus transformations as affected by crop residue management practices and their influence on crop yield. *Soil Use and Management*. 1995; 11(2): 51-54.
23. [23] Pattanayak SK. Effect of long term manure application to a medium land acid laterite on nutrient transformation and changes in some soil properties, Ph.D Thesis, IARI, New Delhi. 1992: 42-44.
24. [24] Yadav BK, Lourdura AC. Effect of Organic Manures and Panchagavya Spray on Yield attributes, Yield and Economics of Rice (*Oryza sativa* L.). *Crop Research*. 2006. 31(1): 1-5.
25. [25] Kandeshwari MS, Jeyaraman N. Evaluation of integrated nutrient management practices under system of rice intensification. *In. International Symposium on 100 years of Rice Science and Looking Beyond*. 2012; 2 : 523-524.
26. [26] Jeyajothi R, Nalliah Durai Raj S. Influence of Integrated Nutrient Management Practices on Yield and Yield Attributes, and Economics of Transplanted Rice (*Oryza sativa* L.) in South Zone of Tamil Nadu. *International Journal for Innovative Research in Science & Technology*. 2015; 1(11) : 462-467.
27. [27] Nayak AK, Gangwa B, Shukla AK, Mazumdar SP, Kumar A, Raja R, Kumar A, Kumar V, Rai PK, Mohan U. Long-term effect of different integrated nutrient management on soil organic carbon and its fractions and sustainability of rice-wheat system in Indo Gangetic Plains of India. *Field Crops Research.* 2012; 127: 129-139.

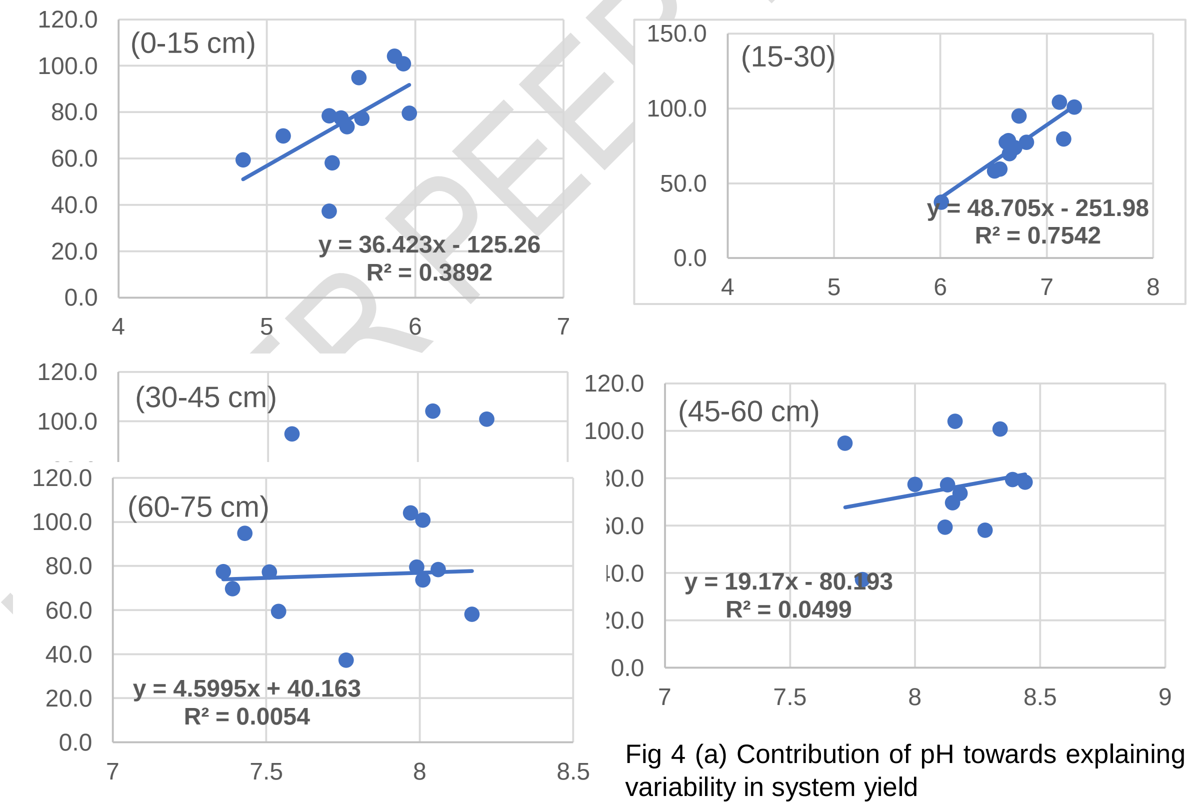

Fig 4 (a) Contribution of pH towards explaining variability in system yield

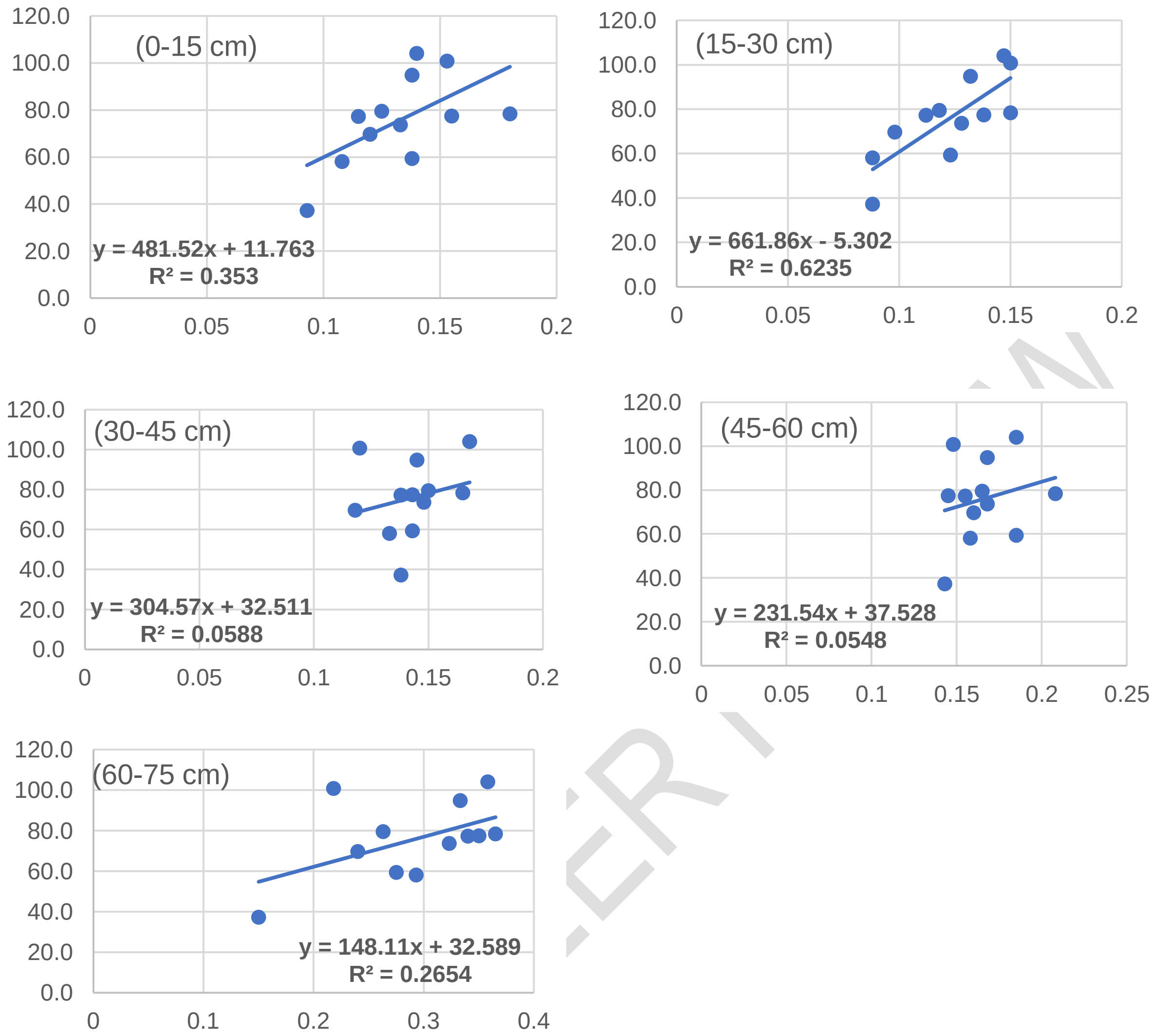

Fig 4 (b) Contribution of EC towards explaining variability in system yield

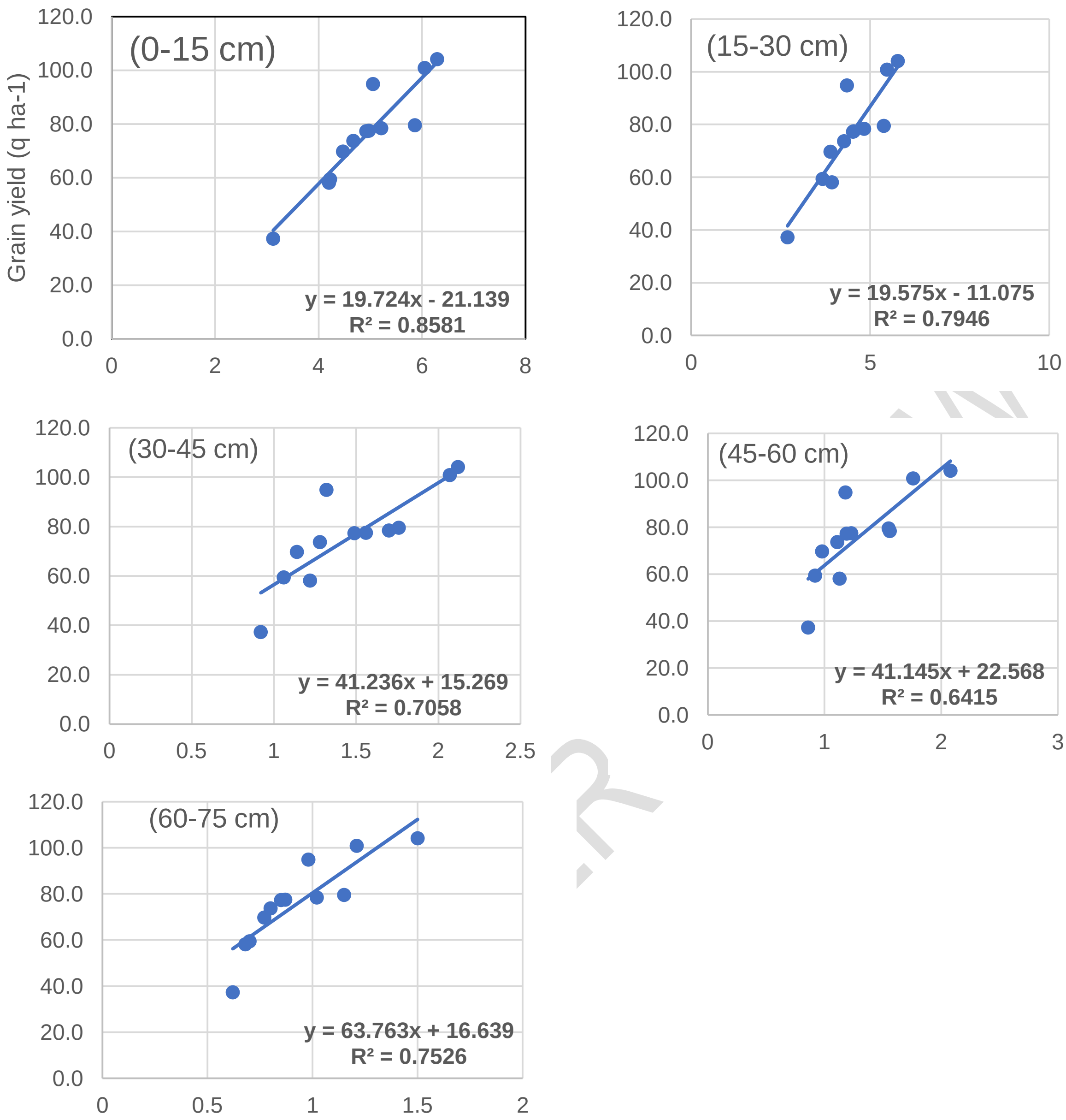

Fig 4 (c) Contribution of SOC towards explaining variability in system yield

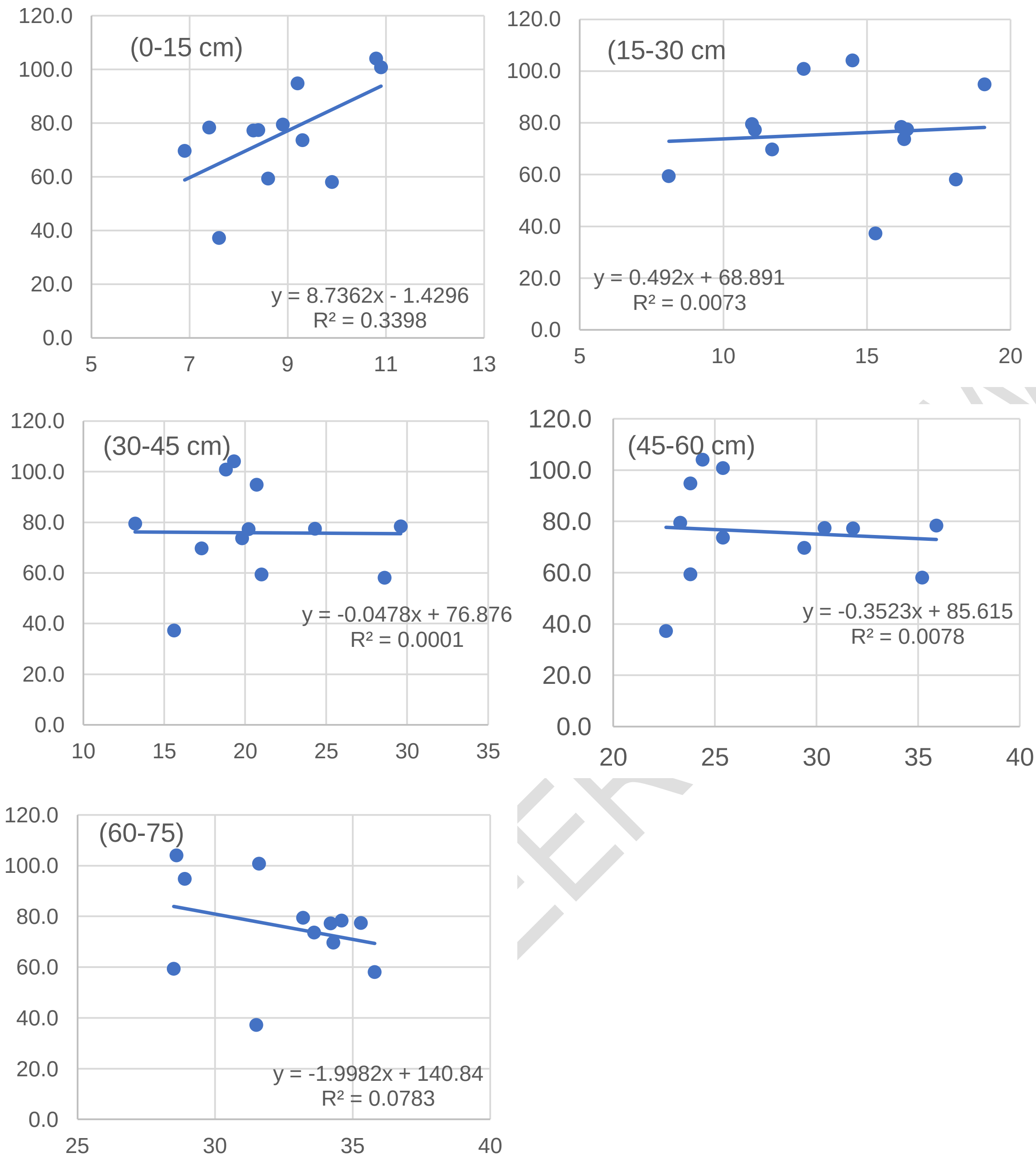

Fig 4 (d) Contribution of clay content towards explaining variability in system yield