

Original Research Article

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Improvement in Soil Physical, Chemical and Microbiological Properties during Cropping Cycles under Different Nutrient Managements in Western Himalayas

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ABSTRACT

It is still unclear that whether organic manure amendment could increase soil organic carbon (SOC) sequestration in an Indian Typic Udorthents. Further, changes accompanied by different organic carbon (C) fractions are not well understood based on long term experiment. The knowledge of this kind is important for assessing the potential for C sequestration and selecting effective management practices for increasing soil C sequestration and productivity in agro-ecosystem of western Himalayan region. Thus, we conducted the research based on 9 years (2004 to 2013) of long-term fertilization experiment with three management practices (organic, inorganic and integrated) and four cropping systems [tomato (*Solanum lycopersicum* L.) –cauliflower (*Brassica oleracea* var. brotytis) - green pea (*Pisum sativum* L var. arvense); french bean (*Phaseolous vulgaris* L.) – french bean - cauliflower; cauliflower – cauliflower- green pea; Maize (*Zea mays* L.) + French bean - garlic (*Allium sativum* L.)]. The results indicate that the soil bulk density in surface depth decreased (1.40 g cm^{-3}) but increased (1.42 g cm^{-3}) in sub surface. The soil top layer had highest organic carbon (1.07 %); growth of soil bacteria ($8.6 \times 10^6 \text{ cfu g}^{-1}$), fungi ($4.5 \times 10^6 \text{ cfu g}^{-1}$) and phosphatase enzyme ($9.3 \mu \text{ p-nitrophenol g}^{-1}$); soil organic carbon stock ($22.5 \text{ t.ha}^{-1} \text{ yr}^{-1}$); carbon sequestration ($17.0 \text{ t.ha}^{-1} \text{ yr}^{-1}$); carbon sequestration rate ($2.5 \text{ t.ha}^{-1} \text{ yr}^{-1}$); C fract1 ($0.48 \text{ t.ha}^{-1} \text{ yr}^{-1}$); C fract2 ($0.25 \text{ t.ha}^{-1} \text{ yr}^{-1}$); C fract3 ($0.14 \text{ t.ha}^{-1} \text{ yr}^{-1}$); C fract4 ($0.21 \text{ t.ha}^{-1} \text{ yr}^{-1}$) with organic inputs. The cropping systems had less effect on soil bulk density but other soil variables were significantly influenced in top soil layer, but not in sub layer. The cauliflower – cauliflower – green pea system recorded maximum improvement for organic carbon (0.88 %); total soil organic carbon stock ($18.9 \text{ t ha}^{-1} \text{ yr}^{-1}$); carbon sequestration ($11.7 \text{ t ha}^{-1} \text{ yr}^{-1}$) and carbon sequestration rate ($2.9 \text{ t.ha}^{-1} \text{ yr}^{-1}$) C fract1 ($0.35 \text{ t.ha}^{-1} \text{ yr}^{-1}$), C fract2 ($0.22 \text{ t.ha}^{-1} \text{ yr}^{-1}$); C fract3 ($0.12 \text{ t.ha}^{-1} \text{ yr}^{-1}$); C fract4 ($0.17 \text{ t.ha}^{-1} \text{ yr}^{-1}$); bacteria ($8.7 \times 10^6 \text{ cfu g}^{-1}$); fungi ($3.2 \times 10^6 \text{ cfu g}^{-1}$) and phosphatase enzyme ($7.6 \mu \text{ p-nitrophenol g}^{-1}$). The results indicate that the Typic Udorthents have a large potential to sequester SOC and applying cattle manure or vermicompost is a recommendable SOC sequestration practice in western Himalayan regions.

Keywords

Carbon sequestration, Nutrient managements, Cropping cycles, Western Himalayas.

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Introduction

There is a growing concern that increasing levels of carbon dioxide in the atmosphere will change the climate, making the Earth warmer and increasing the frequency of

extreme weather events (Sundermeier *et al.*, 2005). Over the past 150 years, the amount of carbon in the atmosphere has increased by 30% (Ecological Society of America). One of

the proposed methods to reduce atmospheric carbon dioxide is to increase the global storage of carbon in soils which can eventually result to simultaneous enhancement in agricultural production (Ecological Society of America). Organic matter in soils acts as a large carbon sink and plays an important role in the CO₂ balance (Sukkel *et al.*, 2008). However, there is little information on how different nutrient management strategies could influence soil carbon sequestration in the long term during cropping cycles. Earlier studies considered soil carbon sequestration in the short term and mostly in tropical climates. This study was specifically conducted in a sub-tropical climate to evaluate soil carbon sequestration potential under different nutrient management strategies. In an era when global warming is increasingly becoming an environmental threat to human existence, there is a need for studies of this nature which can provide information on the best soil amendments and cropping systems which will enhance soil carbon sequestration in the long term with increased crop yield/productivity. Also an understanding of the dynamics of carbon (C) stock in soils, as impacted by management strategies, is necessary to identify the pathways of C sequestration in soils and for maintaining soil organic C (SOC) at a level critical for up keeping soil health and also for restraining global warming (Bastia *et al.*, 2013, Bonilla *et al.*, 2012). Therefore, fractionating and quantifying the labile and recalcitrant C pools could provide valuable information for better understanding SOC changes and the underlying mechanisms (Behera *et al.*, 2007). Long-term fertilizer experiments showed that applying chemical fertilizer in combination with farmyard manure significantly increased SOC content more than using chemical fertilizer alone in tropical cropping system (Lima *et al.*, 2009) and semi-arid tropics (Banger *et al.*, 2009). The responses of various SOC fractions to

increased organic manure and carbon stock and carbon sequestration potential are not well documented in the Typic Udorthents based on long-term experiments. The present study aimed with the hypothesis that continuous manure application under a year-round vegetable production system would store more C in soil and reduce emission of CO₂ and would have the potential to adapt and mitigate the climate change impacts in the western Himalayan regions.

Materials and Methods

Site description

The experiment is located at the experimental farm of Himachal Pradesh Krishi Vishvavidyalaya, Hill Agricultural Research and Extension Centre, Bajaura, Kullu, India (31.8°N latitude, 77°E longitude). The climate is sub-humid and sub-tropical, receives annual rainfall of 1500–3000 mm. Before initiating the field trial, the soil was silty clay loam and soil pH at top layer (0–0.15 m) and sub surface (0.15–0.3 m) was 6.5 and 6.4 (1:2.5 soil: water suspension), bulk density 1.36 g cm⁻³ and easily oxidizable (K₂ Cr₂ O₇ + H₂ SO₄) organic carbon 0.38 and 0.29 %, respectively.

Experimental design

The long-term field experiment was initiated in 2004. The experiment consisted of three management practices [100% organic (recommended dose of NPK fertilizer supplemented through a mix of farmyard manure and vermicompost); 100% inorganic (recommended NPK fertilizer); integrated (50% of recommended NPK fertilizer + 50% NPK supplemented through a mix of farmyard manure and vermicompost)] and four cropping systems [tomato (*Solanum lycopersicum* L. var. commune) –cauliflower (*Brassica oleracea* var. brotytis)- green pea (*Pisum sativum* L.var. arvense); frenchbean

(*Phaseolous vulgaris* L.) – frenchbean-cauliflower; cauliflower – cauliflower- green pea; maize (*Zea mays* L.) + frenchbean - garlic (*Allium sativum* var. sativum] with permanent fixed plot size. The net plot size was 50 m² (10 m × 5 m). Each strip was isolated by 1 m deep plates. Mineral N, P and K fertilization was urea, single superphosphate and muriate of potash, respectively. The mean chemical characteristics of farmyard manure were 2.35% N, 0.27% P, 2.39% K and that of vermicompost was 68% N, 0.20% P, 1.28% K. The farmyard and vermicompost used in the trial were applied on the nitrogen equivalent basis as per nutrient requirement of each crop. Phosphorus requirement of the crops were met through rock phosphate (32% P) in organic treatment. The transplanting of tomato, cauliflower and sowing of pea, maize, frenchbean and garlic was done as per the state level recommended package of practices. The organic manures according to the treatment were applied to organic and integrated nutrient management plot two weeks before sowing. The mineral fertilizers in inorganic and integrated (recommended N: P: K dose of 20:60:30 kg ha⁻¹ for garden pea, french bean, 125:75:55 kg ha⁻¹ for tomato and cauliflower, 100:60:50 kg ha⁻¹ for garlic and 90:60:45 for maize) were applied in two equal splits (half dose at the sowing/transplanting time and remaining half dose 30–45 days after transplanting/sowing). No chemical insecticides and pesticides were used in organic nutrient management strip, however, integrated pest management (IPM) and integrated disease management (IDM) in integrated nutrient management and inorganic treatment were taken up for insect and disease control.

Soil sampling and analysis

Triplicate soil samples at two soil depths (0–0.15, 0.15–0.3 m) from each strip were

collected at the initiation of trial (2004) and after 9th cropping cycle (2013–14). The samples were air-dried, ground and passed through a 0.2-mm sieve and stored at room temperature.

Estimation of soil properties

Soil bulk density (BD, Mg. m⁻³) was determined using a core sampler (diameter 7 cm and height 8 cm). Soil organic carbon was estimated with method of Walkley and Black (1934).

The enumeration of total bacteria and fungi was carried out by serial dilution plate count technique using nutrient agar for bacteria and Martin's Rose Bengal agar for fungi (Martin, 1950). Acid phosphatase activity was measured by the method of (Arutyunyan and Galstyan, 2003).

Estimation of carbon stock, carbon sequestration and potential

The soil carbon stock was computed by the formula given by (Joao Carlos 2001):

$$\text{SOC t ha}^{-1} = \text{bulk density (mg m}^{-3}\text{)} \times \text{organic carbon (\%)} \times \text{soil depth (cm)}$$

The carbon sequestration in soil was calculated as follow:

$$\text{Carbon sequestration (t C ha}^{-1}\text{yr}^{-1}\text{)} = \text{OC}_{\text{current}} - \text{OC}_{\text{initial}}$$

where, OC_{current} and OC_{initial} indicate the organic carbon stocks in 2013 (current) and that at the initiation of the long-term experiment in 2004, respectively.

Carbon sequestration rate was computed using the formula:

$$\text{SOC stock / No. of years of experimentation}$$

Estimation of carbon pools

Organic C fractions were determined by wet oxidation using the method proposed by (Chan *et al.*, 2001). One half gram of ground (0.5 mm) soil was placed in a 500 ml Erlenmeyer flask to which 10 ml 0.167 mol/L $K_2Cr_2O_7$ was first added, followed by 5 and 10 ml of concentrated sulphuric acid instead of the 20 ml specified by Walkley and Black (1934). Oxidation was carried out with an external heat source (average temperature of 140°C) and the extract obtained was dissolved with 80 ml distilled water. The excess dichromate was determined by titrating against 0.5 mol/L $Fe(NH_4)_2(SO_4)_2 \cdot H_2O$. The resulting three acid-aqueous solution ratios of 0.5:1, 1:1, and 2:1 (which corresponded respectively to 6, 9 and 12 mol/L H_2SO_4) allowed comparison of oxidizable organic carbon extracted under increasing oxidizing conditions. The amount of oxidizable organic carbon determined using 5, 10, and 20 ml of concentrated sulphuric acid when compared with total carbon concentration allowed separation of total organic carbon into four fractions of decreasing oxidizability (Chan *et al.*, 2001):

Fraction 1: organic carbon oxidizable under 6 mol l^{-1} H_2SO_4 and corresponds to the labile fraction of organic C;

fraction 2: the difference in oxidizable organic carbon extracted between 9 and 6 mol l^{-1} H_2SO_4 and corresponds to the moderately labile fraction;

Fraction 3: the difference in oxidizable organic carbon extracted between 12 and 9 mol l^{-1} H_2SO_4 and corresponds to the slightly labile fraction. The 12 mol l^{-1} H_2SO_4 is equivalent to the standard Walkley and Black method; and

fraction 4: residual organic carbon after reaction with 12 mol l^{-1} H_2SO_4 and

corresponds to the recalcitrant fraction of organic C.

Data analysis

All the data was arranged in a strip plot design keeping cropping system in main plot and nutrient management practice in sub-plot. Statistical analyses were performed using CPCS1 software package. Significant differences were analyzed using LSD test at significance level $P = 0.05$.

Results and Discussion

Soil properties

Soil organic carbon and bulk density recorded significant change at two depths due to nutrient management practices (Table 1) but cropping systems had no effect on soil bulk density. The largest increase for soil organic carbon (1.07 %) was recorded under organic practice at top layer and decreased at sub surface depth (0.90 %). On the other hand, organic practice tended to decrease soil bulk density in surface depth (1.40 $mg\ m^{-3}$) but increased in sub surface depth (1.42 $mg\ m^{-3}$), which suggests that long-term application of organic amendments significantly improved soil physical conditions (Table 1).

The soil microbial properties due to management practices increased in surface depth and observe decreasing trend with increased soil depth (Table 2). The organic practice in comparison to inorganic and integrated practice recorded higher growth of bacteria (8.6 and 4.8 $10^6\ cfu\ g^{-1}$), fungi (4.5 and 1.6 $10^6\ cfu\ g^{-1}$) and phosphatase enzyme (9.3 and 3.9 $\mu\ p\text{-nitrophenol}\ g^{-1}$) in top layer than sub surface depth. The cropping systems exhibited a significant effect on soil microbial properties in top soil layer, however no effect was observed in sub layer. The highest count in top layer with respect to bacteria (8.7 10^6

cfu g⁻¹), fungi (3.2 10⁶ cfu g⁻¹) phosphatase enzyme (7.6µ p-nitrophenol g⁻¹) was recorded in cauliflower - cauliflower – green pea system as compared to other cropping systems (Table 2).

Our results clearly show that trends in soil properties depend on long-term fertilization regime. Significant changes observed in soil properties over time for organic treatment are consistent with the observations reported by Purakayastha *et al.*, (2008), which attributed improvement in soil bulk density in organic manure incorporated soils to the build-up of soil organic matter and better soil structure. This also agrees with the findings of Bastia *et al.*, (2013) and Lima *et al.*, (2009) where improved soil bulk density was observed due to incorporation of organic manure into the soil. Ma *et al.*, (2011) also attributed the improvement in bulk density of soil treated with organic manures, mainly due to the enhanced microbial population and activity that resulted in the formation of aggregates and increased porosity.

Among tested fertilizer treatments, organic fertilizer had significant impact on soil microbial properties. The maximum microbial growth in organic treated plots was due to the presence of easily water soluble C and N in FYM (Paul *et al.*, 2003), which acts as a source of energy for soil organisms, whereas the easily soluble C component was missing in mineral fertilizer (Behera *et al.*, 2007) and, hence, the microbial population was less in the plots under NPK. The current findings are in the agreement with results obtained by (Bonilla *et al.*, 2012, Zhang *et al.*, 2012). The effect of organic amendments on enzyme activities was probably a combined effect of a higher degree of enzymes stabilization to humic substances and an increase in microbial biomass with increased soil carbon concentration (Garcia *et al.*, 2008), (Liu *et al.*, 2013, Mohammadi *et al.*, 2011). Agricultural

practices such as crop rotation along with inclusion of legumes in rotations, increases carbon biomass resulting higher population of micro flora in soil (Venkatesh *et al.*, 2013).

Carbon stocks and carbon sequestration

Table 3 revealed that organic practice had higher carbon storage (22.5 t.ha⁻¹ yr⁻¹), carbon sequestration (17.0 t.ha⁻¹ yr⁻¹) and carbon sequestration rate (2.5 t. ha⁻¹ yr⁻¹) in top layer than sub surface layer. The maximum value for organic carbon (0.88 %), total soil organic carbon stock (18.9 t. ha⁻¹ yr⁻¹), carbon sequestration (11.7 t.ha⁻¹ yr⁻¹) and carbon sequestration rate (2.9 t.ha⁻¹ yr⁻¹) in top layer was recorded in cauliflower – cauliflower - pea system (Table 3).

The present study revealed that value of carbon sequestration and dynamics was maximum in top layer as compared to sub-surface depth. The decrease in the soil organic carbon stock, carbon potential and rate with the depth may be due to relatively low microbial population in the subsurface layers and decreased decomposition activity (Sukkel *et al.*, 2008). According to (Shrestha *et al.*, 2008), the surface layer in agricultural soil also have more carbon than subsurface layer because the surface layer remains in dynamic equilibrium with biological and anthropological activities and thus is generally richer in carbon than the subsurface layers. The abundance of litter available for decomposition in the surface layer makes the release of the labile compounds in the surface layer thus making it rich in terms of soil organic carbon (Sukkel *et al.*, 2008). According to (Kundu *et al.*, 2007), crop rotation is among the best management practices for increasing soil carbon stock. Similar results were obtained in the study done by (Gaiser *et al.*, 2009, Abreu *et al.*, 2011) in which SOC content in soil was increased due to different crop rotations.

Table.1 Soil organic carbon and bulk density of cropping systems under Different management practices

Treatment	OC (%)		BD (Mg. cm ⁻³)	
	Depth (m)			
	0-0.15	0.15-0.3	0-0.15	0.15-0.3
Management Practice				
Organic	1.07	0.90	1.40	1.42
Inorganic	0.71	0.48	1.46	1.50
Integrated	0.84	0.69	1.42	1.45
CD p=0.05	0.04	0.04	0.01	0.02
Cropping system				
Tomato-cauliflower-pea	0.86	0.68	1.40	1.46
Frenchbean-frenchbean-cauliflower	0.80	0.68	1.41	1.46
Cauliflower-cauliflower-pea	0.88	0.69	1.40	1.45
Maize +frenchbean-Garlic	0.84	0.70	1.40	1.45
CD p=0.05	0.1	NS	NS	NS

Table.2 Soil microbial properties of cropping systems under different management practices

Treatment	Bacteria (10 ⁶ cfu g ⁻¹)		Fungi (10 ⁵ cfu g ⁻¹)		Phosphatase enzyme (μ p-nitrophenol g ⁻¹)	
	Depth (m)					
	0-0.15	0.15-0.30	0-0.15	0.15-0.30	0-0.15	0.15-0.30
Management Practice						
Organic	8.6	4.8	4.5	1.6	9.3	3.9
Inorganic	7.7	1.5	0.9	0.4	3.7	1.6
Integrated	8.2	4.2	4.2	1.3	8.7	3.5
CD p=0.05	0.01	0.13	0.07	0.04	0.17	0.08
Cropping system						
Tomato-cauliflower-pea	8.0	3.7	3.2	1.2	7.4	2.8
Frenchbean-frenchbean-cauliflower	7.0	3.7	3.1	1.0	7.0	2.9
Cauliflower-cauliflower-pea	8.7	3.8	3.8	1.4	7.6	2.8
Maize +frenchbean-Garlic	7.0	3.7	3.2	1.3	7.2	2.7
CD p=0.05	0.01	NS	0.08	NS	0.14	NS

Table.3 Soil carbon storage and sequestration of cropping systems under Different management practices

Treatment	SOC Stock (t.ha ⁻¹ yr ⁻¹)		C-Seq. (t.ha ⁻¹ yr ⁻¹)		C-Seq. Rate (t.ha ⁻¹ yr ⁻¹)	
	Depth (m)					
Management Practice	0-0.15	0.15-0.3	0-0.15	0.15-0.3	0-0.15	0.15-0.3
Organic	22.5	19.5	17.0	13.9	2.5	2.2
Inorganic	15.1	10.5	6.8	5.0	1.7	1.2
Integrated	17.6	14.9	9.3	9.1	1.9	1.6
CD p=0.05	1.2	0.9	1.1	0.6	0.1	0.1
Cropping system						
Tomato-cauliflower-pea	18.1	14.8	11.0	9.3	2.0	1.3
Frenchbean-frenchbean-cauliflower	17.4	14.8	10.0	9.3	1.5	1.1
Cauliflower-cauliflower-pea	18.9	14.9	11.7	9.4	2.9	1.5
Maize +frenchbean-Garlic	18.0	14.3	10.5	9.3	2.3	1.7
CD p=0.05	0.4	NS	0.3	NS	0.2	NS

Table.4 Soil organic fractions of cropping systems under different management practices

Treatment	Carbon Fraction							
	C fraction ₁		C fraction ₂		C fraction ₃		C fraction ₄	
	Depth (m)							
Management Practice	0-0.15	0.15-0.3	0-0.15	0.15-0.3	0-0.15	0.15-0.3	0-0.15	0.15-0.3
Organic	0.48	0.33	0.25	0.21	0.14	0.10	0.21	0.19
Inorganic	0.24	0.24	0.20	0.17	0.10	0.07	0.16	0.11
Integrated	0.30	0.24	0.21	0.19	0.12	0.09	0.18	0.15
CD p=0.05	0.028	0.030	0.017	0.019	0.007	0.01	0.012	0.014
Cropping system								
Tomato-cauliflower-pea	0.32	0.27	0.21	0.21	0.11	0.13	0.16	0.17
Frenchbean-frenchbean-cauliflower	0.32	0.26	0.20	0.21	0.11	0.11	0.15	0.15
Cauliflower-cauliflower-pea	0.35	0.28	0.23	0.20	0.13	0.12	0.17	0.17
Maize +frenchbean-Garlic	0.33	0.26	0.21	0.20	0.10	0.12	0.15	0.16
CD p=0.05	0.016	NS	0.011	NS	0.010	NS	0.017	NS

Agricultural system has shown better results under crop rotations practices as many studies have shown in the past (Kaur *et al.*, 2008). The total carbon stock in agricultural system also included crop residue input into the soil

and in this way it enhanced total carbon stock in agricultural system. According to Shah *et al.*, (2003) the change in soil carbon stock is directly related to C input from crop residues and organic amendments. Enhanced C

sequestration in agricultural soils not only has the potential to help reduce atmospheric CO₂ concentrations, but also promotes the productivity and sustainability of agricultural systems (Kundu *et al.*, 2007).

Carbon fractions

The nutrient management practices had a significant effect on the distribution of different carbon pools at the surface and sub-surface depth (Table 4). The organic treatment over integrated and inorganic treatment significantly increased C fraction 1 (0.48 t.ha⁻¹ yr⁻¹), C fraction 2 (0.25 t.ha⁻¹ yr⁻¹), C fraction 3 (0.14 t.ha⁻¹ yr⁻¹) and C fraction 4 (0.21 t.ha⁻¹ yr⁻¹) in top soil layer compared with low value recorded for C fraction 1 (0.33 t.ha⁻¹ yr⁻¹), C fraction 2 (0.21 t.ha⁻¹ yr⁻¹), C fraction 3 (0.10 t.ha⁻¹ yr⁻¹) and C fraction 4 (0.19 t.ha⁻¹ yr⁻¹) in sub surface.

Different C fractions in surface depth recorded significant variation due to variable crop rotation but no effect was observed in sub surface depth (Table 4). Irrespective of cropping system and nutrient management, content of C fraction 1 at 0–0.15 and 0.15–0.30 m was more than other carbon fractions. The highest C fraction 1 (0.35 t.ha⁻¹ yr⁻¹), C fraction 2 (0.22 t.ha⁻¹ yr⁻¹), C fraction 3 (0.12 t.ha⁻¹ yr⁻¹) and C fraction 4 (0.17 t.ha⁻¹ yr⁻¹) was recorded in top soil layer under cauliflower – cauliflower – green pea system of cropping when compared with other systems. SOC fractions with different stabilities and turnover rates are important variables to detect the influence of agricultural management on soil quality. The carbon fractions have been defined as a labile SOC pool mainly consisting of plant residues partially decomposed and not associated with soil minerals. From 2004 to 2013, SOC concentrations (0–0.15 m layer) increased significantly for all treatments and the greatest increases occurred for treatment that

received organic materials. Apparently, application of only fertilizers did not increase SOC content over long-term cropping. This observation was consistent with that of Rudrappa *et al.*, (2005), Gong *et al.*, (2009), Li *et al.*, (2010) who recorded increase in carbon fractions under organic treatment which was attributed to the availability of additional mineralisable and readily hydrolysable carbon resulting in higher microbial activity (Chan *et al.*, 2001). The inclusion of legumes in cropping systems had beneficial effect on carbon distribution of different soil carbon pools. Higher amounts of carbon fraction under the vegetable cropping systems with legume crops as compared non legume system could be attributed to the addition of more below ground biomass in the form of roots (Ganeshamurthy *et al.*, 2009). Similar increases in soil C fraction due to inclusion of pulses in cropping system were also reported in long-term experiments (Rudrappa *et al.*, 2005).

This study concluded that organic management of cauliflower-cauliflower-green pea cropping system has ability to accumulate higher amount of soil organic to enhance carbon sequestration and is considered to be the best crop management practice in terms of maintenance of soil environment the western Himalayas.

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