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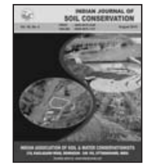

Impact of varying densities of poplar (*Populus deltoides*) plantation on soil physico-chemical properties in the *Tarai* region of Uttarakhand

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ABSTRACT

Present paper deals with changes of soil physico-chemical properties in an age series of poplar (*Populus deltoides* Marsh) plantations in *Tarai* region of central Himalaya. The 1-4 year-old plantations with 666 tree ha^{-1} and 5-9 year-old plantations with 400 trees ha^{-1} were categorized into high density (HD) and low density (LD) plantations. The basal area of tree ranged from 0.83 to 22.22 m^2 ha^{-1} in HD and 18.85 to 34.20 m^2 ha^{-1} in LD poplar plantation, respectively. The soil bulk density was 1.06-1.16 gcm^{-3} and 1.19-1.24 gcm^{-3} in HD and LD plantations. The sand, silt and clay texture were 25.4-29.4, 33.6-50.3 and 24.3-35.6 % in HD plantation and 20.5-28.4, 38.6-52.9 and 26.6-33.0% in LD plantation, respectively. The soil porosity was 54-59% in HD and 52-54% LD plantation. However, soil moisture ranged from 22.8 to 26.0% in HD and 24.2 to 26.8% in LD plantation. The water holding capacity of soils was 84.8-87.2 and 83.6-84.4% in HD and LD plantations, respectively. However, soil pH was 7.0-7.2 and 6.5-6.9, respectively in HD and LD plantations. The organic carbon was 3.0-3.8 and 2.5-3.2% in HD and LD plantations, respectively. The total soil nutrient was 1728.4-1791.4 kg N, 139.2-159.0 kg P and 696.0-731.4 kg K ha^{-1}, respectively in HD plantation. Total soil nutrient in LD plantation was 1723.6-1817.2 kg N, 124.0-153.4 kg P and 719.2-767.0 kg K, respectively. Most of the soil physico-chemical properties decreased with increase in age of HD and LD plantations except bulk density, soil moisture and silt content, which increased with age in each density type plantation. The soil pH, organic carbon, nitrogen, phosphorus and potassium decreased with increase in age of HD and LD plantations. The results indicated that the soil properties changed in each poplar plantation are due to fast growth and higher uptake of soil nutrients. However, important things that associated with poplar are that it produces high amount of leaf litter and decomposes within a year. The soil properties that have been impacted by density and age of trees can be managed only if leaf litter will be utilized judiciously along with certain inputs of inorganic fertilizer (NPK) and farm yard manure (FYM).

1. INTRODUCTION

Soil nutrient availability influences productivity of forest plantations and is also related to the pattern and rates of nutrient cycling. Forest trees have the greatest nutrient need during the first 5-10 years and, therefore, need adequate nutrients for healthy growth and biomass accretion. In commercial plantation forestry, tree species are primarily selected on the basis of growth rate and capacity to achieve high dry matter production over a wide range of sites, especially for timber. However, ecological changes due to introduction of exotic tree species and impact on soil properties are often neglected (Lodhiyal *et al*., 1994). Rapidly growing demands for renewable sources have generated new ideas and turned attention on species for higher wood biomass production, especially in the central Himalayan region, where existing forest cover is under extreme stress.

The soils of *Tarai* zone are very fertile with pronounced deposition of finer organic material as well as more surface water. Among the various exotic species evaluated, Poplar

(*Populus deltoides* Marsh) is important because of its fast growth as compared to indigenous tree species and multiplicity of uses in recent years (pulpwood, plywood and match splints). In the Tarai region, an area of nearly 16000 ha is covered with poplar plantations both in forest and agricultural land and are managed either as pure plantations or as agroforestry systems by foresters and farmers. Changes in soil physical and chemical characteristics as well as cycling of nutrients in short rotation poplar plantations require certain management inputs to ensure productivity and sustainability. A few studies have been carried out by Stewart and Kellman (1982), Kadeba and Aduayi (1985), Bargali *et al.* (1993), Lodhiyal *et al.* (1994) and Lodhiyal and Lodhiyal (1997a,b) on plantations in sub-humid region of Kumaun *Tarai* in Uttarakhand. However, scientific evidences on changes in the physico-chemical characteristics of plantation soils are difficult to find. This study was carried out to investigate the characteristics of soils in two poplar plantations raised in *Tarai* region of Uttarakhand and to assess the physico-chemical characteristics of soils in an age series poplar plantations.

Study Sites

The study sites are located in Tanda and Dhimri blocks of Udham Singh Nagar district (29°3' and 29°12' N latitudes and 79°20' and 79°23' E longitudes) at 280-300 m elevation in the *Tarai* belt (a low lying land with rich soil deposits and high water table) along the foothills in central Himalaya. The climate of *Tarai* is sub-tropical monsoon type with a long dry season (from early October to mid-June) and a wet season (from mid-June to early October). The annual average rainfall for five years was 1593 mm, of which, 86% rainfall occurs from mid-June to September. The mean monthly temperature ranges from 14.4°C (in January) to 31.3°C (in June). The original vegetation in the region consisted of deciduous and evergreen sal mixed broad-leaved tree species- *Shorea robusta* Gaertn F., *Bombax ceiba* Linn. *Syzygium cumini* (Linn.) Skeel., *Terminalia bellerica* Roxb. *Toona ciliata* M Roem., *Butea monosperma* (Lamk.) Taub., *Acacia catechu* Willd., *Mallotus philippinensis* (Lam) Muell Arg, *Adina cordifolia* Hook f, *Albizia lebbeck* Benth. *Bauhinia variegata* (Linn.) and associated other tree and shrub species fall in category of type-3C/c (*i.e.* moist sal bearing forests) and sub-type 3C/c_2c (*i.e.* moist *tarai* Sal) of tropical moist deciduous forests (Champion and Seth,1968). These forests had been removed during the 1960's and replaced with other fast growing species including eucalypt and various poplar clones (*Populus deltoides* Marsh) in short rotation plantation forestry program in the central Himalayan *Tarai* region (Lodhiyal el al., 1995a,b). Presently, many poplar clones such as G48, L39, L34, L129 S7C1, S7C4, S7C8, Udai, Kranti *etc.* have been raised by foresters and farmers in *Tarai* region. Poplar trees produce commercial wood that provides much income to growers at the rate of ₹3000 to 5000 tree^{-1} at a rotation of 8-10 years having 100-150 cm girth and 20-25 m tree height. Apart from this, poplar trees store large amount of atmospheric carbon within a short rotation period (8-10 yrs) and are, therefore, considered important in the mitigation of climate change effects (Singh and Lodhiyal, 2009).

2. MATERIALS AND METHODS

Soil Analysis

Soil samples were collected randomly with the help of a soil corer at 0-10cm, 10-20 cm and 20-30 cm depth in January, May and September, respectively from each age poplar plantation i.e. high density (666-tree ha^{-1} in 1-4 yrs-old) and low density (400-tree ha^{-1} in 5-9 yrs-old) which were located close to adjacent natural forests. All the samples were brought separately to the laboratory in polythene bags for the analysis of physical and chemical properties. Soil texture, bulk density, water-holding capacity, moisture and porosity were determined according to Misra (1968). The pH of the soil was determined by digital pH meter 1:2 proportion of soil and distilled water, respectively, total nitrogen by the micro-Kjeldahl technique (Peach and Tracy, 1956), total phosphorus with a spectrophotometer, total potassium with a flame photometer, organic carbon by the wet Oxidation method (Jackson, 1958). Soil moisture content was estimated by gravimeter method. Collected soil samples from each plantation were oven-dried at 70ºC for constant weight, thereafter, soil was sieved and categorized into soil separates such as sand (0.2-0.02 mm), silt (0.002-0.02 mm) and clay (smaller than 0.002 mm) and weighed.

3. RESULTS AND DISCUSSION

The physico-chemical characteristics of soils in an age series of high density (HD) and low density (LD) poplar plantations were studied and are discussed here. The clay content was 30.5% in HD and 35.6% in LD stands which was decreased significantly with increase in age to 24.3% in HD and 26.6% in LD stands (Table 1). Clay content in poplar plantations was low than the natural Sal mixed-broad-leaved forests growing in the adjacent area where natural forests had more (40%) clay particles in the 20 cm soil depth (Singh and Singh, 1992). The soil bulk density increased with increase in age (1-9 years age) of plantations. It ranged from 1.06 to 1.16 g cm^{-3} in 1-4 yrs HD and 1.18 to1.24 g cm^{-3} in 5-9 yrs LD stands which is higher than the natural forest (1.02 g cm^{-3}). The water holding capacity, porosity and moisture content show an opposite trend to that of soil bulk density. The detailed study carried out for physical properties of soils in each stand of high density and low density of poplar plantations are given in Table 1.

The water holding capacity decreased with increase in age of HD and LD stands, it ranged to 85-87% in HD and 84-85% in LD plantation, which was lower than the natural forests (90-95%) of the region because of higher organic

Table: 1
Physical properties of soils at different age in high density (HD) and low density (LD) poplar plantations.

Parameter	Age of poplar plantation (year)								
	HD plantation				LD plantation				
	1	2	3	4	5	6	7	8	9
Altitude (m)	300	300	300	300	280	280	280	280	280
Area (ha)	20	27	19	24	14	21	51	11	16
Density (tree ha^{-1})	666	666	666	666	400	400	400	400	400
Basal area (m^2 ha^{-1})	0.83	5.45	12.74	22.22	18.85	22.89	26.86	30.57	34.20
Bulk density(g cm^{-3})	1.06	1.09	1.11	1.16	1.18	1.19	1.21	1.22	1.24
Texture (%): Sand	29.4	27.2	26.0	25.4	30.8	28.4	25.7	23.0	20.5
Silt	40.1	44.5	47.5	50.3	33.6	38.6	44.1	49.0	52.9
Clay	30.5	28.3	26.5	24.3	35.6	33.0	30.2	28.0	26.6
Porosity (%)	59	58	56	55	54	54	53	53	52
Moisture (%)	23.5	24.8	25.2	26.0	22.8	24.2	25.0	26.4	26.8
Water holding capacity (%)	87.2	86.9	85.5	85.2	84.8	84.4	84.1	83.8	83.6

matter (6-7 t ha^{-1}) in natural forests. Soil porosity also decreased with age from 59 to 55% in HD and 54 to 52% in LD stands. The soil moisture increased considerably from 23.5 to 26.0% in HD and 22.8 to 26.8% in LD plantation, which falls within the range 21-43% reported for central Himalayan natural forests of the region (Singh and Singh, 1992). It was observed that soils with coarse textured soil particles are less sensitive because of higher porosity in contrast to the fine textured soils because of high sensitivity even to slight change in soil bulk density and approach to growth limiting threshold values.

The soil pH values ranged from 7.0 to 7.2 and 6.5 to 6.9 in high density and low-density poplar plantations, respectively. This indicated that the soils of plantations are somewhat similar to that of the natural forest (6.8-7.2). The soil was slightly acidic in LD older age plantation while slightly alkaline to neutral in younger age HD plantation. The soil pH decreased with increase in plantation age. The soil organic carbon was 3.0 to 3.8% in HD and 2.5 to 3.2% in LD plantation; however, the natural forest had shown somewhat higher (4.0%) organic carbon. As far as nutrients (NPK) are concerned, the nitrogen, phosphorus and potassium were on lower side as compared to natural sal-mixed broad-leaved forest of the central Himalayan region. Nutrient concentration of N in soil declined from 0.17 to 0.15% for N in HD and 0.15 to 0.14% for N in LD stands against 0.21% N in the central Himalayan natural forests (Singh and Singh, 1992). The P and K soil concentration decreased from 0.015 to 0.012% in HD and 0.013 to 0.010% in LD plantation. However, in case of natural forest, it was 0.018%. For K, it ranged from 0.060 to 0.069% in HD and 0.058 to 0.065% in LD plantation, which is lower than 0.089% in natural forests (Singh and Singh, 1992). The detailed analysis carried out for chemical properties of soils in each stand is given in Table 2.

Results indicated that physical properties of soils changed markedly in each density type plantation with increasing age. The decrease in the proportion of fine soil particles at the early age of the stands may be explained as an effect of rainfall erosion that had influenced the removal surface soil rapidly because of the open canopy at the initial stages. Similar effects of deterioration of soil physical structure have been reported for Eucalypt plantations (Bargali *et al.,* 1993) in adjacent areas of Central Himalayan *Tarai*. The removal of biomass in stand harvesting can greatly reduce forest floor amounts, lower soil organic concentrations and affect soil physical properties (Standish *et al*., 1988; Henderson, 1995). However, organic matter induced changes in physical properties may be more important for soil productivity than nutrients removed in the biomass(Page-Dumroese *et al.,* 2010).

Soil bulk density of stands increased with increase in age of plantations, firstly because of higher surface run-off and secondly, higher uptake of nutrients from upper soil (30 cm) by poplar trees (Lodhiyal *et al*., 1995a; Lodhiyal and Lodhiyal, 1997a). De Vries (1983) reported that bulk density indirectly effects tree growth, while a bulk density of 1.25 g cm^{-3} in loamy soil of beech forests hindered root penetration and development of beech seedlings (Hildebrand, 1983). However, Carr (1987) reported that lodge pine (*Pinus contorta*) could establish and grow in soils with bulk density greater than 1.5 g cm^{-3} but height growth was adversely affected. Clay separately accounted for 24.3-32.5% in HD plantation and 30.6-35.0% in LD poplar plantation, which is on the lower side than the range (43-51%) reported for eucalypt plantations of the region (Bargali *et al.,* 1993).

The nutrient concentration of soils decreased with increase in plantation age. The nutrient concentration in soils was influenced by structure and organic matter content occurring in the plantations, possibly as a consequence of greater nutrient uptake of poplar trees uptake and cycling of litter nutrients (Lodhiyal *et al.,* 1995b; Lodhiyal and Lodhiyal 1997b). According to Bormann and Likens

Table: 2
Chemical properties of soils at different age in high density (HD) and low density (LD) poplar plantations

Parameter	Age of poplar plantation (year)								
	HD plantation				L D plantation				
	1	2	3	4	5	6	7	8	9
Soil pH	7.2	7.1	7.0	7.0	6.9	6.9	6.8	6.6	6.5
Organic carbon (%)	3.8	3.5	3.2	3.0	3.2	3.0	2.8	2.6	2.5
	Nutrient concentration (%)								
Nitrogen	0.169	0.160	0.157	0.149	0.154	0.149	0.146	0.143	0.139
Phosphorus	0.015	0.014	0.013	0.012	0.013	0.012	0.011	0.011	0.010
Potassium	0.069	0.066	0.060	0.060	0.065	0.062	0.061	0.059	0.058
	Nutrient Content (kg ha^{-1})								
Nitrogen	1791.4	1744.0	1742.7	1728.4	1817.2	1773.1	1766.6	1744.6	1723.6
Phosphorus	159.0	152.6	144.3	139.2	153.4	142.8	133.1	134.2	124.0
Potassium	731.4	719.4	710.4	696.0	767.0	737.8	738.1	719.8	719.2

(1979), nutrient loss due to surface runoff of organic matter which can be considered in the initial preparation of site that involves the burning of ground vegetation, litter and soil disturbances. Soil properties were subjected to test of significance against each parameter in order to establish a relationship between soil parameters along with plantation age. The relationship between different parameters in each density class is given in Table 3. The tree basal area, soil bulk density, silt and soil moisture values with age showed a positive significant relationship while the parameter such as sand, clay, porosity, water holding capacity, carbon, nitrogen, phosphorus and potassium with age showed a negatively significant relationship (Table 3).

Thus, the decline in soil physico-chemical properties of exotic poplar plantations had changed the total soil nutrient pools because of fast growth and demands of high nutrients from soils through roots. Therefore, it always grows well and produces more biomass in the nutrient rich soil (Lodhiyal *et al.,* 1995b). Similar trends in soil physical characteristics and nutrients were reported for Eucalypt plantations (Bargali *et al.,* 1993). Kang and Juo (1982) reported that vegetation removal tends to loss of soil fertility rapidly because a considerable part of nutrients is removed from the ecosystem. Lundgren (1978) reported that fast growing exotic trees when planted as a monoculture resulted in high removal of organic matter and soil nutrients thus the frequent removal of vegetation results in poor fertility and instability of soils which consequently reduces plant growth and productivity.

The nutrient balance in poplar plantation soils was mainly brought by quick (89-96%) annual leaf litter decomposition (Lodhiyal *et al*., 1995a, b; Lodhiyal and Lodhiyal, 1997a, b). It also depends on how much litter and nutrient inputs occur to plantation but it varies from species to species that have been raised in plantations. The vegetation soil nutrient balance can be determined by soil nutrient concentration solution at tree root-soil interface and also depends on the supply and demands of particular nutrient (Nambiar and Sands, 1993). Manna *et al.* (2012) evaluated a continuous crop cultivation in rotation and use of fertilizer and manure application to enhance the grain yield increment and carbon sequestration efficiency in various types of soils and suggested soil organic carbon restoration process can be improved by a set of management practices in long turn that maintained soil quality that supports better crop productivity and carbon sequestration. But significance correlation was developed between nodulation and nitrogen accretion in *Robinia pseudoacacia* for their growth and establishment in wasteland soils (Raverkar *et al*., 2012) while the soil organic carbon and sequestration of forests has been assessed by Chaturvedi and Melkania (2012).

In tree based system, decomposition and carbon is slightly higher than field crop system in a similar agro-climatic condition (Kundu *et al*., 2006) but it depends on nature of leaf litter and their decomposition rate (Raizada *et al.,* 2002). Conservation of top fertile soil and rainwater are the major concern for resource conservation and greater productivity of rain-fed areas in India (Narayan and Biswas, 2012). The magnitude of nutrient loss such as organic carbon, N, P and K was higher in vegetative treatments than contour bunds practiced by farmers (Narayan *et al.,* 2014). However, the availability of micronutrients and their distribution is influenced by physico-chemical characteristics of soils while the soil moisture regimes play a pivotal role in governing the nutrient dynamics and soil fertility (Bhriguvanshi, *et al*., 2012). The organic matter availability in soil greatly influences the water transmission properties (Bhattacharya *et al*., 2009), which subsequently reduces surface runoff and land degradation (Raizada *et al*., 2014). Soil organic matter in poplar comprised with the accumulation of hydrophobic compounds and carbohydrates that has lowered the organic nitrogen availability because of lowering the microbial colonization

Table: 3

Relationship between plantation age (HD, 1-4yrs-old and LD, 5-9 yrs- old) and basal area (m^2 ha^{-1}); bulk density (g cm^{-3}); sand (%), silt (%), clay (%), porosity (%), soil moisture (%), water holding capacity (%), soil pH, organic carbon (%), concentration of nitrogen, phosphorus and potassium (%). The 'r' is correlation coefficients, 'a' is the intercept and 'b' is slope given in the table. The following are the linear regression equations which were statistically significant at p<0.01

Parameter	Age of poplar plantation (year)					
	HD plantation			LD plantation		
	a	b	r	a	b	r
1. Basal area(m^2 ha^{-1})	-7.56	7.15	0.998	-0.19	3.838	0.999
2. Bulk density (g cm^{-3})	1.03	0.03	0.982	0.10	0.015	0.993
3. Sand (%)	30.30	-1.30	-0.994	43.88	-2.60	-0.999
4. Silt (%)	37.20	3.36	0.996	9.34	4.90	0.998
5. Clay (%)	32.50	-2.04	-0.999	46.78	-2.30	-0.993
6. Porosity (%)	60.50	-1.40	-0.989	56.70	-0.50	-0.945
7. Soil moisture (%)	22.90	0.79	0.977	17.90	1.02	0.987
8. Water holding capacity (%)	88.05	-0.74	-0.958	86.24	-0.30	-0.993
9. Soil pH (%)	7.25	-0.07	-0.944	7.51	-0.011	-0.957
10. Organic carbon (%)	4.05	-0.27	-0.996	4.08	-0.18	-0.994
11. N concentration (%)	0.175	-6.30	-0.984	-0.17	-0.0036	-0.995
12. P concentration (%)	0.016	-0.001	-1.000	-0.02	-0.00007	-0.970
13. K concentration (%)	0.072	-0.0029	-0.992	0.07	-0.0017	-0.981

with an increased ratio of fungal to bacterial biomass (Baum *et al.*, 2013).

For raising fast growing plantation trees, deep ploughing may be one of the reasons of soil loss through its erosion. The nutrient loss along with soil loss occurred immediately when the trees were very young having a low tree canopy cover. However, Bormann and Likens (1979) pointed out that the soil loss along with their nutrient was due to invasion of reorganisation phase of development as the losses of biomass and nutrients occurred from the concerned ecosystem. Thus the soil and nutrient loss is one of the major destabilising forces in exotic plantation than natural forest if the vegetation removed from existing sites. The decomposition of leaf litter of poplar trees is fast compared to natural vegetation and eucalypt tree species but it was slightly decreased significantly (P<0.01) with increase in age from 0.26% day^{-1} in 1-yr-old to 0.24% day^{-1} in 9-yr-old plantations (Lodhiyal, 1990; Lodhiyal and Lodhiyal, 1997a; Lodhiyal *et al.*, 1995a). The decrease in fine soil particle, water holding capacity, moisture content, organic carbon and nutrient concentration with increase of plantation age had suggested that poplar trees take more water and nutrients from soils as the age of plantation increases. Thus the modification of soil structure and nutrients in the poplar plantations needs a judicious management inputs till its rotation age so that the soil structure and nutrient levels could be maintained.

4. CONCLUSIONS

On the basis of present findings, it is concluded that physical and chemical properties of soils of poplar plantations changed with age of trees in HD and LD poplar stands. The changes in soil properties were due to soil compactness with increase in age and fast growth of poplar trees. The age of poplar trees reduces the soil aeration, consequently decreases the root respiration and microbial activity in soils (Cannell, 1977). The poor soil aeration was due to the increase in age of poplar plantation that also results of the decreased mycorrhiza growth and penetration of mycelia (Skinner and Brown, 1974; Mitchell *et al.,* 1982). The creation of chemicals also reduces soil condition because of unavailability of soil nutrients to the plants and or even toxic to plant uptake resulted decline in the productivity (Castillo *et al.,* 1982; Mitchell *et al.,* 1982). The total amount of soil nutrients was declined with age of poplar plantations because of fast growth of poplar, canopy cover and poor understorey vegetation as well as the effects of nutrient uptake and removal of litter from forest floor surface (Lodhiyal *et al*., 1995b; Lodhiyal and Lodhiyal, 1997b) and the poplar trees were also harvested at a very short period; therefore, could not able to maintain proper biological regulations because of early site degradation. The other fact consisted with poplar as its nutrient use efficiency (net primary productivity/net nutrient uptake ratio) is comparatively low than natural Sal forests, Eucalypt plantations and Shisham forests of region (Rana *et al*., 1989; Bargali *et al*., 1993; Lodhiyal *et al*., 1995b; Lodhiyal and Lodhiyal, 1997b, Lodhiyal *et al.*, 2002; Lodhiyal and Lodhiyal, 2003). Therefore poplar demands more nutrients for dry matter production and productivity because of its poor nutrient efficiency (Lodhiyal, 2014).

The regular tree harvest of poplar in short rotation plantation influenced the disturbance to the forest floor and upper soil surface and consequently changes the physico-chemical properties of soil and their composition. Thus interestingly, the decrease in physico-chemical properties of soils with increased age of plantations showed that poplar can be managed by the proper use of leaf litter for nutrient cycling within the growing period of plantations. Although, the main focus in plantation forestry is only given how to achieve the good quantity and quality of timber within a short period from available soil nutrients. The use of essential fertilizers and technical inputs for their management is very essential otherwise continuous growing and harvesting of poplar plantations will soon exhaust the soil properties. Therefore it is suggested that the use of leaf litter, essential fertilisers and check of biotic interference can improve the physico-chemical properties of soils of plantations even if the poplar trees are raised in varying densities that needs sufficient inputs of management upto their rotation period.

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