International Journal of Environment and Climate Change

Volume 13, Issue 11, Page 2216-2224, 2023; Article no.IJECC.107721
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Effect of Nutrient Management Practices on Carbon Pools Following 13 Year of Cropping with Soybean (*Glycine max*) Based Cropping Systems in Vertisol of Central 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/IJECC/2023/v13i113384

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/107721

Original Research Article

Received: 24/08/2023
Accepted: 31/10/2023
Published: 03/11/2023

ABSTRACT

Organic manure application has its significant impact on the soil health. Low organic matter in tropical soils is a major factor contributing to their poor productivity. Soil properties have been continuously influenced by the management practices and land uses, in which latter one has been,

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identified as profound influence on soil properties especially on soil organic carbon. A thirteen year experiment on soybean based cropping system in a vertisol of central india under organic farming was used for this investigation An investigation was carried out on “Soil organic carbon dynamics under long-term nutrient management in soybean based cropping system” at the Indian Institute of Soil Science, Bhopal on an on-going research project on organic farming. The effect of organic, integrated and inorganic nutrient management was assessed in three cropping systems viz. soybean (JS 335)-wheat (Malwa Shakti), soybean-mustard (Pusa Bold) and soybean-gram (JG 130) on aggregate size fractions, carbon content in aggregate as well as soil organic carbon pools dynamics on a split plot experimental design with three replications. The study relevant to dynamics of soil organic carbon pools revealed higher content of soil organic carbon, labile carbon, water soluble carbon, SMBC as well as dehydrogenase activity that varied between 1.04 and 0.86 percent; 440 and 538 mg kg^{-1}, 52.97 and 70.43; 288 and 375 mg kg^{-1}, 88 and 137 µg TPF g^{-1} soil d^{-1}, respectively in surface 0-15 cm soil under organic nutrient management.

Keywords: Organic; carbon pools; vertiso; cropping system.

1. INTRODUCTION

“Long term experiments are primary source of information determining the effect of cropping systems, soil management, fertilizer use and residue utilization etc on changes on SOC” [1]. “Long-term application of farmyard manure and vermi-compost in crop production can contributes to both sustainable food production and mitigation of greenhouse gas emissions through soil C sequestration. Large scale implementation of the organic manure amendments will help in enhancing the capacity of carbon sequestration and promote food security in the region” [2]. “In response, new management strategies have emerged, including soil-focused approaches such as no-tillage, which aim to improve soil regulating and supporting ecosystem services by reducing soil disturbance” Williams et al., 2016. **“**Aggregation results from the rearrangement of the soil constituent particles, flocculation and cementation and is arbitrated by SOC, biota, ionic bridging, clay and oxide content. The aggregate dynamics vary among different crops, crop rotations and cover crops” [3]. “Stability of aggregate is the measure of the structural stability of soils” [4]. “Any reduction in soil aggregate stability is a powerful early indicator of the onset of land degradation. Favorable soil aggregation is important to improve soil fertility and quality with particular emphasis on SOC sequestration, increasing agronomic productivity, enhancing porosity and decreasing erodibility. Vegetation cover can influence soil aggregate stability because of contribution of organic matter through litter and plant root turnover [5], root exudates rizho-deposition” [6,7]. Hence, there is strong need to evaluate the effect of different nutrient inputs on soil health in Vertisols, as these soils occupy about 35% of the area under cultivation in India. Also, soybean-wheat, is the predominant cropping system in deep Vertisols of central India along with soybean-chickpea and soybean-mustard cropping systems. Keeping above in view the limited information available on the effect of nutrient management practices in prominent cropping systems in central India, the present investigation was carried out to assess the effect of nutrient management practices under different cropping systems in black soils of central India.

2. MATERIALS AND MATHODS

2.1 Experimental Site, Climate and Soil Characteristics

The field experiment was conducted during *kharif* season of 2017-18. at the research farm, ICAR-IISS, Bhopal, Madhya Pradesh The on-going experiment on Network project on organic farming was used for this investigation. The study area falls under semi-arid and sub-tropical zone characterized by hot summer and cold winter. Mean annual precipitation is about 1146 mm, most of which is received during the monsoon period of July to September. The average maximum temperature during summer is 35°C, while the average minimum temperature during winter is 4^{0}C.

2.2 Treatments Detail

The on-going experiment on Network project on organic farming was used for this investigation. Soybean (cv JS 335), wheat (cv Malwa Shakti), mustard (cv Pusa Bold) and chickpea (cv JG-130) were sown during kharif and rabi seasons at a spacing of 45X5; 22.5; 45X10 and 30X10 cm as per standard cultural practices in split plot design. The recommended dose of fertilizer for these crops was 30:60:20; 80:40:40; 60:40:0 and 30:40:0 for N, P_2O_5 and K_2O, respectively. The plot size of the experiment is 90 sq meters.

Soil samples (0-5, 5-15 and 15-30 cm) were collected and homogenized from long-term experiment on organic farming at Indian Institute of Soil Science under soybean-wheat, soybean-mustard, soybean-gram cropping system. Visible litter and roots were picked out by hand. Part of the soil samples were air-dried at room temperature and gently passed through a < 2 mm sieve for determining different soil organic carbon pools, biological properties and other soil properties.

Soil organic carbon content (%) in soil samples was determined in soil passed through 0.2 mm sieve by [8] method. A known weight of soil was treated with an excess volume of standard $K_2Cr_2O_7$ in the presence of concentrated H_2SO_4 as described. The excess of $K_2Cr_2O_7$ not reduced by the organic matter was titrated back against a standard solution of ferrous ammonium sulphate, in the presence of diphenylamine indicator.

Labile carbon in soil samples was analysed by using procedure outlined by dilute slightly alkaline $KMnO_4$ which reacts with the most readily oxidizable (active) forms of soil carbon as per procedure described by [9] and [10]. The results were expressed as mg kg^{-1}.

The water soluble carbon in soil was extracted by shaking 10 g soil in 20 ml distilled water for one hour as described by [11]. Then water soluble organic carbon was estimated in the extract by using Shimadzu make TOC (Total Organic Carbon) analyser. The result was expressed as mg kg^{-1}.

Microbial biomass was determined by the incubation and fumigation technique [12]. The soil samples were subjected to chloroform fumigation, which causes cell walls to lyses and denature. The soil was then extracted with 0.5 M K_2SO_4. The readily oxidizable carbon contained in the extract was measured through standard chemical procedures.

Biological activity of a soil is function of number of organisms present in soil coupled with their physiological efficiency. Dehydrogenase activity was measured and expressed as the rate of formation of TPF from TTC as per method outlined by [13]. The result was expressed as µg TPF g^{-1} soil d^{-1}.

3. RESULTS AND DISCUSSION

3.1 Easily Oxidizable Carbon

The data on WBC has been presented in table 1. The easily oxidizable carbon in surface 0-5 cm soil depth varied between 0.72 and 1.13 percent under different cropping systems and nutrient management practices. The organic nutrient management registered highest organic carbon content under different cropping systems with a mean value of 1.05 percent. The WBC was significantly lower in integrated and inorganic nutrient management where it was found to be 0.86 and 0.72 percent respectively. Among cropping systems soybean – wheat cropping system registered highest organic carbon content which was statistically at par with soybean gram but statistically higher over soybean mustard cropping system. In 5-15 cm soil depth, soil organic carbon varied between 0.90 and 0.96 percent under organic sources of nutrients with a mean value of 0.91 percent. Integrated sources of nutrients resulted in significantly lower soil organic carbon as compared to organic source of nutrient and ranged between 0.79 and 0.83 among different cropping systems with a mean value of 0.81 percent. Application of inorganic sources of nutrients resulted in lowest value of soil organic carbon with a mean value of 0.62 percent. The effect of different cropping systems was not found significant with respect to WBC in 5-15 cm soil depth. Soil organic carbon varied between 0.54 and 0.58 percent in 15-30 cm soil depth under organic sources of nutrients with a mean value of 0.56 percent. Jha et al. (2014) observed “an increment of 49.1% in TOC with the application of FYM @ 15 t ha^{-1} Y^{-1} along with recommended dose of NPK on long term basis (38 years) over control in a Vertisol of Jabalpur under soybean-wheat sequence”. Similarly, also reported 105 and 71% higher TOC in long term organic farming practice over absolute control and recommended dose of NPK fertilizers, respectively under soybean-wheat cropping system. Manna et al. (2012) and Lakaria et al. [14] also found increase in WBC with the application of FYM alone Lakaria et al. [15] or in combination with recommended NPK fertilizers over absolute control and sole NPK fertilizer application. The results of this study are in close agreement with these findings. “The higher C accumulation in the Vertisol may be attributed to their high silt+clay content which increase the C stabilization capacity” [4,15].

Table 1. Effect of nutrient management on easily oxidizable carbon (%) under different cropping systems

Treatment	Soybean-Wheat	Soybean-Mustard	Soybean-Gram	Mean
0-5 cm				
Organic	1.13	1.00	1.04	1.05
Integrated	0.90	0.83	0.85	0.86
Inorganic	0.72	0.73	0.73	0.72
Mean	0.91	0.85	0.87	
LSD (p=0.05)	CS	NM	CS X NM	
	0.04	0.06	NS	
5-15 cm				
Organic	0.96	0.90	0.86	0.91
Integrated	0.83	0.80	0.79	0.81
Inorganic	0.63	0.61	0.63	0.62
Mean	0.81	0.77	0.76	
LSD (p=0.05)	CS	NM	CS X NM	
	NS	0.03	NS	
15-30 cm				
Organic	0.58	0.55	0.54	0.56
Integrated	0.48	0.48	0.45	0.47
Inorganic	0.48	0.44	0.42	0.45
Mean	0.51	0.49	0.47	
LSD (p=0.05)	CS	NM	CS X NM	
	NS	0.03	NS	

CS- cropping system, NM – nutrient management

Table 2. Effect of nutrient management on Water soluble carbon (mg kg^{-1}) under different cropping systems

Treatment	Soybean-Wheat	Soybean-Mustard	Soybean-Gram	Mean
0-5 cm				
Organic	70.43	62.27	60.86	64.52
Integrated	58.47	50.78	52.43	53.89
Inorganic	48.45	46.15	43.49	46.03
Mean	59.11	53.06	52.26	
LSD (p=0.05)	CS	NM	CS X NM	
	NS	4.34	NS	
5-15 cm				
Organic	56.57	53.57	52.97	54.37
Integrated	53.03	51.75	48.86	51.21
Inorganic	42.61	49.62	42.98	45.07
Mean	50.74	51.64	48.27	
LSD (p=0.05)	CS	NM	CS X NM	
	NS	3.32	NS	
15-30 cm				
Organic	50.19	48.78	47.50	48.82
Integrated	41.11	45.18	42.34	42.88
Inorganic	37.85	41.50	39.89	39.75
Mean	43.05	45.15	43.25	
LSD (p=0.05)	CS	NM	CS X NM	
	NA	3.69	NA	

CS- cropping system, NM – nutrient management

3.2 Water Soluble Carbon Content

Water soluble carbon content in different soil depths have been presented in Table 2 In 0-5 cm soil depth, the water soluble carbon varied widely among the different nutrient management options. Under organic sources of nutrient application the water soluble carbon ranged between 60.86 and 70.43 mg kg^{-1} with a mean value of 64.52 mg kg^{-1}. With integrated system of nutrient application the water soluble carbon ranged between 50.78 and 58.47 mg kg^{-1} with a mean value of 53.89 mg kg^{-1}. Least water soluble carbon in 0-5 cm was recorded in inorganic nutrient management where it varied between 43.49 to 48.45 mg kg^{-1} among cropping systems with a mean value of 46.03 mg kg^{-1}. In 5-15 cm soil depth, the water soluble carbon decreased as compared to surface layer and it varied between 42.61 and 56.57 mg kg^{-1} among the cropping systems. Under organic sources of nutrient application the water soluble carbon ranged between 52.97 and 56.57 mg kg^{-1} with a mean value of 54.37 mg kg^{-1} across the plots. Integrated system of nutrient application resulted in slightly lower water soluble carbon but a significant decrease could be recorded only with inorganic nutrient management (45.07 mg kg^{-1}). There was no significant different between the cropping systems with respect to water soluble carbon in 5-15 cm soil depth. Water soluble carbon varied widely among the different nutrient management options in 15-30 cm soil depth. It was registered the highest in organic treatment where ranged between 47.50 and 50.19 mg kg^{-1} with a mean value of 48.82 mg kg^{-1} across the cropping systems (Table 2). Integrated nutrient management resulted in significantly lower water soluble carbon which varied between 41.11 and 45.18 mg kg^{-1} with a mean value of 42.88 mg kg^{-1}. Under only inorganic addition of nutrients the water soluble carbon has been found to vary from 37.85 to 45.15 mg kg^{-1} with a mean value of 39.75 mg kg^{-1}. Lakaria et al. [16] also found that the WSC was ranged from 30.9 mg kg^{-1} to 101.6 mg kg^{-1} under different land use whereas Jha et al. [14] recorded WSC in the range of 13.8 to 101.6 mg kg^{-1} under different treatments in Vertisols.

3.3 Labile Carbon

Potassium permanganate oxidizable carbon i.e. labile carbon determined in different cropping systems with nutrient management options has been presented in table 3. In 0-5 cm soil depth, labile carbon content also varied widely among the different nutrient management options. The content of labile carbon under different sources of nutrient application varied between 417 to 538 mg kg^{-1} with a mean value of 515 mg kg^{-1}. With integrated nutrient management practice the labile carbon varied between 479 and 484 mg kg^{-1}. Among different cropping system no significant difference could be observed in labile carbon content, however, the interaction among nutrient management and cropping systems was significant. In 5-15 cm soil depth, labile carbon content also varied widely among the different nutrient management options. Labile carbon under organic sources of nutrient varied from 440 to 470 mg kg^{-1} with a mean value of 450 mg kg^{-1}. It was decreased with addition of only integrated nutrient it varied between 423 and 446 mg kg^{-1} with a mean value of 431 mg kg^{-1}. Labile carbon In 15-30 cm soil depth, was found the lowest where it varied between 341 and 391 mg kg^{-1} with a mean value of 374 mg kg^{-1}. Integrated system of nutrient resulted in lower labile carbon as compared to organic nutrient management and it varied between 329 and 365 mg kg^{-1} with a mean value of 344 mg kg^{-1}. Hassink [17]; Lakaria et al. (2012b) and Jha et al. [14] also observed "the $KMnO_4$-C content between 463 and 621 mg kg^{-1} and 311.8 and 555.5 mg kg^{-1} under soybean-wheat rotation in a Vertisol. Further, the results showed that the continuous application organic manures significantly improved soil $KMnO_4$-C content as compared to application of chemical fertilizers, sole biodynamic and absolute control .The organic treatments increased $KMnO_4$-C by 72-81% and 64-73% over control and RDF, respectively". Lakaria et al. (2012b) and Jha et al. [14] also reported "12% and 34%; 12% and 99% higher $KMnO_4$-C under organic farming than conventional farming and control, respectively".

3.4 Soil Microbial Biomass Carbon

Soil microbial biomass carbon as influenced by different nutrient management practices under three cropping systems have been presented in table 4. In 0-5 cm soil depth, the SMBC among the different nutrient management options varied between 224 and 375 mg kg^{-1}. Under organic sources of nutrient application the SMBC ranged between 336 and 375 mg kg^{-1} with a mean value of 354 mg kg^{-1}. With integrated system of nutrient application SMBC ranged between 254 and 312 mg kg^{-1} with a mean value of 284 mg kg^{-1}. Application of only inorganic nutrients In 5-15 cm soil depth, the SMBC varied widely where it ranged between 288 and 307 mg kg^{-1} with a mean value of 297 mg kg^{-1} under organic nutrient management. With integrated nutrient management the SMBC values range was between 244 and 247 mg kg^{-1} with a mean value of 245 mg kg^{-1}. The lowest SMBC was recorded with inorganic nutrient sources and it was found to vary from 179 to 191 mg kg^{-1} with a mean value of 185 mg kg^{-1} (Table 4). In 15-30 cm soil depth, the SMBC decreased sharply irrespective of the nutrient management practices. Under organic sources of nutrient application the SMBC ranged between 69 and 72 mg kg^{-1} among the cropping systems with a mean value of 70 mg kg^{-1}. The integrated and inorganic nutrient management led to significant decrease in the SMBC. All the cropping systems were at par with respect to SMBC values. Resulted in lowest SMBC (224 to 247 mg kg^{-1}) with a mean value of 238 mg kg^{-1}. Lakaria et al. (2012c) found that SMBC was ranged from 113 mg kg^{-1} to 430.7 mg kg^{-1} under different land use whereas Jha et al. [14] recorded SMBC in the range of 88.9 to 430.7 mg kg^{-1} under different treatments in Vertisols. The results also showed that the SMBC were higher under the treatments receiving the organic source of nutrient application.

3.5 Dehydrogenase Enzymes Activity

The data on activity of dehydrogenase enzymes in soil under different cropping systems as influenced by nutrient management has been presented in table 5. In surface soil (0-5 cm) DHA under different nutrient management varied between 124 and 137 µg TPF g^{-1} soil d^{-1} under organic sources of nutrients with a mean value of 131.8 µg TPF g^{-1} soil d$^{-1.}$ A significant decrease in DHA was recorded with the application of integrated and inorganic source of nutrients. With the integrated use of nutrients the DHA ranged between 104 and 117 µg TPF g^{-1} soil d^{-1} with a mean value of 113 µg TPF g^{-1} soil d^{-1} among different cropping systems. Inorganic sources of nutrients resulted in lowest dehydrogenase activity (106 and 117) with a mean value of 92 µg TPF g^{-1} soil d^{-1}. Highest DHA was recorded under soybean – wheat cropping system followed by soybean – mustard and soybean - gram. In 5-15 cm soil depth, DHA varied between 86 and 89 µg TPF g^{-1} soil d^{-1} under organic sources of nutrients while it decreased further under integrated sources of nutrients (64 and 71 µg TPF g^{-1} soil d^{-1}). Application of only inorganic nutrients further decreased DHA (50 and 54 µg TPF g^{-1} soil d^{-1}). All the cropping systems were statistically at par with respect to DHA in 5-15 cm soil depth. DHA in 15-30 cm depth were decreased sharply and different nutrient management treatment showed impact on its activity. Organic sources of nutrients resulted in mean value of 28 µg TPF g^{-1} soil d-1. It was further decreased significantly

Table 3. Effect of nutrient management on Labile carbon (mg kg^{-1}) under different cropping systems

Treatment	Soybean-Wheat	Soybean-Mustard	Soybean-Gram	Mean
		0-5 cm		
Organic	538	508	499	515
Integrated	479	481	484	481
Inorganic	417	421	466	435
Mean	478	470	483	
LSD (p=0.05)	CS	NM	CS X NM	
	NS	17	30	
		5-15 cm		
Organic	470	440	441	450
Integrated	446	425	423	431
Inorganic	363	404	385	384
Mean	427	423	416	
LSD (p=0.05)	CS	NM	CS X NM	
	NS	14	24	
		15-30 cm		
Organic	391	389	341	374
Integrated	365	338	329	344
Inorganic	342	318	309	323
Mean	366	348	326	
LSD (p=0.05)	CS	NM	CS X NM	
	13	10	17	

CS- cropping system, NM – nutrient management

Table 4. Effect of nutrient management on SMBC (mg kg^{-1}) under different cropping systems

Treatment	Soybean-Wheat	Soybean-Mustard	Soybean-Gram	Mean
		0-5 cm		
Organic	375	336	351	354
Integrated	312	254	287	284
Inorganic	247	224	244	238
Mean	312	271	294	
LSD (p=0.05)	CS	NM	CS X NM	
	16	17	NS	
		5-15 cm		
Organic	307	294	288	297
Integrated	247	244	244	245
Inorganic	191	185	179	185
Mean	249	241	237	
LSD (p=0.05)	CS	NM	CS X NM	
	7	8	NS	
		15-30 cm		
Organic	72	69	69	70
Integrated	56	55	54	55
Inorganic	48	45	44	46
Mean	58	56	56	
LSD (p=0.05)	CS	NM	CS X NM	
	NS	5	NS	

CS- cropping system, NM – nutrient management

Table 5. Effect of nutrient management on DHA (µg TPF g^{-1} soil d^{-1}) under different cropping systems

Treatment	Soybean-Wheat	Soybean-Mustard	Soybean-Gram	Mean
		0-5 cm		
Organic	137	134	124	132
Integrated	117	117	104	113
Inorganic	97	90	89	92
Mean	117	114	106	
LSD (p=0.05)	CS	NM	CS X NM	
	8	7	NS	
		5-15 cm		
Organic	89	86	88	88
Integrated	70	64	71	69
Inorganic	54	50	51	52
Mean	71	67	70	
LSD (p=0.05)	CS	NM	CS X NM	
	NS	4	NS	
		15-30 cm		
Organic	29	27	26	28
Integrated	21	24	21	22
Inorganic	16	15	16	16
Mean	22	22	21	
LSD (p=0.05)	CS	NM	CS X NM	
	NS	3	NS	

CS- cropping system, NM – nutrient management

under integrated and inorganic nutrient management. The soil enzyme activities are positively significantly correlated with TOC, active, slow and passive pools of carbon, soil respiration, microbial biomass and soil available nitrogen [13,18,19,20]. The organic farming practices are known to increase the microbial enzyme activities in soil as reported by Marinari et al*.* [21]. Results of the present investigation are in accordance with other researchers who also observed higher enzyme activities with the application of FYM [22,23,24].

4. CONCLUSION

Thus, present investigation on long term nutrient management through organic inputs, integrated improved soil aggregation and carbon pools compared to inorganic nutrient management. The effect of these nutrient management practices was more pronounced in the surface layer (0-5 to 5-15 cm) as compared to sub surface layer (15-30cm). The soil organic carbon pools was significantly improved with 100% organic treatment followed by integrated nutrient management over inorganic fertilizer application. It decreased sharply in the 15-30 CM soil layer although treatment effects were the same. In lower layers soybean – wheat cropping systems maintained significantly higher labile carbon as compared to soybean- mustard and soybean-gram.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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