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Effect of Cultivation on Organic Carbon Pools and Nutrient Availability in Soil under Different Land Use System: A Review

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A B S T R A C T

Soil organic carbon (SOC) is an essential component of soil organic matter and being dynamic in nature controls the nutrients release as well as their availability. Different fractions of organic carbon plays different role in governing the nutrient availability. The various fractions of SOC includes- microbial biomass carbon (MBC), dissolved organic carbon (DOC), light and heavy fraction carbon pool. Among these fraction MBC and DOC fractions are readily soluble or highly mineralizable while heavy fraction carbon constitute the resistant fraction and account higher percentage compared to all other fractions. DOC accounts smallest fraction but it is directly involves in plant nutrition. Microbial biomass carbon was reported higher (430.7 µg g^{-1}) under forest land use system followed by organic farming (230.0 µg g^{-1}) land use system while both these system are significantly higher in MBC as compared to agricultural and riverine land.). Agricultural soil has 50-75% less C stocks compare to reference site which is under native forest. Light fraction carbon (LFC) comprised largely of incompletely decomposed organic residues, may provide a sensitive indicator of the effects of cropping practices on soil organic matter. Soil under no tillage and forest preserved respectively 167% and 94% more LFC than those under conventional tillage. Conversion of native forests and pristine soils to cultivation is usually accompanied by decline in SOC and deterioration of soil structure. Trees had long been found to increase organic carbon, extractable P, and exchangeable cations. The soil solution concentration of N, P, S and several micronutrients are intimately related to organic fraction in soil. Altering land use system have multiple effects on soil properties and nutrients availability.

Keywords

Organic carbon, Light fraction carbon, Nutrients availability, Microbial biomass carbon

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Introduction

Soil organic matter, of which carbon is a major part, holds a great proportion of nutrients, cations and trace elements that are of importance to plant growth. The distribution of soil organic carbon (SOC) within different pools is an important consideration for understanding its dynamics and diverse role in ecosystems (Mandal *et al.,* 2007 and Benbi *et al.,* 2010). As an essential indicator of soil fertility, SOC and its different fractions have an important role in determining soil chemical, physical and biological properties. Different carbon pools changes rapidly in response to land use change

(Guo and Gifford, 2002). Soil organic carbon fractions, such as microbial biomass carbon and light fraction organic carbon generally respond more rapidly to changes in land use systems than total organic carbon content. Soil microbial biomass constitutes a transformation matrix for natural organic materials in soil and acts as a labile reservoir of plant available nutrients (Maia *et al.,* 2007 and Lakaria *et al.,* 2012).

Small change in soil organic carbon pools could have significant impact on atmospheric CO_2 concentration in future (Smith *et al.,* 2008). The changes in soil quality caused by different types of land use must be quantified prior to selecting the most sustainable type of use and management that will minimise the soil disturbances. The effect of cropping systems and management practices on soil properties provide essential information for assessing environment impact.

There is considerable concern that land use change could alter soil carbon (Houghton, 1999) and nitrogen (Potter *et al.,* 1996) cycle. Nitrogen is the most required plant nutrient, which is found in several chemical forms in soil (Cantarella, 2007), resulting in a very dynamic behaviour. Land-use changes affect the soil carbon storage and cause quantitative and qualitative changes on soil organic matter and consequently on physical and chemical characteristics that directly affect the nutrient availability to the plants (Bayer and Mielniczuk, 2008).

The changes in soil quality caused by different types of land use must be quantified prior to selecting the most sustainable type of land use and management that will minimise the soil disturbances. Keeping in mind the above facts the present document is prepared highlighting the influence of different land use system on organic carbon pools and nutrient availability in soils of different agro ecological regions.

Soil organic carbon

Soil organic carbon is the second largest carbon pool on the surface of the earth after the oceans (Swift, 2001) and the possibility of increasing the organic carbon content of the soil through changing agronomic management practices may play a role in combating climate change (Lal, 2002). Although the amount of SOC in soils of India is relatively low, ranging from 0.1 to 1% and typically less than 0.5%, yet its influence on soil fertility and physical condition is of great significance (Swarup *et al.,* 2000). Organic matter (OM) acts as the storehouse of essential nutrients and source or sink to atmospheric CO_2 and act as major factor in overall health (Lal, 2002; Mishra *et al.,*. 2002).

The clearing of forest and subsequently cultivation and tillage practices resulted in the decline of the soil quality and these changes affects on soil sensitivity to degradation and erosion (Sharif Abad *et al.,* 2014). Conversion of forest or silvipastoral system to arable lands is expected an effective decrease in soil carbon stocks (Haile *et al.,* 2008; Apezteguıa *et al.,* 2009). Martinez-Mena *et al.,* (2008) had done an experiment to evaluate the impact of cultivation on the soil carbon dynamic and carbon stock in a semiarid area of south-east Spain. They concluded that change inland use from forest to cultivate reduced the soil carbon stock (in the top 5 cm) by about 50%. The conversion of forest ecosystem to other forms of land cover may decrease the stock of SOC due to changes in soil moisture and temperature regimes, and succession of plant species with differences in quantity and quality of biomass returned to the soil (Offiong and Iwara, 2012). The SOC is recognized to consist of various fractions varying in degree of decomposition, recalcitrance and turnover rate among which active pool responds quickly to the change in the land use system or other management practices (Huang *et al.,* 2008). Offiong *et al.,* (2009) reported that the levels of SOC, total N and cation exchange capacity (CEC) were substantially higher in soils of the undisturbed secondary forest than in soils adjoining the road. Freixo *et al.,* (2002) studied the effect of tillage on soil C and N content and their fractions under two cropping systems wheat/soybean and vetch/maize. They compared it with uncultivated soil adjacent to field and concluded that higher amount of C and N soil under uncultivated than cultivated in the 0-5 cm depth.

Land use profoundly influence soil functions at multiple levels within agro ecosystems (Griffin and Broos 2009). Agricultural soil has 50-75% less C stocks compare to reference site which is under native forest (Spaccini *et al.,* 2001). Singh *et al.,* (2011) revealed that organic carbon content in kitchen garden based land use system is highest (26.1 g kg^{-1}) followed by natural forest (23.6 g kg^{-1}) and lowest under low land paddy (9.1 g kg^{-1}). Highest SOC under natural forest is due to the continuous addition of litter fall and lower addition of organic matter and intensive tillage reduces the organic carbon in the paddy land use system. Saha *et al.,* (2011) reported that the SOC in surface soils significantly decreased by 27% in forest and 45% in agricultural land whereas Geissen *et al.,* (2009) contradict to the former findings and concluded significantly higher SOC content under seasonal agriculture (2.23 g $100g^{-1}$ of soil) than under fruit plantations (1.16 g $100g^{-1}$ of soil) while other land use system such as sugarcane, forest, primary and secondary forest and pasture does not show any significant difference and ranged 1.85 to 2.70 g $100g^{-1}$ of soil content of SOC. Gupta *et al.,* (2014) revealed that the maximum SOC was under forest (37.61 t/ha) followed by horticulture (27.26 t/ha), agriculture (17.72 t/ha) and agro forestry land use system (10.84 t/ha).

Datta *et al.,* (2015) concluded that soil under guava plantation recorded highest SOC storage (61.0 Mg C ha^{-1}) upto the depth of 60 cm. However, a reverse trend of soil fertility was observed as agriculture > agri-horti-silvi-pastoral > livestock based farming system (Majumdar *et al.,* 2002 and Singh *et al.,* 2003). Lakaria *et al.,* (2012) reported that forest and organic farming systems have higher SOC content but the mineralization rate was found to be the minimum as compared to farmer's practices. An increase in SOC levels is directly linked to the amount and quantity of organic residues return to the soils (Mandal *et al.,* 2007). After each change in the land use system a new quasi-equilibrium stage is arrived over a period of constant management in terms of new land use pattern, vegetation cover and management practices (Bhattacharyya *et al.,* 2008).The dynamics of SOC with change in land use and management can better be explained by the way C is allocated in different fractions of soil organic matter (Tan *et al.,* 2007).

Organic carbon fractions

Microbial biomass plays a dual role in the soil, first as an agent for the decomposition of plant residues, with concurrent release of nutrients and second as labile pool of nutrition. Most soil organic carbon is constituted 1-3% by MBC and due to its rapid turnover rate make it important potential source of nutrients (Stevenson, 1982).

Microbial biomass carbon (MBC) corresponds to a small portion of total organic carbon and is sensitive to variations in land-use and soil management practices which provide indications of changes and future trends in SOM caused by modified management practices (Llorente and Turrion, 2009). Land use/land cover changes (degradation of natural forest and subsequent cultivation of soils) resulted in significant decreases in microbial biomass (Islam *et al.,* 2000). The decreases in soil microbial biomass and microbial biomass to total organic matter ratio by intensification of cropping systems was also reported by Bradley *et al.,* (2001). Microbial biomass carbon was reported higher (430.7 µg g^{-1}) (Table 1) under forest land use system followed by organic farming (230.0 µg g^{-1}) land use system while both these system are significantly higher in MBC as compared to agricultural and riverine land (Lakaria *et al.,* 2012). Contrasting these findings, Hungria *et al.,* (2009) observed that the microbial biomass was not clearly affected by different land use systems.

Soil solution contains varying amounts of dissolve organic carbon (DOC) which originates from plant litter, soil humus (Mc Dowell and Lickens, 1988), and microbial biomass from root exudates. Although DOC comprises of small fractions of soil organic carbon, it acts as a buffering agent in replenishment mechanism like desorption from soil colloids, dissolution from litter, and exudation from plant roots (Six *et al.,* 2000). Dissolved organic carbon is an important component of C cycling and it is supposed to be most active and mobile form of organic matter in soil and considered as indicator of soil health (Kalbitz *et al.,* 2000; Royer *et al.,* 2007; Pan *et al.,* 2010). Although DOC represents only small parts of C pools, it appears to be involved in many processes, such as translocation of nutrient and their biogeochemistry of N and P (Kalbitz *et al.,* 2000) microbial decomposer activities (Peichl *et al.,* 2007).

Studies conducted in arable soils demonstrated that quality of dissolved organic matter was highly related to soil and management associated factors rather than seasonality (Embacher *et al.,* 2007, 2008). Lakaria *et al.,* (2012) studied different pools of organic carbon under dominant land use systems in a Vertisol of Central India. They observed that the SOC pools *viz.,* water soluble carbon was the highest under forest land use system [eucalyptus (*Eucalyptus globules)*, mahua (*Madhuca longifolia*) and *tendu* (*Diospyros melanoxylo*) and horticulture [mango (*Mangifera indica*)] plantation. They also reported that among agriculture land use systems, the continuous application of farmyard manure (FYM) @ 6 t ha^{-1} yr^{-1} to soybean-wheat cropping system significantly increased DOC. Under agri-horticulture system *aonla* (*Emblica officinalis*) and guava (*Psidium guajava*) plantations along with gram as *rabi* season companion crop improved the DOC.

Light fraction carbon (LFC) comprised largely of incompletely decomposed organic residues, may provide a sensitive indicator of the effects of cropping practices on soil organic matter (Stevenson 1982). Chemical analysis indicates that LFC material is intermediate between plant material and humified organic matter with regard to carbohydrate composition, amino acid composition, and C/N ratio (Greenland, 1971; Oades and Ladd, 1977; Turchenek and Oades, 1979).

Because of its high density, clay-associated organic material is excluded and the LF, therefore, consists primarily of "free" organic matter (Greenland and Ford, 1964). Light fraction is mainly derived from plant residues, but it also contains appreciable amounts of microbial and micro faunal debris including fungal hyphae and spores (Molloy and Speir, 1977; Spycher *et al.,* 1983).

Dalal and Mayer (1987) concluded that the different land use system and management practices that enhance the amount of light fraction would increase the rate of nutrient cycling through microbial biomass and may increase the overall availability of nutrients in soil (Table 2).

Table.1 Soil organic carbon, water soluble carbon, labile carbon, soil microbial biomass carbon and microbial count under different land use systems

Land use	Soil organic carbon (g kg^{-1})	Water soluble carbon (mg kg^{-1})	Labile carbon (mg kg^{-1})	Soil microbial biomass carbon (mg kg^{-1})	Microbial count (× 10^4)
Agriculture (soybean-wheat)					
Control	5.2^{ef}	31.1^{f}	463de	133^{g}	**20-50**
Inorganic fertilization	6.3^{e}	36.7^{e}	555^{cd}	201^{ef}	**23-87**
Farmer practice (organic) **Agri-horti system (fallow-gram)**	10.8^{d}	48.2^{c}	621^{e}	230de	**36-145**
Aonla **(*Emblica officinalis*)**	4.1^{fg}	42.8^{d}	363^{e}	283^{d}	**26-95**
Guava (*Psidium guajava*) **Horticulture**	3.7^{g}	40.9^{d}	388^{c}	201^{ef}	**26-95**
Mango (*M. indica*) **Forest**	16.0^{c}	69.2^{b}	677^{b}	356^{c}	**50-185**
Eucalyptus	18.7^{b}	71.8^{b}	1527^{a}	519^{a}	**26-105**
Mahua (*M. longifolia*) and	24.8^{a}	103.9^{a}	1817^{f}	431^{b}	**50-185**
tendu (*D. melanoxylo*) **Riverine**					
Near river-bed	**2.2^{h}**	**33.2^{f}**	**173^{g}**	**149f^{g}**	**17-65**

The difference between values in a column followed by different superscripts is significant at P< 0.05
(Source: Lakaria *et al.*, 2012)

Table.2 Total C, inorganic C (SIC), total organic C (TOC), soil organic C (SOC) and total N concentration in soils of agroforestry, rice-wheat, and maize-wheat systems in the Rupnagar district of Indian Punjab

Land-use	Total C (g kg^{-1} soil)	SIC (g kg^{-1} soil)	TOC (g kg^{-1} soil)	SOC (g kg^{-1} soil)	Total N (g kg^{-1} soil)
Agroforestry	8.83^{a} (0.83)	0.48^{a} (0.08)	8.35^{a} (0.80)	6.56^{a} (0.53)	**1.1^{a} (0.08)**
Maize-wheat	8.95^{a} (0.79)	0.89^{a} (0.20)	8.06^{a} (0.70)	6.52^{a} (0.51)	**0.73^{b} (0.06)**
Rice-wheat	6.90^{a} (1.32)	0.40^{a} (0.20)	6.50^{a} (1.41)	3.88^{b} (0.89)	**0.61^{b} (0.10)**
LSD (0.05)	**NS**	**NS**	**NS**	**1.89**	**0.24**

Mean values in a column followed by same letter are not significantly different at *P* >0.05. NS = non-significant Values in parenthesis indicate standard error of mean (Source: Benbi *et al.*, 2011)

Table.3 Chemical properties of soils under different land use systems

Soil properties	Cropped area	*Leucaena leucocephala*	Grassland area	Ravine under MF	Ravine under AS
pH	7.78^{a} (0.012)	7.04^{c} (0.062)	7.32^{b} (0.012)	7.81^{a} (0.167)	**8.01^{a} (0.044)**
EC (dS m^{-1})	0.48^{a} (0.009)	0.32^{b} (0.058)	0.26^{b} (0.015)	0.45^{a} (0.035)	**0.44^{a} (0.025**
SOC (%)	0.48^{b} (0.01)	0.69^{a} (0.07)	0.76^{ab} (0.01)	0.63^{a} (0.03)	**0.45^{ab} (0.11)**
Av-N (kg ha^{-1})	277.33^{c} (3.71)	365.00^{ab} (5.51)	390.33^{a} (1.67)	291.67^{c} (1.33)	**222.0^{bc} (8.62)**
Av-P (kg ha^{-1})	14.45^{c} (0.33)	23.86^{a} (0.87)	23.82^{a} (0.95)	20.09^{b} (0.80)	**17.37b^{c} (1.50)**
Av-K (kg ha^{-1})	403.33^{a} (5.90)	421.00^{b} (17.62)	473.00^{b} (41.74)	430.00^{b} (8.66)	**563.00^{b} (10.54)**
Na [c mol (p+)kg^{-1}]	3.37^{ab} (0.20)	3.91^{a} (0.09)	3.08^{ab} (0.40)	2.97b (0.39)	**3.51a^{b} (0.06)**
Ca [c mol (p+)kg^{-1}]	26.37^{bc} (3.23)	12.24^{d} (2.09)	19.17^{cd} (1.49)	32.13^{ab} (2.37	**37.97^{a} (3.77)**
Mg [c mol (p+)kg^{-1}]	7.73^{b} (0.34)	7.14^{b} (0.03)	6.80^{bc} (0.30)	4.50^{c} (1.20)	**14.90^{a} (1.23)**
CEC [c mol (p+)kg^{-1}]	**31.20^{a} (0.72)**	**24.92^{a} (0.57)**	**18.34^{b} (1.37)**	**15.44^{b} (1.41)**	**12.96^{b} (0.58)**

Values are in parenthesis indicate standard errors. Different alphabet along row indicates significant effect.
(Source: Somasundaram *et al.*, 2014)

Table.4 Effect of land-use systems on chemical properties of soil

System ↓	Soil layer(cm) →	0-15	15-30	30-45	45-60
pH					
Forest		5.22	5.30	5.34	**5.21**
Grassland		5.69	5.70	5.61	**5.72**
Horticulture		5.46	5.56	5.50	**5.59**
Agriculture		5.50	5.49	5.53	**5.53**
Wasteland		5.60	5.69	5.65	**5.64**
$LSD_{0.05}$		L = 0.12	D = NS	L × D = NS	
Organic carbon (%)					
Forest		3.01	2.29	1.86	**1.25**
Grassland		2.16	1.85	1.69	**1.17**
Horticulture		1.68	1.52	1.04	**1.23**
Agriculture		0.90	0.65	0.49	**0.36**
Wasteland		0.85	0.56	0.50	**0.45**
$LSD_{0.05}$		L = 0.045	D = 0.006	L × D = 0.031	
Electrical conductivity ($dS\ m^{-1}$)					
Forest		0.24	0.26	0.24	**0.26**
Grassland		0.25	0.25	0.25	**0.24**
Horticulture		0.25	0.23	0.22	**0.26**
Agriculture		0.22	0.22	0.25	**0.25**
Wasteland		0.23	0.22	0.25	**0.26**
$LSD_{0.05}$		L = NS	D = NS	L × D = NS	
Cation exchange capacity ($c\ mol\ kg^{-1}$)					
Forest		15.20	15.01	14.42	**15.12**
Grassland		15.81	15.01	15.00	**14.96**
Horticulture		14.90	14.65	13.98	**14.21**
Agriculture		14.30	13.65	14.35	**13.87**
Wasteland		13.80	13.23	13.01	**14.20**
$LSD_{0.05}$		**L = 0.25**	**D = NS**	**L × D = NS**	

Note. L – Land-use system, D - Soil layer, NS - Non significant. LSD, least significant difference at the 5% probability level. (Source: Pal *et al.*, 2013)

Table.5 Effect of land-use systems on available nutrients in soil profile

System ↓	Soil layer (cm) → 0-15	15-30	30-45	45-60
Available nitrogen (kg ha^{-1})				
Forest	699	654	623	**597**
Grassland	426	401	395	**352**
Horticulture	401	357	346	**321**
Agriculture	301	295	258	**278**
Wasteland	286	249	271	**250**
LSD$_{0.05}$	**L = 16.25**	D = 7.21	L × D = 12.43	
Available phosphorus (kg ha^{-1})				
Forest	17.23	16.44	16.21	**15.01**
Grassland	15.47	14	13.91	**13**
Horticulture	13.24	12.9	14.23	**13.21**
Agriculture	12.31	12	11.96	**10.90**
Wasteland	11.48	10.21	11.12	**12.13**
LSD$_{0.05}$	**L = 0.21**	D = NS	L × D = NS	
Available potassium (kg ha^{-1})				
Forest	301.61	295.4	290.1	**287.3**
Grassland	285.21	273.1	282.72	**267.5**
Horticulture	271.5	267	254	**265**
Agriculture	265	278	264	**276**
Wasteland	264	278	254	**267**
LSD$_{0.05}$	**L = 13.25**	**D = NS**	**L × D = NS**	

Note. L – Land-use system, D - Soil layer, NS - Non significant. LSD, least significant difference at the 5%
(Source: Pal *et al.*, 2013)

Light fraction carbon is associated with non-aggregated soil and it is not ready losing from any tillage practices, and it easily accumulated in microbial biomass compared to other C fractions (David *et al.*, 2006).

Soil under no tillage and forest preserved respectively 167% and 94% more LFC than those under conventional tillage. The mass of LFC decreased with an increase in soil depth.

Carbon concentration in heavy fraction average 20, 10, 8g kg^{-1} under no tillage, forest and conventional tillage land use system respectively (Tan *et al.*, 2007). Carbon heavy fraction represented highest fraction in soil and corresponded to 82% of total organic carbon (TOC) at depth of 0-20 cm and arable land site tended to present the lowest value of heavy fraction carbon (HFC) at 0-10 cm depth (7.2 Mg ha^{-1}) as compared to silvopasture system (Matos *et al.*, 2011). Wu *et al.*, (2003) revealed that lower amount of HFC (7.8 Mg ha^{-1}) in 0-10 cm layer of continuous cultivated soil as compared to soil which is under pasture from more than 10 years after 70 years of arable cultivation.

Sekhon *et al.*, (2009) revealed that significantly higher HFC content was observed in rice-wheat cropping system which was amended with pressmud and FYM because mature compost have higher of stable product which constitute the HFC.

Available nutrient status in Soil

Soils under particular land use system may affect physic-chemical properties which may modify fertility status and nutrient availability to plants (Sharma *et al.,* 2013). The soil solution concentration of N, P, S and several micronutrients are intimately related to organic fraction in soil (Havlin *et al.,* 2005). Schipper and Sparling (2000) suggested that land use change modifications are biologically and chemically more rapid than are physically. Conversion of native forests and pristine soils to cultivation is usually accompanied by decline in SOC and deterioration of soil structure. Trees had long been found to increase organic carbon, extractable P, and exchangeable cations (Tomlinson *et al.,* 1995)

Land use pattern also plays a vital role in governing the nutrient dynamics and fertility of soils (Venkatesh *et al.,* 2003). Offiong *et al.,* (2009) reported that the levels of SOC, total N and CEC were substantially higher in soils of the undisturbed secondary forest than in soils adjoining the road. In Indian condition, Somasundaram *et al.,* (2014) observed higher amount of available nitrogen, phosphorous, potassium and CEC in soil under natural vegetation compared to other land use system (Table 3). The status micronutrients under different land use system varies as Mn>Fe>Zn>Cu which was lower in agricultural fields and ravine lands as compared to other land uses (Table). Singh and Bordoloi (2011) noted that uncultivated land recorded the maximum (308 kg ha^{-1}) potassium content followed by natural forest (218 kg ha^{-1}) and jhum cultivation (205 kg ha^{-1}). They also found higher amount of available Zn (4.2 mg kg^{-1}) was recorded in citrus orchard based land use system than pineapple orchard and higher amount of Fe was recorded by under low land paddy land use system compared to other system due to reduced conditions. Land use changes from forest and grazing lands to cultivated land increased the contents of basic extractable (Ca, Mg and K) ions and decreased the contents of extractable Al and Fe ions resulting in lower contents of total P in soils of the cultivated land than the remaining land use types (Chimdi *et al.,* 2014). Chhibba *et al.,* (2007) studied the nutrient availability in different land use system of Punjab and observed 14% more available phosphorus content in cotton-wheat system than that in the rice-wheat system. However, 15.5% more available potassium was observed in rice-wheat system than cotton- wheat system. The DTPA- extractable Zn, Fe, Mn, and Cu, were significantly greater in the surface soil under rice-wheat than that under the cotton-wheat system (Table 4 and 5).

The conversion of forest land into agriculture for crop cultivation decreased the soil organic carbon content and nutrient availability. The dynamics of SOC with change in land use and management can better be explained by the way C is allocated in different fractions of soil organic matter. The available nutrient in cultivated soil was also decreased as compared to uncultivated soil and natural forest.

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