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Effect of long term organic manure application on soil properties, carbon sequestration, soil - plant carbon stock and productivity under two vegetable production systems in Himachal Pradesh

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Abstract

Changes in soil properties, carbon sequestration, carbon stock and productivity under two vegetable production systems supplied with five organic nutrient sources were evaluated after five cropping cycles. The results showed that cropping systems did not influence soil bulk density, carbon biomass, bacteria, fungi, enzyme activity, Fe, Mn, and Cu. However, maximum soil organic carbon (0.50%), N (166.6 kg ha^{-1}), P (41.3 kg ha^{-1}), K (162.2 kg ha^{-1}), Zn (1.59 mg kg^{-1}), soil carbon stock (11.3 t ha^{-1} yr^{-1}), plant carbon stock (54.3 t ha^{-1} yr^{-1}), carbon sequestration (2.8 t ha^{-1} yr^{-1}), total carbon stock (65.6 t ha^{-1} yr^{-1}), actenomycetes (33.2 10^{5} cfu g^{-1}) , marketable yield (6.6 t ha^{-1}), crop biomass (5.8 t ha^{-1}) and leaf litter (0.40 t ha^{-1}) was recorded in tomato-cauliflower-radish/pea as compared to capsicum/cabbage-coriander-spinich/pea. All the measured variables were significantly influenced among nutrient sources. Maximum soil organic carbon (0.48%), bulk density (1.419 g cm^{-3}), N (189.3 kg ha^{-1}), P (54.8 kg ha^{-1}), K (193.8 kg ha^{-1}), Fe (64.6 mg kg^{-1}), Mn (29.0 mg kg^{-1}), Zn (1.83 mg kg^{-1}), Cu (1.35 mg kg^{-1}), soil carbon stock (12.5 t ha^{-1} yr^{-1}), plant carbon stock (65.8 t ha^{-1} yr^{-1}), carbon sequestration (3.0 t ha^{-1} yr^{-1}), total carbon stock (78.3 t ha^{-1} yr^{-1}), bacteria (84.0 10^{6} cfu g^{-1}), fungi (72.0 10^{5} cfu g^{-1}), actenomycetes (55.5 10^{5} cfu g^{-1}), microbial carbon biomass (1741.2 µg g^{-1}), dehydrogenase enzyme (0.023 µg TPF g^{-1}) and acid phosphatase enzyme (21.1 µ p-nitrophenol g^{-1}), marketable yield (7.9 t ha^{-1}), crop biomass (7.0 t ha^{-1}), litter fall (0.54 t ha^{-1}) were observed in treatment receiving 50% N supplemented with farmyard manure enriched rock phosphate and 50% N supplemented with vermicompost. The current study indicates that long term use of farmyard manure and vermicompost showed better yield, soil quality and greater amount of carbon stock and carbon sequestration under tomato-cauliflower-radish/pea cropping pattern.

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Introduction

Soil organic carbon (SOC) has beneficial effects on soil quality and productivity. Cropping systems that maintain and/or improve levels of SOC may lead to sustainable crop production. Quantification of soil carbon (C) cycling as influenced by management practices is needed for C sequestration and soil quality improvement. Organic matter in soils acts as a large carbon sink and plays an important role in CO_2 balance (Sukkel et al. 2008). Cropping systems and management practices that ensure greater amounts of crop residue returned to the soil are expected to cause a net build-up of the soil organic carbon (SOC) stock. Identifying such systems or practices is a priority for sustaining crop productivity. Upon application of organic amendments a part of their C is stabilized into SOC and distributed among different pools. This process is governed by interplay of factors including climate, substrate biochemistry, C loading, soil associated precinct and so on (Majumdar *et al.,* 2007). As such, the different organic amendments are likely to differentially affect the amount of C stabilized and the size and dynamics of organic carbon pools and ultimately crop productivity. Long-term experiments have added much to our understanding of carbon sequestration in soil and particularly the quantification and prediction of carbon sink potential of arable soils (Rogasik *et al.,* 2004). According to literature, considerable work has been done by various researchers (Verma and Sharma, 2007; Logah *et al.,* 2011; Vincett et al. 2011; Basita *et al.,* 2013; Manna *et al.,* 2005; Hati et al. 2007; Ganeshamurthy et al. 2009; Nayak *et al.,* 2012; Bhardwaj, *et al.,* 2013 and Pal *et al.,* 2013) on the impact of organic manure on carbon sequestration and crop yield under different land uses, cereal –cereal and cereal-pulse based cropping systems. However, the impact of long-term organic amendments on C sequestration, soil health and crop productivity of vegetable production systems in Himachal Pradesh have not been examined. Therefore the present study was undertaken to assess the effect of different management practices on soil quality and carbon sequestration in two vegetable production systems.

Materials and Methods

Data reported in the present study was generated from a long-term fertility experiment at the experimental farm of Himachal Pradesh Krishi Vishvavidayalaya, Hill Agricultural Research and Extension Centre, Bajaura, Kullu, India (1090m above mean sea level). The climate of the area is sub- humid and sub-tropical, receiving annual rainfall of 1500-3000 mm. Soils of the experimental site were silty loam in texture with bulk density 1.623 g cm^{-3} and low organic carbon content (0.35%) at the time of initiation of the experiment.

Experimental design and treatments: Long-term trial was initiated during kharif (rainy season) in 2004 in order to determine the effect of different cropping systems CS_1= tomato (*Solanum lycopersicum* L. var. commune) - cauliflower (*Brassica oleracea* L. var. botrytis) – radish/pea (*Raphanus sativus* L. / *Pisum sativum* L.var. arvense) and CS_2= capsicum/cabbage (*Capsicum annuum* L. var. annuum/*Brassica olerecea* var. capitata) -green coriander (*Coriandrum sativum* L) – spinach/pea (*Spinacia oleracea* L.var. bengalensis) and five nutrient sources NS_1= 100 % N supplemented with vermicompost; NS_2= 100% N supplemented with rock phosphate enriched farmyard manure; NS_3= 50 % N supplemented with farmyard manure and 50% N supplemented with vermicompost; NS_4= 50 % N supplemented with farmyard manure enriched rock phosphate and 50% N supplemented with vermicompost and NS_5= control (radish and spinach crops were changed with pea in the year 2006 due to their low premium in the market and capsicum crop was replaced with cabbage in the same year, due to severe wilt problem in capsicum crop).

Soil was sampled after fifth year (2008) of cropping cycle. Treatment was laid out in a split plot design (cropping system in main plots and nutrient source in sub-pot) with three replications. The Form yard manure (FYM) used in the study contained 2.35% N, 0.27% P, 2.39% K vermicompost contained 1.68% N, 0.20% P, while 1.28% K. Summer, autumn and winter vegetable crops were transplanted/sown as per state package of practices in a fixed plot of 54 m^2. Fresh marketable yield and crop biomass (dry matter and litter fall) of each vegetable was recorded. The total crop biomass was converted into carbon by the method of multiplying total crop biomass (dry matter + litter fall) with a factor of 0.45 (Woomer 1990).

Soil sampling and analysis: Soil sampling was done at 0-15 cm depth in 2004 and after 5th crop cycle in 2008 season. The soil sample were analyzed for organic carbon (Walkley and Black 1934); available N (Subbiah and Asija 1956); available phosphorus (Olsen et al. 1954) and available potassium (Merwin and peech 1950). DTPA-extractable Zn, Cu, Mn and Fe in the soil were estimated by 'ECIL' 4901 model of atomic absorption spectrophotometer as per the procedure of Lindsay and Norvell (1978). Enumeration of total bacteria, fungi and actenomycetes in fresh rhizosphere soil samples was carried out by following serial dilution plate count technique using nutrient agar for bacteria, Martin's Rose Bengal agar for fungi (Martin 1950) and Kuster's agar (Kuster and Williams 1964) for actenomycetes. Microbial biomass carbon was analysed by the chloroform fumigation method (Vance *et al.,* 1987). Dehydrogenase activity was estimated using 2, 3, 5 triphenyal tetrazolium chloride (Casida *et al.,* 1964). Acid phosphatase activity was measured by the method of Arutyunyan *et al.* (1995). The soil carbon stock was computed by the formula given by Joao Carlos *et al.* (2001): SOC t ha^{-1} = bulk density (g cm^{-3}) × organic carbon (%) × soil depth (cm) .The carbon sequestration in soil was calculated using equation: Carbon sequestration (t C $ha^{-1} yr^{-1}$) = $OC_{current} - Oc_{initial}$ where, $OC_{current}$ and $OC_{initial}$ indicate organic carbon stocks in 2008 (current) and that at the initiation of long-term experiment in 2004, respectively.

Data were subjected to ANOVA and means were separated by critical difference at 5% level of significance using CPCS1 statistical package.

Results and Discussion

Cropping system had significant impact on soil organic carbon and was significantly increased by 11.1 % in CS_1 as compared to CS_2 (Table1). Field studies suggest that enhanced crop rotation complexity produces long term increases in soil organic carbon (West and Post, 2002 and Ganeshamurthy *et al.,* 2009). Long-term manure

Table 1: Effect of cropping systems and organic fertilizers on some soil chemical and physical properties

Treatment	OC (%)	Bulk density ($g\ cm^{-3}$)	N ($kg\ ha^{-1}$)	P_2O_5 ($kg\ ha^{-1}$)	K_2O ($kg\ ha^{-1}$)	Fe ($mg\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)	Cu ($mg\ kg^{-1}$)
Cropping system (CS)									
CS_1	0.50	1.519	166.6	41.3	162.2	53.6	21.5	1.59	1.09
CS_2	0.45	1.514	158.4	31.1	157.6	53.9	22.0	1.51	1.04
CD p=0.05	0.03	NS	8.5	5.1	2.3	NS	NS	0.17	NS
Nutrient source (NS)									
NS_1	0.44	1.464	162.2	33.2	159.9	59.2	23.7	1.78	1.22
NS_2	0.44	1.464	164.1	35.2	176.9	59.6	24.5	1.72	1.24
NS_3	0.39	1.464	175.5	37.9	181.3	60.1	24.7	1.72	1.24
NS_4	0.48	1.419	189.3	54.8	193.8	64.6	29.0	1.83	1.35
Ns_5 (Control)	0.34	1.731	121.3	20.0	93.7	28.1	10.9	0.67	0.37

Table 2: Effect of cropping systems and nutrient sources on soil microbiological properties

Treatments	Bacteria	Fungi	ACT	MCB	DH	AP
Cropping system (CS)						
CS_1	69.8	50.2	33.2	887.7	0.017	16.8
CS_2	71.4	49.0	28.8	860.7	0.017	16.8
CD p=0.05	NS	NS	0.9	NS	NS	NS
Nutrient source (NS)						
NS_1	63.5	37.0	24.0	410.8	0.013	13.8
NS_2	78.0	53.5	29.0	813.3	0.017	18.2
NS_3	75.0	53.0	30.5	1164.8	0.020	19.2
NS_4	84.0	72.0	55.5	1741.2	0.023	21.1
NS_5	52.5	32.5	16.0	240.8	0.012	11.9
CD p=0.05	2.3	1.9	2.3	39.2	0.001	1.7

Bacteria (10^6 cfu g^{-1}); Fungi (10^5 cfu g^{-1}); ACT-Actenomycetes (10^5 cfu g^{-1}); MCB-Microbial carbon bio mass (µg g^{-1}); DH-Dehydrogenase enzyme (µg TPF g^{-1}); AP-Acid phosphatase enzyme (µ p-nitrophenol g^{-1})

Table 3: Effect of cropping systems and organic fertilizers on carbon sequestration and carbon stock

Treatment	Total soil C stock ($t\ ha^{-1} yr^{-1}$)	Initial soil C stock ($t\ ha^{-1} yr^{-1}$)	Carbon sequestration ($t\ ha^{-1} yr^{-1}$)	Total plant C stock ($t\ ha^{-1} yr^{-1}$)	Total soil + plant C stock ($t\ ha^{-1} yr^{-1}$)
Cropping system (CS)					
CS_1	11.3	8.5	2.8	54.3	65.6
CS_2	10.1	8.4	1.7	49.2	59.3
CD p=0.05	0.06	NS	0.8	2.24	2.17
Nutrient source (NS)					
NS1	9.3	7.7	1.7	47.5	56.5
NS_2	10.9	8.8	1.1	54.6	65.5
NS_3	10.4	8.2	1.2	56.6	67.0
NS_4	12.5	10.5	3.0	65.8	78.3
NS_5	7.9	6.7	1.2	34.5	42.4
CD p=0.05	0.7	1.1	0.7	2.4	1.79

applications increase soil organic carbon through the addition of organic matter (OM) and through increased OM return in crop residues due to increased crop production (Whalen and Chang, 2002). Increased cropping system complexity would be expected to create a diversity of crop residue qualities, crop rooting depths and patterns and possibly greater C inputs (Pathak *et al.,* 2011). The earlier workers (Bhattacharyya *et al.,* 2007 and Hati *et al.,* 2007) and have also reported increased soil organic carbon under long term fertilizer experiments and attributed it to length of cropping system and loss of organic matter from tillage operation. Soil organic carbon recorded significant differences amongst the nutrient sources and the highest value (0.48 %) was obtained in NS_4 and lowest in control (0.34 %). Such increase in soil organic carbon was quite obvious due to the reason that carbonaceous materials contribute to soil organic carbon after their decomposition. These observations are in agreement with the findings of Venkatesh *et al.* (2013) and Basita *et al.* (2013).

Soil bulk density did not change under cropping systems but improved in the organic fertilizer amended plots (Table1) with higher increase up to 21 % in NS_4 over control (NS_5). It may be attributed to the reduction in bulk density in residue and cow manure incorporated soil to build up of soil organic matter and better soil structure (Sharma *et al.,* 2000, Venkatesh *et al.,* 2013) .This agrees with the findings of Bastia *et al.* (2013) and Liu *et al.* (2013), who reported improved soil bulk density due to incorporation of organic manure in the soil. Parthasarathi (2010) also attributed the improvement in bulk density of soil treated with organic manures, mainly due to enhanced microbial population and activity that resulted in the formation of aggregates and increased porosity.

Available N was which might by 5.2 % in CS_1 when compared to CS_2 (Table1) be due to the capacity of pea crop to supply biologically fixed atmospheric nitrogen as a replacement or supplement for inorganic nitrogen fertilizer (Keith, 2006). Significant difference in soil N was observed among nutrient sources and maximum build up of soil N (56 %) was recorded in NS_4. Production of appreciable quantity of carbonic acids during decomposition of organic matter mineralizes complex organic substances, which in turn would contribute to N pool. Increased available N due to applied organic matter is also attributable to greater multiplication of soil microbes caused by addition of organic materials which mineralize organically bound N to inorganic form (Islam *et al.,* 2011). Cropping system had significant effect on soil P and its availability in CS_1 increased by 32.7 % over CS_2 (Table1). According to Keith (2006) crop plants raised in rotations generally have better root function, and therefore are able to take up phosphorous from soil. This study further emphasized that inclusion of legume crop in a cropping system have a tendency to increase soil microbial activity, as well as, plant available phosphorous. Significant difference in soil P among various nutrient sources were observed and maximum soil P improvement in NS_4 was 174 % over control. K availability was influenced within cropping system, which recorded an increase of 2.9 % in CS_1 over CS_2 (Table1). Improved soil K status was due to the reason that rotations help to better distribute phosphorous and potassium from deep within the soil profile to the soil surface, where plant roots have better access to them. Crop rotation usually increase organic matter and prompt K availability for plants (Montemurro *et al.,* 2008). Nutrient sources had significant effect on soil K availability and maximum build up of 106.8 % was observed in NS_4 compared to control (NS_5). The increased K availability may be attributed to direct addition of potassium to the available pool of soil from organic manures. This is in agreement with the findings of Srikanth (2006).

Table 4: Effect of cropping systems and organic fertilizers on marketable and crop biomass yield

Treatment	Marketable yield (t ha^{-1})	Dry matter yield (t ha^{-1})	Litter fall (t ha^{-1})
Cropping System (CS)			
Cs_1	6.6	5.8	0.40
CS_2	5.9	5.2	0.26
CD p=0.05	0.4	0.17	0.042
Nutrient source (NS)			
NS_1	5.9	4.8	0.21
NS_2	6.7	5.7	0.30
NS_3	6.6	6.2	0.41
NS_4	7.9	7.0	0.54
NS_5 (Control)	4.1	3.7	0.51
CD p=0.05	0.4	0.2	0.05

Cropping systems did not exhibit any significant effect on the availability of soil Fe, Mn and Cu, whereas Zn recorded 5.3 % increase in CS_1 compared to CS_2 (Table1) and this effect could be explained on the ground that vegetables grown in the present study were heavy feeder and micronutrient build up might have exceeded crop removal. Different nutrient sources significantly affected soil Fe, Mn, Zn and Cu and recorded a varying increase from 7.5-129.8, 17.4- 166, 2.8-173 and 8.9-265 %, respectively, highest being in NS_4 and lowest in NS_5.However, their contents were more or less identical within applied nutrient but found superior to control. Increased in micronutrients in soils with addition of organics was a result of enhanced microbial activity and consequent release of complex organic substances (chelating agents) Besides addition of these nutrients to the available pool on decomposition of organic materials (Whalen and Chang, 2002; Meng, et al., 2005). Regular addition of organic material to soil for more than 10 years, through compost or manures, enhanced both soil C and availability of micronutrients, indicating a physical protection of these nutrients within soil macro aggregates Mallory and Griffin, 2007 and Sodhi, *et al.,* 2009). Sharma *et al.,* (2000) also observed significant enhancement in DTPA-extractable micronutrients due to incorporation of crop residues and FYM compared to application chemical fertilizers.

No significant difference among cropping systems were observed in relation to soil microorganisms, carbon biomass and enzyme activity (Table2). However, soil actenomycetes population in CS_1 was 15.3 % higher than CS_2.

Among different nutrient sources, highest value of soil bacteria (52.5 x 10^6 cfu g^{-1}), fungi (72 x 10^5 cfu g^{-1}), actenomycetes (55.5 x 10^5 cfu g^{-1}), carbon biomass(1741.2 µg g^{-1}) , dehydrogenase (0.023 µg TPF g^{-1}) and acid phosphatase (21.1 µ p-nitrophenol g^{-1}) activity was noticed in NS_4 (Table 2). Higher microbial biomass in organic amended treatment might be due to increase in organic carbon, total N and P content in soil, which are directly related to the dehydrogenase activity in soil. A positive effect of organic fertilizers on the microbial biomass and the carbon content of soil was also observed by Cerny *et al.* (2008). This is also in accordance with Chauhan *et al.* (2011), who found improved in microbial biomass due to application of farmyard manure and compost that might have cumulative effect of organic manures in increasing organic carbon content of soil which acted as carbon and energy source for microbes and fermented organics in quick build up of micro flora and fauna. These results also corroborate with the findings of Ferreras *et al.* (2006).

The values of carbon pool inventory differ among cropping system (Table3). Maximum increase in soil carbon stock (11.8 %), plant carbon stock (10.4 %), carbon sequestration (6.5 %) and total carbon stock (38.6 %) was recorded in CS_1 as compared to CS2 (Table 3). All the measured variables in relation to carbon stock recorded significant increase due to nutrient sources and corresponding increase for soil carbon stock, initial carbon stock carbon sequestration, plant carbon stock and total carbon stock in NS_4 was 58.2, 56.7, 172, 90.7 and 84,7 %, respectively in NS_5 over control (NS_5). The amount of carbon sequestered was significantly increased among cropping systems and nutrient sources being highest in CS_1 and NS_4 (Table3). The results are in conformity with the previous study of Logah *et al.* (2011) and Mandal *et al.* (2007) who reported increased carbon sequestration under different organic nutrient managements during cropping cycles. Use of organic amendments is known to improve soil productivity in rice-wheat cropping (Ghosh *et al.,* 2010) and has capacity to add soil organic carbon and to improve soil condition. Several long-term experiments in Europe have shown that the rate of SOC sequestration is higher due to application of organic manures than chemical fertilizers (Verma and Sharma, 2007; Purakayastha *et al.,* 2008; Nayak *et al.,* 2012).

Marketable fresh yield, dry matter yield and litter fall in CS_1 as compared to increased to the extent of 11.9, 11.5 and 53.8 % CS_2 (Table4). High volume crops resulting high amount of crop residue turn over under CS_1 may be one of the possible reason for better marketable and crop biomass yield (Venkatesh et al. 2012). The nutrient sources significantly increased fresh marketable yield and crop biomass in NS_4 by 92.7, 89.2 and 157.7 % respectively, compared to control (NS_5). Increased yield with addition of organic manure was due to correction of unrecognized nutrient deficiency, indirect effect of nutrient supply such as effect of potassium on resistance to lodging (Manna *et al.,* 2005) and control of soil borne diseases (Regmi *et al.,* 2002) and improvement of the soil conditions, which encouraged root development by improving soil aeration (Arisha *et al.,* 2003). Similarly by Russo and Taylor (2006) and Sadanandan and Hamza (2006) reported positive effect of organic amendment on yield and economics of vegetables and Indian spices.

Long-term application of farmyard manure and vermicompost in vegetable 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.

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