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VARIATION IN SOIL PHYSICO-CHEMICAL PROPERTIES IN DRY TROPICS: EFFECT OF LAND-USE CHANGE

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Abstract

In the dry tropics, the soil properties especially the soil quality and function affected significantly due to the land-use change. In the present study, the impact of land-use change involving natural forest (NF), degraded forest (DF), *Jatropha* plantation (JP) and agroecosystem (AG) was analyzed on the potential of soil quality in terms of the concentration of soil organic carbon (SOC), total nitrogen (TN), pH, bulk density (BD), porosity (PO) and water holding capacity (WHC). Concentration of SOC, TN, PO and WHC was found to be maximum in NF (0.85 %, 0.132 %, 56.89 and 46.37 %) followed in decreasing order by JP (0.66 %, 0.078 %, 54.33 % and 42.63 %), DF (0.48 %, 0.068 %, 52.49 % and 40.64 %) and minimum in AG (0.34 %, 0.063 %, 47.87 % and 38.34 %). The plantation of *Jatropha curcas* on a patch of DF for 12 years improves the soil physico-chemical properties over DF and AG. It can be suggested that the JP on degraded land may be crucial strategy for the restoration of degraded land by improving soil quality and function in dry tropics.

Key words: Soil organic carbon, total nitrogen, dry tropics, *Jatropha* plantation.

Introduction

Land-use changes worldwide are responsible for degradation in soil quality (Vagen *et al*., 2006; Khormali and Nabiollahy, 2009). The capacity of a soil to function is often described as soil quality used to assess status of land or soil under various management systems (Ayobi *et al*., 2011). A soil quality indicator is a measurable soil property that affects the capacity of a soil to perform a specified function (Karlen *et al*., 1997). Soil properties that are responsive to the land-use change are considered as suitable soil quality indicators (Carter *et al*., 1993). Among others various soil physico-chemical properties are considered as index of soil quality.

Conversion of natural forest to other land-use patterns leads to not only climate change, loss of biodiversity, change in ecosystem services etc, but also affects soil physico-chemical properties (Tilman, 2001; Ashagrie *et al*., 2007). Due to an increasing demand for firewood, timber, pasture, food, and residential dwelling, the hardwood forests are being degraded or converted to cropland at an alarming rate during the last few decades.

Since soil organic matter is critically linked to the physical and chemical properties of soil (Li *et al*., 2007) may change in soil properties will affect soil organic matter and vice-versa. Maintaining soil quality (which includes various soil physical and chemical properties) is of major importance for any soil management strategy. Land-use change affects soil organic carbon accumulation and storage in soils, which in turns greatly influences the composition and quality of organic matter (Six *et al*., 2002; John *et al*., 2005; Helfrich *et al*., 2006). Land-use change not only affects soil organic carbon but it also affects other nutrient contents of soil *viz*. Nitrogen, phosphorus etc.

In the dry tropical region, most of the studies have been carried out to evaluate the effect of land-use change on the distribution and storage of soil organic carbon and nitrogen (Wu *et al*., 2003; Zhou *et al*., 2007; Yan *et al*., 2012), whereas, the study of major physical properties are lacking. It is prerequisite in terms of the sustainable management of lands to evaluate the impact of the land-use change on soil properties such as pH, bulk density (BD), porosity (PO) and water holding capacity (WHC) in addition to soil organic carbon (SOC), total nitrogen

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(TN). Since land-use change also alter the soil properties by affecting the transport of organic matter in deeper soil horizon either through alteration of belowground input of organic matter or surface mixing by soil organisms (Degryze *et al*., 2004; Richter *et al*., 1999). Study of soil properties in deeper soil horizons is needed to draw the complete scenario of impact of land-use change on soil properties through the entire soil profile.

Conversion of forest to cropland is one of the major land-use changes which result in severe degradation of soil quality (Kang and Juo, 1986; Nadri *et al*., 1996; Islam *et al*., 1999; Islam and Weil, 2000). Other factors responsible for degradation of natural forests are excessive harvesting of woody and/or non-woody product of forest, grazing, poor management and other anthropogenic disturbances. These activities severely degrade the soil quality and erode the soil at limit which inhibit or slow down the restoration process to its natural state (ITTO, 2002; Fu *et al*., 2010). These deviation of natural forest from its own native state resulted in degraded forest/lands with poor soil quality. Restoration of degraded land/forest is of great interest in the dry tropics. Plantation of *Jatropha curcas* (a perennial shrub of Euphorbiaceae family) in degraded land may be a good alternative for the reclamation of these degraded lands as the *Jatropha curcas* is drought resistant and not preferred by the animal (Krishnamurthy *et al*., 2012).

In the present study we hypothesized that (i) the land-use change from natural forest to the degraded land alters major soil physico-chemical properties through soil profile and (ii) *Jatropha curcas* plantation on degraded land may serve as an alternative to improve the soil properties after the degradation in dry tropics. To examine these hypotheses the present study was aimed to evaluate the impact of land-use change involving natural forest, degraded forest, agroecosystem and plantation *Jatropha curcas* on major soil physico-chemical properties *viz*. soil organic carbon, total nitrogen, pH, bulk density, porosity and water holding capacity through the soil profile.

Material and methods

Study sites

Four land-use patterns were selected for the study including natural forest, degraded forest, agroecosystem and *Jatropha* plantation were distributed between 25^{0}15"N. latitude, 82^{0}58"E. longitude, and ~160-190 m amsl altitude in the dry tropic region of India. Natural forest, situated at Marihan range Mirzapur, Uttar Pradesh, India, is initially spread over the entire region. Three sites *i.e.* degraded forest (NF), agroecosystem and *Jatropha* plantation were located at Rajiv Gandhi South Campus, Banaras Hindu University, Barakachha, Mirzapur, Uttar Pradesh. Degraded forest, formed mainly due to harvesting of forest products and cattle grazing for the past 50 years. Agroecosystem, with rice-barley-summer fallow as the crop sequence, was a part of degraded forest. For degraded forest rehabilitation, *Jatropha curcus* plantation was established in 100 ha area.

Soil sampling and analysis

Soil samples were collected during summer season of second annual cycle at 0-10 cm (upper), 10-20 cm (middle) and 20-30 cm (lower) soil depth for the analysis of soil organic carbon, total nitrogen, pH, bilk density, porosity and water holding capacity from all the land-use pattern sites. Each experimental site was divided into three study sites which get further subdivided randomly into nine sub-sites for natural forest, degraded forest, *Jatropha* plantation and eight for agroecosystem; out of which five were selected randomly for the sampling at a time. Two soil samples were collected from each sub-site, (*i.e.* total of 10 soil samples from each study site) with the help of soil corer (diameter 4 cm and height 10 cm, and mixed together to represent a single composite sample of a study site.

Estimation of soil organic carbon and total nitrogen

Soil organic carbon (SOC) was estimated by the dichromate oxidation and titration method (Kalembasa and Jenkinson, 1973). Total nitrogen (TN) concentration was measured by the microkjeldahl method (Jackson, 1973) by using a Gerhardt digester and distillation unit. Most of the nitrogen in soil is inorganic form relatively small amount ordinary occurs in form of ammonium and nitrates. Porosity (PO) is a value that expresses the relative amount of pore space in the soil. It is not measured directly but is calculated from the bulk density (BD) and particle density. Water holding capacity (WHC) was determined using perforated circular brass boxes (Piper, 1966).

Statistical Analysis

SPSS (version 16.0) package were used for the evaluation of the data. All the values were expressed as mean ± standard error (SE). Mean values were compared using Honestly significant difference (HSD). Significance of difference was indicated at $p < 0.05$ and $p < 0.01$.

Results and Discussion

Soil organic carbon

Across all the land-use patterns and soil depth the value of soil organic carbon varied considerably and ranged 0.21-0.85%. The maximum soil organic carbon content was observed in natural forest and followed the decreasing order by *Jatropha* plantation, degraded forest and agroecosystem. Although the content of soil organic carbon was higher on the top layer across all the land-use patterns, yet variation through the soil depth was statistically (table 1).

Soil total nitrogen

A drastic change of soil total nitrogen among all the land-use patterns was observed. The value of soil total nitrogen, varied considerably across all the land-use patterns and soil depth follow the same trend to that of soil organic carbon and ranged from 0.053-0.153%. Among the land-use patterns total nitrogen was highest in natural forest followed by *Jatropha* plantation, degraded forest and lowest in agroecosystem in all soil layers. The total nitrogen content was observed maximum at upper soil depth and decreased with middle and minimum content at lower soil depth in all the land-use patterns (table 1).

Soil pH

The soil pH changes drastically among all the land-use pattern and observed maximum in agroecosystem and followed the decreasing order by degraded forest, *Jatropha* plantation and minimum in natural forest, ranged

Table 1: Impact of land-use change involving natural forest (NF), degraded forest (DF), agroecosystem (AG) and *Jatropha* plantation (JP) on major soil physico-chemical properties through the soil profile in dry tropics. Values are mean ± standard error, at 0-10, 10-20 and 20-30 cm soil depth. In each row and column values having same alphabetic and numeric superscript respectively are not significantly different from each other ($P < 0.05$).

Soil depth (cm)	Land-use patterns				HSD
	NF	DF	AG	JP	
Soil organic carbon (%)					
0-10	$0.85^{a1} \pm 0.04$	$0.48^{c1} \pm 0.04$	$0.34^{c1} \pm 0.03$	$0.66^{b1} \pm 0.05$	0.174
10-20	$0.48^{a1} \pm 0.03$	$0.27^{b1} \pm 0.02$	$0.23^{b1} \pm 0.01$	$0.45^{a1} \pm 0.02$	0.099
20-30	$0.42^{a1} \pm 0.02$	$0.23^{b1} \pm 0.01$	$0.21^{b1} \pm 0.02$	$0.29^{b1} \pm 0.02$	0.085
HSD	0.593	0.346	0.192	0.484	
Total nitrogen (%)					
0-10	$0.132^{a1} \pm 0.002$	$0.068^{c1} \pm 0.001$	$0.063^{c1} \pm 0.001$	$0.078^{b1} \pm 0.002$	0.008
10-20	$0.111^{a1} \pm 0.004$	$0.065^{bc1} \pm 0.004$	$0.057^{c1} \pm 0.002$	$0.077^{b1} \pm 0.001$	0.013
20-30	$0.102^{a1} \pm 0.003$	$0.056^{c1} \pm 0.002$	$0.053^{c1} \pm 0.002$	$0.071^{b1} \pm 0.001$	0.010
HSD	0.04	0.016	0.014	0.01	
pH					
0-10	$6.46^{b1} \pm 0.12$	$6.76^{ab1} \pm 0.11$	$6.96^{a1} \pm 0.11$	$6.66^{ab1} \pm 0.12$	0.495
10-20	$6.37^{b1} \pm 0.09$	$6.69^{ab2} \pm 0.09$	$6.86^{a1} \pm 0.13$	$6.44^{b1} \pm 0.07$	0.439
20-30	$6.16^{c1} \pm 0.05$	$6.68^{ab2} \pm 0.08$	$6.84^{a1} \pm 0.10$	$6.39^{bc1} \pm 0.06$	0.334
HSD	0.435	0.129	0.475	0.383	
Bulk density (gcm^{-3})					
0-10	$1.14^{c1} \pm 0.01$	$1.26^{b1} \pm 0.02$	$1.38^{a1} \pm 0.01$	$1.21^{b1} \pm 0.01$	0.064
10-20	$1.19^{c1} \pm 0.02$	$1.28^{b1} \pm 0.02$	$1.42^{a1} \pm 0.01$	$1.24^{bc1} \pm 0.01$	0.064
20-30	$1.25^{c1} \pm 0.02$	$1.33^{b1} \pm 0.01$	$1.47^{a1} \pm 0.01$	$1.28^{bc1} \pm 0.02$	0.063
HSD	0.138	0.109	0.109	0.102	
Porosity (%)					
0-10	$56.89^{a1} \pm 0.52$	$52.49^{b1} \pm 0.73$	$47.87^{c1} \pm 0.17$	$54.33^{b1} \pm 0.54$	2.404
10-20	$55.01^{a1} \pm 0.69$	$51.58^{b1} \pm 0.58$	$46.57^{c1} \pm 0.41$	$53.08^{ab1} \pm 0.38$	2.400
20-30	$52.80^{a1} \pm 0.76$	$49.89^{b1} \pm 0.27$	$44.65^{c1} \pm 0.15$	$51.81^{ab1} \pm 0.65$	2.379
HSD	5.218	4.103	4.098	3.866	
Water holding capacity					
0-10	$46.37^{a1} \pm 0.73$	$40.64^{bc1} \pm 0.63$	$38.34^{c1} \pm 0.74$	$42.63^{b1} \pm 0.22$	2.791
10-20	$42.91^{a1} \pm 0.39$	$36.95^{b1} \pm 0.95$	$35.51^{b1} \pm 0.89$	$41.18^{a1} \pm 0.50$	3.268
20-30	$41.29^{a1} \pm 0.65$	$35.63^{bc1} \pm 0.66$	$32.95^{c1} \pm 1.69$	$38.42^{ab1} \pm 0.77$	4.698
HSD	6.821	6.833	7.215	5.657	

from 6.16-7.05. Across all the soil depth no significant variation was observed in the value of soil pH (table 1).

Soil bulk density

The soil bulk density (BD) was drastically differ across the land-use patterns and soil depth and ranged from 1.14-1.47 gcm^{-3}. Higher bulk density was observed in the soil of agroecosystem than all the land-use patterns for three different soil depths. The trend of soil bulk density decreased through degraded forest, *Jatropha* plantation and lowest in natural forest in all the soil depth. No significant variation was observed in the value of soil bulk density across the soil depth. The value of soil bulk density was observed minimum at upper soil depth and followed the increasing order by middle and maximum at lower soil depth (table 1).

Soil porosity

The soil porosity ranged from 44.65-56.89% in all the land-use patterns and soil depth. The soil porosity showed a reverse trend to that of soil bulk density and observed highest in natural forest followed in decreasing order by *Jatropha* plantation, degraded forest and agroecosystem in all the soil depth. At the upper soil depth, the soil porosity was found maximum and decreased through middle and minimum at lower soil depth (table 1).

Water holding capacity

Across all the land-use patterns and soil depth the soil water holding capacity ranged from 32.95-46.37%. Across the soil profile, the water holding capacity was observed highest at upper layer and decreased in middle and lowest at the lower soil depth. Among the land-use patterns the soil water holding capacity was found maximum in natural forest followed by *Jatropha* plantation, degraded forest and minimum in agroecosystem in all the soil depth (table 1).

Discussion

Impact of land-use change on soil physico-chemical properties

In the present study, the soil organic carbon and total nitrogen content in the soil of natural forest may be associated with the large annual input of organic matter in the form of leaf litter which remains in the soil due to the lower disturbance consequently results in accumulation of organic carbon and total nitrogen in natural forest. The accumulation of carbon in soil is proportional to the organic matter inputs in soil which inturn is reported to be dependent on plant biodiversity (Catovasky *et al.*, 2002). Perennials trees and ground flora of natural forest having extensive root systems might have favoured accumulation of soil organic carbon in natural forest as it is reported that the contribution of roots in storage of soil organic carbon in soil is more as compared to above ground biomass (Puget and Drinkwater, 2001). Higher input of organic matter in the soil of natural forest along with lower disturbances might be the reason of lower compaction of soil which was observed in the form of lowered bulk density and higher porosity in the soil than other land-use patterns in the present study (table 1).

In the present study, at the upper soil layer 51% reduction in soil organic carbon and 48% reduction in soil total nitrogen occurred as the result of conversion of natural forest to degraded forest (table 1) which might be due to the change in vegetation cover leading to lower input of organic matter in soil than natural forest, as degraded forest faces high logging and grazing activity (Houghton, 1999; Tripathi and Singh, 2009). It was also reported that the change in land-use practices through the change in the composition and diversity of plants exerts major influences on the transfer and accumulation of carbon into the soil (Tilman *et al.*, 2006). Since high anthropogenic disturbances especially the cattle grazing (Wiesmeier *et al.*, 2012) results in increasing the compactness of soil might explain the higher bulk density of soil in degraded forest. Lower organic matter accumulation and higher compaction of soil resulted in lower porosity and water holding capacity in degraded forest (Bronson *et al.*, 2004)

Removal of major portion of crops through harvesting and leaving behind only the stubble and roots in the agroecosystem might explain the loss of 68% of soil organic carbon and 52% soil total nitrogen as compared to natural forest in the present study. In addition the repeated tillage practices in agroecosystem and maximum loss due to the lower input of organic matter disturb the equilibrium of carbon input and output and results the reduction in soil organic carbon content. The conversion of natural forest to agroecosystem by land-use practices, change the quantity and quality of organic matter input to the soil, nutrient addition and loss, and stimulate the decomposition of organic matter which alters the soil organic carbon (Murty *et al.*, 2002). The lower soil organic carbon content in agroecosystem than virgin forest and grassland due to the lower organic matter input and minimum protection of soil organic carbon by ploughing activity and accelerated rate of oxidation of soil organic matter (Chen *et al.*, 2010; Abera and Belachew, 2011; Singh and Ghoshal, 2011). The concentration of soil total nitrogen in agroecosystem was observed lower than the natural forest (52%) and other land-use patterns at upper soil layer might be due to the high disturbances trough tillage activity which inturn loss of soil organic matter in the present study (Aghasi *et al*., 2011).

In the present study, the 17% reduction in WHC, 16% reduction in porosity and 21% increase in bulk density due to the conversion of natural forest into agroecosystem (table 1) was due to the reduction in soil organic matter and increase in soil compactness due to the repeated tillage and other agricultural practices. Such trends were also reported by Singh *et al*. (2009) and Chen *et al*. (2010). Although the soil organic carbon and total nitrogen content was lower *i.e.* 22% and 41% respectively in the *Jatropha* plantation as compared to natural forest yet it was significantly higher than degraded forest and agroecosystem probably because of higher addition of leaf and root litter in the soil. The addition of nutrient rich litter of *Jatropha* to the soil and recycling of these nutrients was probably the reason of higher accumulation of soil organic carbon and soil total nitrogen in the soil of *Jatropha* plantation (Chaudhary *et al*., 2008). The higher organic matter accumulation and relatively lower disturbances from cattle grazing improve the soil aggregation processes resulted in increase in volume of micropore, which inturn resulted in increased porosity, water holding capacity and decreased bulk density. Leaf litter of *Jatropha curcas* is reported to enhance the activity of earthworm (Singh *et al*., 2007). Earthworm makes soil porous thereby increasing the porosity, water holding capacity and decreasing the bulk density, might be one of the reason for lowered bulk density and higher porosity in the *Jatropha* plantation (Vanden *et al*., 1999).

Variation in soil physico-chemical properties with soil depth

The content of soil organic carbon and soil total nitrogen was observed highest at upper soil layer than middle and lower layer across all the land-use patterns which might be due to the more activity and accumulation of leaf litter and other plant parts at upper soil horizon. Presence of higher level of microbial biomass at upper layer (Singh and Ghoshal, 2014) might help in the conversion of litter into soil organic matter and consequently increase the soil organic carbon and soil total nitrogen, water holding capacity and soil porosity at 0-10 cm of soil than the 10-20 cm and 20-30 cm and increase in soil bulk density with soil depth across all the land-use patterns in the present study (table 1). This implies that the upper layer is the most active part of the soil profile in terms of biological activity and therefore to protect the soil profile from degradation the conservation of this layer is essential. The decrease in content of soil organic carbon and soil total nitrogen with depth in the present study in dry tropics was in agreement with the study of many other studies in different region (Abera and Belachew, 2011; Wang *et al*., 2012). The destruction of natural status of soil surface by disturbance causes harmful impact on soil organization and infiltration rate which leads to increasing runoff and become a major factor of depletion of soil total nitrogen from upper soil layer. The decline in soil total nitrogen with soil depth was also supported by many other studies (Singh *et al*., 2012; Wang *et al*., 2012). With the increase in depth, the increase in bulk density was probably due to the weight of soil of upper layers. Compaction of soil with increase in depth resulted in decrease in porosity and water holding capacity (Yi *et al*., 2014). The plantation of *Jatropha curcas* on a patch of degraded forest for 12 years improved the soil physico-chemical properties over degraded forest and agroecosystem. It can be suggested that the *Jatropha* plantation on degraded land maybe crucial strategy for the restoration of degraded land by improving soil physico-chemical properties in dry tropics.

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