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Variation in key soil properties after eleven years of poplar plantation in calciorthents of Bihar

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Abstract
Poplar based agroforestry systems are economically viable and more sustainable than many other crop rotations prevalent in northern India. In Bihar, about 57.2% land is under agriculture and little scope for cultivating trees of long gestation/ rotation period (25-60 years). The doubling of the growth rate of food production is still required to feed the rapidly increasing population. In recent years, poplar has emerged as a popular short rotation tree for agroforestry in north and eastern India. A study was undertaken for 11 years to judge the suitability of different poplar clones (PP-5, Uday, L-52, L-49, G-48 and L-188) along with control (treeless) plots on key soil properties. The results revealed that irrespective of poplar clones, there was significant decrease in soil pH, electrical conductivity (EC), soil bulk density and increase in soil organic carbon content (SOC) as well as soil organic carbon density (SOCD) for both surface (0-15 cm) and subsurface (15-30 cm) soil resulted in better soil conditions for crop growth under agroforestry system. In terms of soil properties and environmental sustainability, among studied poplar clones, L-52 and L-49 emerged as best clones for cultivation and promotion under calciorthent soils of Bihar.

Keywords: Agroforestry, Bulk density, Poplar, Soil organic carbon

Introduction

Deterioration of soil fertility is the most fundamental cause of low agricultural productivity and making households vulnerable to food security and income. Maintenance of soil quality is considered essential for ensuring sustainable land use. In recent years, poplar has emerged as a popular short-rotation tree for agroforestry in north and eastern India. Poplar based agroforestry systems are economically viable (Jain and Singh, 2000) and more sustainable than many other crop rotations prevalent in northern India. Poplar plantations improve soil physical, chemical and biological properties through accretion and decomposition of litterfall and roots. Deep and extensive root systems of trees enable them to absorb substantial quantities of nutrients below the rooting zone of crops and transfer them to surface soil (Allen *et al.*, 2004). Nutrient return to soil varies greatly depending on tree species, spacing, plantation age, intercrops, nature of soil, and management techniques (Mohsin *et al.*, 1996). The root of tree turnover contributes a significant proportion of recycled nutrients in agroforestry systems (Munoz and Beer, 2001). The decomposition and release of nutrients from organic matter is a function of biomass quality, soil conditions and climate (Mugendi and Nair, 1997).

In Bihar, about 57.19% land is under agriculture (Sinha *et al.* 2017), hence there is little scope for cultivating trees of long gestation/ rotation period (25-60 years). In recent years, large numbers of fast-growing exotic tree species have been raised in various parts of India under short-rotation tree-based agricultural systems. These species have been chosen for the diversification of agriculture to attain maximum benefits per unit land on a sustainable basis. Among exotic species, thinly crowned poplars (*Populus deltoides*) have a large acceptability among farmers due to their fast growth, multiple uses of their wood, low competition level with associated crops, and pruning-tolerant nature. Where climatic and ecological conditions are suitable, poplar-based agroforestry systems are economically viable and more profitable than most other crop rotations (Balooni, 2003; Puri and Nair, 2004). Intercropping provides agricultural returns on the one hand and results in increased growth rate of poplar on the other. Plantations receiving various silvicultural treatments of pruning, irrigation, fertilization, and inter-cultivation have better growth and timber production than sole trees or poorly managed plantations (Singh and Sharma, 2007). Thus, besides high returns from the wood as a supplementary income, the efficient cycling of nutrients is an essential factor for the sustainability of agriculture and the broader acceptance of poplar-based agroforestry. Keeping these facts in view, an evaluation study for the suitability of different poplar clones on crucial soil properties affecting soil health after eleven years of plantations was carried out.

Materials and Methods

Experimental site and design: A field experiment was carried out at Birouli farm, Rajendra Agricultural University, Pusa (Samastipur), Bihar under All India Coordinated Research Project on Agroforestry (ICAR) since February 2004. The present study was conducted after 11 years, *i.e.* in 2015 after the establishment of plantation in February 2004. The experimental site is situated at 25^0 39' N latitude, 85^0 48' E longitude and 53.12 m elevation above mean sea level. The site experiences subtropical climate having three distinct seasons, *i.e.,* rainy (mid-June to September), winter (October to February) and summer (March to mid-June). During 2015, there was 23% rainfall deficiency from the normal. The average annual rainfall for 11 years *i.e*., from 2004 to 2015 was 1148.2 mm. The higher variability was present for maximum and minimum temperatures, which ranged from 19.4 °C (January) to 36.7 °C (June) and 9.6 °C (January) to 25.6 °C (June), respectively.

Soil in the experimental site is calcareous, alkaline in reaction [pH (1: 2) 8.7], high in free $CaCO_3$ (38%), highly deficient in organic carbon (0.28%), poor in available N (130.20 kg ha^{-1}), P_2O_5 (19.05 kg ha^{-1}) and K_2O (97.82 kg ha^{-1}) with textural class of sandy loam (sand, silt and clay: 53.8, 35.6 and 10.5%, respectively; Table 1). The site was an abandoned agricultural land, which was fallow and not cultivated for the last five years.

Table 1. Initial soil properties of the poplar plantations site before plantation at Birouli farm of RAU, Pusa

Soil properties	Soil depth (cm)	
	0-15	15-30
Sand (%)	53.8	-
Silt (%)	35.6	-
Clay (%)	10.5	-
Textural class	Sandy loam	-
pH (1 : 2, soil : water)	8.7	8.8
EC (dSm^{-1})	0.32	0.20
Organic carbon (%)	0.28	0.21
Available N (kg ha^{-1})	130.2	111.6
Available P_2O_5 (kg ha^{-1})	19.05	13.28
Available K_2O (kg ha^{-1})	97.82	82.25
Free $CaCO_3$ (%)	38	34

Site preparation and establishment of Populus deltoides clones: Clonal trial of poplar (*Populus deltoides*) was established as an agroforestry system on 1 ha land leaving 15 m buffer to serve as a control (treeless plots) for growing sole crop. Before establishment of the experiment, six promising clones of poplar cuttings *viz.,* PP-5, Uday, L-52, L-49, G-48, and L-188 were procured from G. B. Pant University of Agriculture and Technology, Pantnagar, India and grown in nursery for one year. One-year-old Entire Trans Plants (ETP) without any co-leader or branches and with necked root (without any ball of earth) was planted in February at 4 x 5 m spacing in pits (size 50 cm × 50 cm × 100 cm) as monoclonal blocks in a randomized block design. Each clone was replicated quadruple times with a total number of 16 trees maintained for a clone per replication (plot) and thus forming 384 trees in the entire field (6 clones x 4 replications x 16 trees per replication). The size of the plot was 16×20 m^2. Each tree was fertilized with 5 kg well-rotten farmyard manure, 50 g of single super phosphate (SSP) and 25 g of muriate of potash. Nitrogen in the form of diammonium phosphate (DAP) was given at 100 g $plant^{-1}$ in two split doses (last week of June and September). The fertilization was done initially during the first two years. The plantation was irrigated weekly in summer (March-June) and fortnightly in winter seasons (October-February). No irrigations were provided during rainy season (July-September). Lower one-third portion of the stem was kept clean by the removal of emerging buds for proper growth of leading shoot up to third year. Pruning of 50% of height of the tree from 3rd year was done during winter.

A cropping pattern of 'rice (*Oryza sativa*)–wheat (*Triticum aestivum*)' was taken as intercrops in the plantation of poplar clones during 2nd and 3rd year. In 4th and 5th year 'urd (*Phaseolus mungo*)–wheat' was taken as intercrops. From 6th to 8th year of the plantations, only wheat was taken as intercrop in *rabi* season. Monospecific crop plots (treeless controls) were established block-wise in the contiguous area for comparative purposes. Crops were grown following local recommendations in respect of agronomical practices and fertilizer applications.

Collection and preparation of soil samples: Representative soil samples from 0-15 and 15-30 cm depths were collected. Collected soil samples were air-dried in shade and ground with the help of pestle and mortar. These ground samples were then passed through a 2 mm sieve and stored in polyethylene bags for further analysis of soil to determine various characteristics.

Soil chemical and physical analysis: Soil pH by glass electrode (Jackson, 1973), EC by electrical conductivity meter (Jackson, 1973), Bulk density by core sampler (Singh, 1980), Organic carbon by titration (Walkley and Black, 1934) was estimated. Mean weight diameter (MWD) and geometric mean diameter (GMD) were calculated as an index of aggregation (Kemper and Roseneau, 1986) using the formula:

$$MWD = \sum_{i=1}^{n} XiWi$$

Where, *Xi* : Arithmetic mean diameter of each size fraction (mm)
Wi : Proportion of the total sample weight occurring in the fraction i

$$GMD = \exp\left[\sum_{i=1}^{n} (Wi\log Xi) / \sum_{i=1}^{n} Wi\right]$$

Where, *Wi* is the weight of aggregates in a size class of average diameter Xi, and the denominator $\sum_{i=1}^{n} Wi$ (for values 1 to n) is the total weight of the samples. Soil organic carbon density was calculated in one-hectare furrow slice (up to 15 cm) basis: SOC density = Soil organic carbon (%) × mass of one-hectare furrow slice. Where mass of one-hectare furrow slice = volume of one-hectare furrow slice × bulk density.

Statistical analysis: The data generated from the present investigation were subjected to statistical analysis using the statistical package SPSS (14.0) and Microsoft Excel. The least significant difference (LSD) at the 5 percent level was used for testing the significant difference among the treatment means.

Results and Discussion

Soil pH: In general, there was decrease in pH of surface (0-15 cm) and sub-surface soil (15-30 cm depth) under all the plantations of poplar clones as compared to open (without trees) and initial pH (Fig 1). Sub-surface soil had more pH than that of surface soil. Irrespective of the soil depths, maximum reduction in pH (0.47 unit) was noticed under the canopy of L-52 followed by L-49 (0.37 unit), and the less change was noticed under L-188 (0.16 unit). The pH of surface soils (0-15 cm) varied from 8.20 in L-52 to 8.45 in L-188 and at 15-30 cm depth followed the same trend and varying from 8.36 (L-52) to 8.74 (L-188). Surface soil of all poplar clones except L-188 showed a significant reduction in pH as compared to open.

On the other hand, pH of the sub-surface soil significantly reduced only under L-52, L-49, and PP-5. Smallest and a non-significant decrease in soil pH under some aforesaid poplar clones might be due to low influence of acidity caused by the decomposition of lower quantity of the leaf litter, dead root biomass, and root exudates. In this situation, high content of free calcium carbonate in the soil (36%) might have the buffering capacity to resist the change in soil pH. Newaj *et al*. (2007) also observed very nominal changes in soil pH under white siris (*Albizia procera*) based Agri silvicultural system after four years of experimentation as compared to initial values due to very high free calcium carbonate content in the soils.

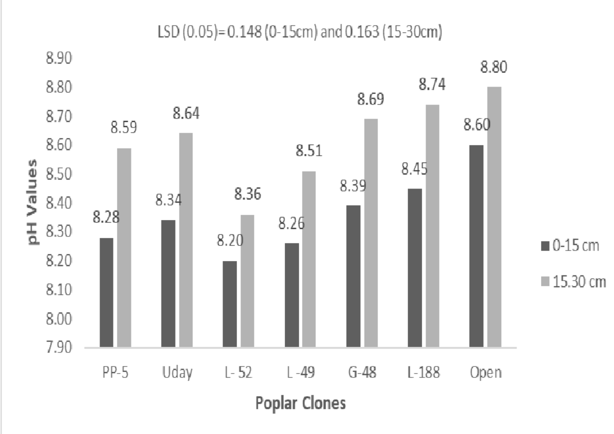

Fig 1. Effect of 11-year old poplar clones on soil pH

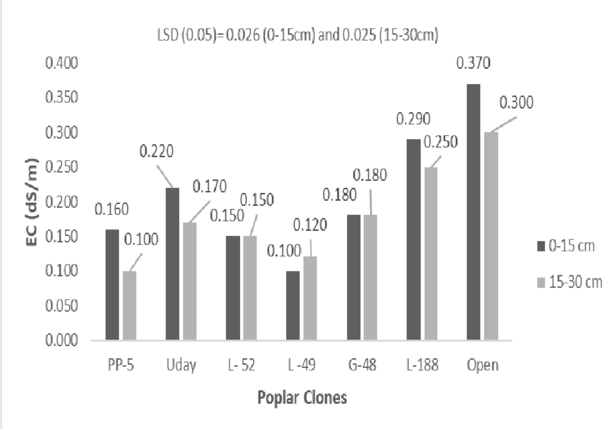

Fig 2. Effect of 11-year-old poplar clones on EC

Electrical conductivity (EC): Electrical conductivities under all the poplar plantations were significantly lower as compared to open (Fig 2). In surface soil EC varied from 0.10 in L-49 to 0.29 dSm^{-1} in L-188. In sub-surface soil it ranged from 0.10 in PP-5 to 0.25 dSm^{-1} in L-188. Irrespective of soil depths, minimum EC (0.11 dSm^{-1}) was recorded under L-49 poplar clone plots, while maximum (0.27 dSm^{-1}) was under L-188.

A significant decrease in EC of afforested plots over open plot (without trees) could be attributed to the decomposition of organic matter with the release of organic acids in the afforested plots. The effectiveness of different poplar clones in improving the soil by lowering its EC might be due to increased biomass of roots and leaf litter of different poplar clones which probably mobilized the salts after decaying. The variation in ameliorative efficiency of different poplar clones may be due to differences in absorption and translocation of sodium and its salts (Das and Chaturvedi, 2008). Reduction in soluble salt content due to plant growth was also reported by Das *et al.* (2008). In general, soil EC was more in 0-15 cm depth compared to lower depth due to presence of more litter at the surface soil. Similar variations in EC in soil profile were reported by Newaj *et al.* (2007) and Akhtar *et al.* (2008).

Soil organic carbon (SOC) and soil organic carbon density (SOCD): Initially, the status of SOC was 0.28% in surface and 0.21% in sub-surface soil (Table 1). After eleven years of rotation of poplar clones, it ranged from 0.48 to 0.63% in surface and from 0.20 to 0.35% in sub-surface soil (Table 2). At both the depths, the lowest status of SOC was in L-188 and the highest under the plots of L-52 poplar clone. All treatments had significantly higher status of SOC as compared to open (without trees) in both the soil depths. Organic carbon in soil decreased with increase in soil depth. Soil organic carbon density significantly increased in both the soil depths when compared to open plots. It varied from 10.22 (L-188) to 12.33 Mg ha^{-1} furrow slice (L-49) in surface soil layer and from 4.32 (L-188) to 7.19 Mg ha^{-1} furrow slice (L-52) in sub-surface layer. However, SOCD under L-188 did not show any marked difference when compared to open. The improvement in SOCD under plantations over open plots varied between 40% in L-188 to 85% in L-52 poplar clone plots. L-52 and L-49 had similar SOCD up to 30 cm soil depth followed by PP-5.

The site before plantation was largely carbon depleted (2.8 g kg^{-1} soil) showing low soil test rating. Hence, it had high potential to act as a sink for additional carbon. Present study revealed that the upper 0-15 cm soil in the L-52 poplar clone plot after 11- years rotation had highest value of SOC (6.30 g kg^{-1} soil) and it was 110% more over open plot. It could be because of the widespread canopy and massive litter under the trees. Besides, L-49 had almost similar soil organic carbon status. Hence, the soils under these two plantations had more potentials for sequestering organic carbon. Higher SOC in afforested area than open (treeless) could be attributed to addition of decomposable roots and litter from trees and root stubbles and leaves from crops (Chauhan *et al.,* 2009; Singh and Gill, 2014). Poplar trees, on average added 3.5 Mg ha^{-1} of litterfall every year (Arora *et al.,* 2014). Das and Chaturvedi (2005) found that tree litter fall increased with increase in age of the poplar plantations and ranged from 1.95 in 3-years-old to 10.0 Mg ha^{-1} year^{-1} in 9-years-old plantations growing in calcareous belt of north Bihar.

The superiority of L-52, L-49, and PP-5 over other tree species in improving soil properties might be due to greater litterfall of these species leading to improvement in SOC. Das and Chaturvedi (2005) reported that 17-18% of total living biomass of the young and matured *Populus deltoides* trees is in the roots and through the constant addition of dead and decayed roots, it improved organic matter status of the soil. Application of recommended doses of NPK fertilizers to the intercrops grown under these plantations from 2nd year to 8th year might have influenced favourably the root growth, leading to the accumulation of organic residues and direct

Table 2. Effect of eleven-year-old poplar clones on soil organic carbon (SOC) content, soil organic carbon density (SOCD) and soil bulk density (BD)

Poplar clones	SOC (%)			SOCD (Mg ha^{-1} furrow slice)			BD (g cm^{-3})		
	0-15 cm	15-30 cm	Mean (cm)	0-15 cm	15-30 cm	Mean (cm)	0-15 cm	15-30 cm	Mean (cm)
PP-5	0.57	0.27	0.42	11.80	5.67	8.74	1.38	1.40	1.39
Uday	0.55	0.25	0.40	11.55	5.29	8.42	1.40	1.41	1.41
L- 52	0.63	0.35	0.49	12.05	7.19	9.62	1.36	1.37	1.37
L -49	0.60	0.30	0.45	12.33	6.26	9.30	1.37	1.39	1.38
G- 48	0.53	0.23	0.38	11.21	4.90	8.06	1.41	1.42	1.42
L -188	0.48	0.20	0.34	10.22	4.32	7.27	1.42	1.44	1.43
Open	0.30	0.18	0.24	6.44	3.94	5.19	1.43	1.46	1.45
SEm ±	0.010	0.009		0.23	0.193		0.012	0.016	
LSD (P<0.05)	0.031	0.026		0.69	0.58		0.04	0.05	
CV (%)	3.656	6.486		3.66	6.49		1.79	2.25	

incorporation of organic matter in the soil. Generally, trees with lignified cells in its plant parts like litter, bark, small branches, root, etc. may lead to biochemical stabilization of organic carbon in the soil and leads to improved SOC under agroforestry as concluded by Six *et al.* (2002). Hence, one of the reasons which reveal the lower concentration of SOC under sole crop (without trees) is lack of lignified cells in agricultural residues. Soil organic carbon build-up by afforestation was reported earlier in several experiments (Dagar *et al.* 2001; Kumar *et al.* 2008; Gupta *et al.* 2009; Arora *et al.* 2014; Swami and Mishra, 2014). Swami and Mishra (2014) found the most marked differences in soil organic carbon in the upper than deeper soil layers in plantations. However, the deeper layers seem to be more stable and respond to long term C sequestration. Gupta and Sharma (2009) explained that the organic carbon found in lower layers consisted of the leached fractions of organic matter from upper layers and the decayed products of underground root biomass. Hence, a considerable increase in the organic matter content of the soil is the most important benefit of agroforestry system; it plays a vital role in improving soil health.

Soil Bulk Density (BD): Bulk density in upper 15 cm soil layers varied between 1.36 g cm^{-3} in L-52 clone to 1.42 g cm^{-3} in L-188. While in lower 15 cm soil layers, the variation was between 1.37 g cm^{-3} in L-52 and 1.44 g cm^{-3} in L-188 (Table 2). Bulk density significantly decreased under L-52, L-49, and PP-5 in both the depth of soils when compared to open (without trees).

Bulk density increased with increasing soil depth because the lower layers became more compact under the weight of the upper portion of the soil and due to the lower amounts of organic matter in deeper layers (Gupta and Sharma, 2009). Forest had significantly lower bulk density than other sites indicating relatively low soil compaction and better pore size distribution (Jha *et al.,* 2010). There was 1.38 to 5.52% decrease in bulk density in the soils under different clones of poplar plantations as compared to open land. This may be because of higher accumulation of organic matter through leaf fall, fine root recycling, twigs, etc. regularly for last ten years in the soils under plantations of poplar clones. Accumulation decreased with soil depth, and bulk density was conversely affected as shown in this study.

Inverse relationship of BD and SOC was established by several workers (Gupta and Sharma, 2008; Tandel *et al.*, 2009; Laik *et al.*, 2009; Singh *et al.,* 2004). Nayak *et al.* (2009) observed lower bulk density under *Prosopis juliflora* tree as compared to the open field. Similar results were also reported by Pingale (2009) and Ghimire (2010) under different poplar tree densities.

Aggregate stability: Mean weight diameter (MWD) and geometric mean diameter (GMD) for the surface soil under different plantations of poplar clones showed maximum values with L-52 which was at par with that of L-49 followed by PP-5 (Table 3). These parameters were also significantly higher under plantations when compared to open (without the tree). The increase in values of MWD and GMD might be attributed by higher values of organic carbon in these treatments, and this resulted in better aggregation and stability. These findings also corroborated with the findings of Ge *et al.* (2018).

Table 3. Effect of eleven-year-old poplar clones on mean weight diameter (MWD) and geometric mean diameter (GMD) of surface soils (0-15 cm)

Poplar clones	Mean weight diameter (mm)	Geometric mean diameter (mm)
PP-5	3.10	1.20
Uday	2.99	1.16
L- 52	3.42	1.32
L -49	3.26	1.26
G- 48	2.88	1.11
L -188	2.61	1.01
Open	1.63	0.63
SEm ±	0.05	0.02
LSD (P<0.05)	0.17	0.07
CV (%)	8.85	6.68

Conclusion

The findings of the present study indicated that the key soil properties *viz.*, soil pH, electrical conductivity, bulk density, soil organic carbon and aggregate stability improved after 11 years of poplar plantation in agrisilvicultural systems under upland calcareous soil condition.

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