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Long term effect of integrated nutrient management practices on soil organic carbon stock, sequestration and fractions in an acid upland Inceptisols under intensive cropping

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Abstract
The present investigation was carried out to study the long term effect of integrated nutrient management under cereal-vegetables-pulses cropping system on soil organic carbon at College of Agriculture, OUAT, Bhubaneswar. The treatments consisted of different combinations of inorganic fertilizers, organics (FYM and vermicompost), ameliorant (lime) and biofertilizers. At the end of 14th crop cycle (5 years) and 29th crop cycle (10 years), the effect of various treatments were studied. The results showed that organic carbon stock and build up was higher in the integrated treatments of STD with FYM/vermicompost, biofertiloizers and lime at both surface and sub-surface soil. Sole use of inorganics (STD) resulted in lower amount of soil organic carbon (SOC) sequestration. Integration of inorganics with organics resulted in improvement in SOC sequestration and further gain was observed in integration with organic, biofertilizers and lime. The amount of soil organic carbon sequestration (Mg C ha^{-1}) varied as control (0.89) < STD (1.24) < STD + VC (1.53) < STD + F (1.69) < STD + VC + BFs (2.76) < STD + F + BFs (2.96) < STD + F + L + BFs (3.31) < STD + VC + L + BFs (4.27) in 10 years of cropping. The SOC sequestration rate followed similar trend. Irrespective of INM practice and years of cropping very labile carbon fraction was most predominant followed by labile and less labile carbon fraction. Integrated treatment of STD with organics, biofertilizers and lime influenced the various soil organic carbon fractions much more compared to other treatments.

Keywords: Long term experiment, soil organic carbon stock, soc sequestration, intensive cropping, acid soil

Introduction
In India, from food security point of view sustainable and increased production of crops is very vital. Due to increasing population pressure, the demand for food, feed, fibre, fuel, pulses and oilseed products is rapidly increasing. To meet the future demand we would need better planning and resource management as well as intensification of crop production. Intensive cropping has high requirements for nutrients and may adversely affect crop production on long run and hence, appropriate nutrient management needs attention for sustainable soil productivity. Integration of chemical and organic sources and their efficient management have shown promising results not only in sustaining the productivity but also in maintaining soil health (Vijay Shankar Babu *et al.*, 2007) [13].
Soil organic carbon (SOC) is central to soil health and sustainability. It plays a crucial role in maintaining agricultural productivity by enhancing soil physical, chemical and biological properties (Stockman *et al.*, 2013) [12]. Increasing SOC stock by 1Mg C ha^{-1} in the root zone can increase crop yield by 15-33 kg ha^{-1} for wheat (Benbi and Chand, 2007) [14], 160 kg ha^{-1} for rice, 170 kg ha^{-1} for pearl millet, 13 kg ha^{-1} for groundnut, 18 kg ha^{-1} for lentil, 90 kg ha^{-1} for sorghum, 101 kg ha^{-1} for finger millet and 145 kg ha^{-1} for soybean (Srinivasarao *et al.*, 2013) [15]. Manure and fertilization can be recognized as important agricultural measures to restore the soil organic carbon pool to an optimum level (Lal *et al.*, 2016) [16].
In view of the projected climate change in near future and soil's role in mitigating atmospheric CO_2concentration, the management of soil organic carbon and soil health enhancement assumes great significance. Because of the potential of agro-ecosystems to absorb a large amount of atmospheric CO_2 through soil C sequestration, SOC management is recognized as a "Win-Win strategy" (Lal, 2002) [20]. The addition of organic sources improve the formation of macro aggregates and C storage inside the aggregates, which is protected from

decomposition (Benbi and Senapati, 2010) [17]. Crop residues returned to the soil provide substrate to soil organisms which help in soil organic matter turn over. Adoption of improved management practices such as residue recycling and integrated use of inorganic fertilizers and organic manures enhance nutrient use efficiency and crop biomass production, thereby increasing plant-mediated C input to soil (Benbi *et al.*, 2011) [18]. Many long term experiments have verified that both chemical fertilizers and manures could increase soil organic carbon but organic manure had larger influence (Hati *et al.*, 2007) [19].

Long term experiments are the primary source of information to determine the effect of cropping systems on soil quality attributes like organic carbon, inorganic carbon and total organic carbon content that are most sensitive to management of inputs and to ascertain the impact of long term use of integrated nutrient management on these attributes (Kharche *et al.*, 2013) [4].

Practically, very little information is available on long term effects of INM practices on soil organic carbon in acid upland *Inceptisols* of Odisha. Therefore, the present investigation was carried out to find out the effect of integrated nutrient management on soil organic carbon stock, sequestration and fractions and to identify the most suitable integrated nutrient management practice under an acid upland condition.

Materials and Methods

The present investigation 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 initiated during 2010 at College of Agriculture, Bhubaneswar (OUAT). The experimental site is located at 20°15’ N latitude and 85° 28’ E longitude at an altitude of 25.9m above mean sea level and hot and humid sub-tropical climate. The soil of the experimental site belongs to order Inceptisols (*VerticUstochrept*) and loamy sand texture having pH 5.14, EC 0.03 dSm^{-1}, organic carbon 3.91 g kg^{-1} soil; and available nitrogen (N), phosphorus (P) and potassium (K) were 207, 37 and 85 kg ha^{-1} respectively. There were eight treatments *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). Each treatment was replicated thrice in a randomized block design. 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 per cent 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.

At the end of 14th crop cycle (5 years) and 29th crop cycle (10 years), the long term effect of various treatments were studied. Standard agronomic practices were followed for all the crops. Crop residues were incorporated in situ in all the treatments. Soil samples from 0-15 cm and 15-30 cm depth were collected after 5 years of cropping (2010-2014) and 10 years of cropping (2015-2019) and were analysed for organic carbon content by wet oxidation method (Walkley and Black, 1934) [9]. Different fractions of organic carbon i.e., very labile, labile and less labile were estimated by a method described by Mandal *et al.* (2008) [10]. The undisturbed soil samples were collected from the plots using a tube core sampler and bulk density was determined following the method of Blake and Hartge (1986) [11]. The soil organic carbon stock was calculated as: soil organic carbon stock (MgC ha^{-1}) = SOC (%) x soil bulk density (Mg m^{-3}) x sampling depth (cm). Organic carbon sequestration (MgC ha^{-1} soil) = current SOC stock – Initial SOC stock.

Results and Discussion

Organic carbon stock and per cent C build up

The results of long term influence of INM practices on organic carbon stock and per cent carbon build up in surface and sub-surface soil have been presented in Table 1.

Table 1: Organic Carbon stock (Mg C ha^{-1}) in surface and sub-surface soil under the influence of long term INM practices

Treatments	Organic Carbon stock (Mg C ha^{-1} soil)									
	Surface soil (0-15 cm)					Sub-surface soil (15-30cm)				
	Initial	5 years	% carbon buildup over initial	10 years	carbon buildup over initial	Initial	5 years	% carbon buildup over initial	10 years	carbon buildup over initial
Control	10.32	10.74	4.07	11.21	8.62	9.21	9.34	1.41	9.88	7.28
STD	10.32	11.0	6.80	11.56	12.01	9.21	9.87	7.12	10.09	9.55
STD + F	10.32	11.09	7.46	12.01	16.38	9.21	10.05	9.12	10.43	13.24
STD +VC	10.32	11.11	7.66	11.85	14.83	9.21	10.09	9.55	10.54	14.44
STD + F + BFs	10.32	11.87	15.02	13.28	28.68	9.21	10.81	17.37	10.94	18.78
STD + VC + BFs	10.32	12.30	19.19	13.08	26.74	9.21	10.76	16.83	10.90	18.34
STD + F + L + BFs	10.32	12.50	21.12	13.63	32.07	9.21	10.85	17.81	11.00	19.43
STD + VC + L + BFs	10.32	12.81	24.13	14.59	41.38	9.21	10.95	18.89	11.73	27.36
LSD(P=0.05)		0.25		0.54			0.22		0.23	
CV (%)		8.0		9.0			7.0		8.0	

The results showed that the organic carbon stock at the start of the experiment in the surface and sub-surface soil was 10.32 and 9.21 Mg C ha^{-1} respectively. In the surface soil, due to intensive cropping (14 crop cycles) over 5 years resulted in organic carbon stock ranging from 10.74 Mg C ha^{-1} in control to 12.81 Mg C ha^{-1} in STD + VC + L + BFs treatment. There was significant variation in organic carbon stock in different treatments receiving FYM, vermicompost, lime and biofertilizers. Compared to sole STD treatment, all the integrated treatments had higher organic carbon stock. Treatments where STD was integrated with FYM or VC resulted in slightly higher carbon stock than sole STD.

However, integration of STD with FYM/VC + BFs and FYM / VC + L + BFs showed higher organic carbon stock to the tune of 12.50 to 12.81 Mg Cha^{-1}. The variation in organic carbon stock of surface soil resulted in differential buildup of carbon in different treatments. The per cent build up over initial soil was lowest in control (4.07 per cent) and highest in STD + VC + L + BFs treatment (24.13%). Sole STD treatment showed lower buildup of organic carbon (6.8 per cent). Treatments containing vermicompost showed higher C build up than FYM containing treatments.

In the surface soil, 10 years of intensive cropping (29 crop cycles), the INM treatments receiving organic manures (FYM/VC), biofertilizers and in-situ crop residue incorporation resulted in higher organic carbon stock compared to 5 years of intensive cropping.

The treatment receiving own crop residues and no external inputs (control) had lowest organic carbon stock (11.21 Mg C ha^{-1}) and the integrated treatment receiving STD + VC + L + BFs showed highest carbon stock (14.59 Mg C ha^{-1}). Just like the data in 5 years cropping, lower increase in carbon stock was observed in sole STD and STD + F/VC treatments and higher in STD + VC/F + L + BFs treatments. Data pertaining to per cent organic carbon build up over initial soil showed similar trend as that of 5 years cropping. With advances in year of cropping, there was cumulative buildup of organic carbon in the surface soil.

The gradual improvement of SOC stock under INM treatments with the advancement of year was possibly due to resultant effect of addition of organic manures and crop residues and carbon input excess the loss of SOC due to decomposition. Higher SOC build up in lime integrated treatments may be due to better root growth and biomass which added to SOC. Sole chemical fertilizer application showed lower SOC stock may be due to lower amount of carbon input. Long term application of chemical fertilizers could not maintain optimum soil carbon content (Rao *et al.*, 2017) [8]. Integrated nutrient management practices enhanced SOC stock has been reported by Singh *et al.* (2020) [3], Tripura *et al.* (2020) [2], Kafle *et al.* (2019) [7].

Sub-surface soil initial SOC stock of 9.21 Mg C ha^{-1} showed lower carbon stock compared to surface soil. After 5 years of intensive cropping the SOC stock was increased in all the treatments which ranged from 9.34 to 10.95 Mg C ha^{-1} and the per cent buildup of C was from 1.41 to 18.89 per cent. Like surface soil, higher SOC stock was observed in 10 years cropping than 5 years cropping in all the treatments.

Soil organic carbon sequestration

The data pertaining to 5 years and 10 years of long term intensive cropping on C sequestration in *Inceptisols* under different INM treatments has been presented in Table 2.

Table 2: Long term influence of INM treatments on SOC sequestration at surface and subsurface soil

Treatments	Organic Carbon sequestration (Mg C ha^{-1} soil)							
	Surface soil (0-15 cm)				Sub-surface soil (15-30cm)			
	5 years	Sequestration rate (Mg C ha^{-1}year^{-1})	10 years	Sequestration rate (Mg C ha^{-1}year^{-1})	5 years	Sequestration rate(Mg C ha^{-1}year^{-1})	10 years	Sequestration rate (Mg C ha^{-1}year^{-1})
Control	0.42	0.08	0.89	0.09	0.13	0.03	0.67	0.07
STD	0.68	0.14	1.24	0.12	0.66	0.13	0.88	0.09
STD + F	0.77	0.15	1.69	0.17	0.84	0.17	1.22	0.12
STD +VC	0.79	0.16	1.53	0.15	0.88	0.18	1.33	0.13
STD + F + BFs	1.55	0.31	2.96	0.30	1.60	0.32	1.73	0.17
STD + VC + BFs	1.98	0.40	2.76	0.28	1.55	0.31	1.69	0.17
STD + F + L + BFs	2.18	0.44	3.31	0.33	1.64	0.33	1.79	0.18
STD + VC + L + BFs	2.49	0.50	4.27	0.43	1.74	0.35	2.52	0.25

The various treatments resulted in sequestration of SOC, the magnitude being 0.42 Mg C ha^{-1} in control to 2.49 Mg C ha^{-1} in STD + VC + L + BFs during 5 years of cropping in the surface layer. Sole use of inorganics (STD) resulted in lower amount of SOC sequestration (0.68 Mg C ha^{-1}). Integration of inorganics (STD) with organics (FYM/vermicompost) resulted in improvement in SOC sequestration. However, further gain was observed in integration with organics, biofertilizers and lime. The amount of SOC sequestration of 5 years was in the following order: control < STD < STD + VC/F < STD + VC/F + BFs < STD + VC/F + L + BFs. Vermicompost applied treatments showed comparatively higher SOC sequestration over FYM applied treatments. The sequestration rate also varied maintaining the same trend. Highest sequestration rate was observed in STD + VC + L + BFs (0.50 Mg C ha^{-1}year^{-1}) treatment and lowest in control (0.08 Mg C ha^{-1} year $^{-1}$). Comparatively higher sequestration rate was maintained in STD integrated with organics, biofertilizers and lime (0.44 to 0.50 Mg C ha^{-1}year^{-1}).

The amount of SOC sequestered over 10 years of intensive cropping under different INM treatments varied between 0.89 and 4.27 Mg C ha^{-1}. Higher amount of SOC was sequestrated in all the treatments compared to 5 years of intensive cropping. Compared to 5 years of cropping a reverse trend was observed i.e., FYM applied treatments showed higher SOC sequestration than vermicompost applied treatments. The SOC sequestration rate over 10 years of cropping followed similar trend as that of SOC sequestration amount.

Soil organic carbon sequestration is a homeostasis of SOC decomposition and carbon input. Sole application of inorganic fertilizers maintained lower level of SOC sequestration which may be due to low carbon inputs from roots and crop residues and higher rate of decomposition. Integrated nutrient management practices added higher amounts of carbon inputs through crop residue recycling, organic manure application, higher root and plant biomass resulting in higher SOC sequestration. Similar results were also reported by Kharche *et al.* (2013) [4], Singh *et al.* (2019) [5] and Benbi (2015) [6].

In the sub-surface soil, the amount of SOC sequestered was lower in all the treatments compared to surface soil over 5 years and 10 years of intensive cropping. Irrespective of the years of cropping, STD + F/VC + L +BFs treatments maintained higher SOC sequestration both in amount and rate.

Different treatments of organic carbon in surface soil

The results of long term effect of INM practices on various fractions of soil organic carbon in surface soil have been presented in Table 3.

Table 3: Change in different fractions of organic carbon in surface under the influence of long term INM practices

Treatments	Fraction of organic carbon in soil (g kg^{-1})											
	Total			Very labile			Labile			Less labile		
	Initial	5 years	10 years	Initial	5 years	10 years	Initial	5 years	10 years	Initial	5 years	10 years
Control	3.91	4.21	4.50	2.86	2.83	2.93	0.59	0.55	0.58	0.46	0.82	1.00
STD	3.91	4.13	4.48	2.86	3.20	2.55	0.59	0.74	0.64	0.46	1.00	1.29
STD + F	3.91	4.84	5.10	2.86	3.01	3.11	0.59	0.80	0.79	0.46	1.03	1.20
STD +VC	3.91	4.82	5.00	2.86	2.96	3.00	0.59	0.80	0.77	0.46	1.06	1.24
STD + F + BFs	3.91	5.90	5.92	2.86	3.61	3.56	0.59	0.84	0.88	0.46	1.45	1.48
STD + VC + BFs	3.91	5.94	5.98	2.86	3.73	3.58	0.59	0.81	0.88	0.46	1.40	1.52
STD + F + L + BFs	3.91	6.04	6.08	2.86	3.75	3.73	0.59	0.87	0.90	0.46	1.42	1.45
STD + VC + L + BFs	3.91	6.32	6.39	2.86	3.93	3.87	0.59	0.95	1.00	0.46	1.44	1.52
LSD(P=0.05)		0.70	0.76		0.17	0.40		0.07	0.11		0.38	0.19
CV (%)		7.0	8.0		8.0	6.0		9.0	8.0		7.0	7.0

The results showed that total organic carbon (g kg^{-1}soil) content of surface soil varied due to different treatments. Under both 5 years and 10 years of intensive cropping, all the integrated treatments showed higher total organic carbon compared to lone STD and control treatment. The content of total organic carbon in different treatments under both 5 years and 10 years of cropping followed the following trend; STD + VC/F + L + BFs > STD + VC/F + BFs > STD + VC/F > STD > control.

The results of long term influence of INM treatments on different fractions of soil organic carbon *viz*., very labile carbon (VL), labile carbon (L) and less labile carbon (LL) showed that irrespective of INM practice and years of cropping very labile carbon fraction was most predominant followed by less labile carbon and labile carbon fraction. All the fractions of organic carbon were significantly influenced by integrated nutrient management practices over STD and control.

The very labile carbon fraction in different treatments constituted 61.2 to 67.4 per cent of total organic carbon in 5 years of cropping and 56.9 to 61.4 per cent in 10 years of cropping. With advancement in year of cropping it was decreased slightly. The labile carbon fraction followed similar trend but the per cent composition was least i.e., varied between 13.1 to 16.6 per cent over the years of experimentation. However, the less labile fraction of organic carbon constituted the moderate per cent of total organic carbon. With increasing years of cropping, there was increase in less labile fraction.

Different fractions of organic carbon in sub-surface soil

The data pertaining to total organic carbon and its fractions in sub-surface (15-30 cm) layer under the influence of long term INM practices over 5 years and 10 years of cropping have been presented in Table 4.

Table 4: Change in different fractions of organic carbon in sub-surface (15-30 cm) layer under the influence of long term INM practices

Treatments	Fraction of organic carbon in soil (g kg^{-1})											
	Total			Very labile			Labile			Less labile		
	Initial	5 years	10 years	Initial	5 years	10 years	Initial	5 years	10 years	Initial	5 years	10 years
Control	3.61	3.67	3.78	1.74	1.70	1.93	0.93	1.01	0.90	0.94	0.96	0.95
STD	3.61	4.31	4.21	1.74	2.50	2.53	0.93	0.92	0.88	0.94	0.89	0.80
STD + F	3.61	4.38	4.68	1.74	2.45	2.82	0.93	0.99	0.91	0.94	0.94	0.95
STD +VC	3.61	4.37	4.67	1.74	2.44	2.88	0.93	0.96	0.94	0.94	0.97	0.86
STD + F + BFs	3.61	4.67	4.55	1.74	2.34	2.90	0.93	1.26	1.18	0.94	1.07	0.47
STD + VC + BFs	3.61	4.76	4.48	1.74	2.32	2.70	0.93	1.39	1.25	0.94	1.05	0.53
STD + F + L + BFs	3.61	5.65	5.75	1.74	2.65	3.05	0.93	1.32	0.81	0.94	1.68	1.90
STD + VC + L + BFs	3.61	5.71	5.88	1.74	2.74	3.00	0.93	1.33	1.06	0.94	1.64	1.82
LSD(P=0.05)		0.42	0.34		0.22	0.28		0.10	0.12		0.14	0.18
CV (%)		8.0	7.0		6.0	7.0		8.0	8.0		7.0	9.0

The data revealed that the total organic carbon content was less in initial soil compared to surface soil. There was gradual increase in total organic carbon in all the treatments irrespective of years of experimentation. Integrated application of lime along with FYM or VC, biofertilizers influenced the SOC content more.

Among the various fractions of SOC, the very labile fraction was the most predominant fraction followed by labile fraction and less labile fraction. With advancement in years of cropping there was gradual increase in very labile carbon fraction in all the treatments from the initial content. However, the labile and less labile carbon fractions showed gradual decrease. Irrespective of years of cropping, the integrated treatment of STD with organics (FYM/VC), lime and BFs influenced the various SOC fractions much more compared to other treatments. In the sub-surface soil layer very labile carbon fraction constituted 46.9 to 63.7 per cent whereas labile carbon constituted 14 to 29.2 per cent and less labile carbon constituted 10.3 to 33 per cent of respective total organic carbon under various INM treatments over 5 years and 10 years of intensive cropping.

Various fractions of organic carbon tended to decrease with depth (Dhamak *et al.*, 2020) [1]. Integrated nutrient management practices influenced SOC fractions significantly. Similar results have also been reported by Singh *et al.* (2020) [3] and Tripura *et al.* (2020) [2].

Conclusion

Long term application of STD with organics (FYM/vermicompost), biofertilizers and lime resulted in higher soil organic carbon stock and build up at both surface and subsurface soil. Sole inorganic fertilizers (STD) treatment showed slightly higher SOC stock and build up over initial soil with 10 years of intensive cropping. There was improvement in amount and rate of SOC sequestration through integration of inorganics with organics and further increase was observed in integration with organics, biofertilizers and lime.

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