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Biomass and nitrogen dynamics of fine roots of poplar under differential N and P levels in an agroforestry system in Punjab

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Abstract: The understanding of root distribution in the soil profile is useful for proper management of agroforestry systems. Depthwise (0-15, 15-30, 30-45 and 45-75 cm) distribution of fine root biomass (FRB), concentration and accumulation of N in the fine roots of poplar (*Populus deltoides* Bartr.) were determined during four months (April, July, October and January) in a five year old poplar plantation under different levels of N and P in an agroforestry system in Punjab. Leaf N concentration was also determined and correlated to root N concentration. Significant variations ($P < 0.0001$) were observed for these parameters among soil depths, months and nutrient levels. Total FRB and N accumulation (0 - 75 cm depth) were the lowest in unfertilized trees (33.7 g m^{-2} and 191 mg m^{-2}, respectively) and the highest at the highest level of nutrient application (95.7 g m^{-2} and 1290 mg m^{-2}, respectively). More than 35 % FRB and 42 % N accumulation were confined to 0 - 15 cm soil depth which declined with increasing depth. Fine root biomass and N accumulation were significantly higher in July and October than April and January whereas root and leaf N concentration were the highest in April (1.04 and 1.19 %, respectively) and the lowest in January (0.72 and 0.90 %, respectively). Root and leaf N concentration also increased significantly ($P < 0.0001$) with the application of nutrients. It may be concluded that the root competition between tree and intercrop roots would be higher in summer season crops (sown in June/July and harvested in September/October) than the winter crops (sown in November and harvested in April).

Key words: Depthwise, fine root biomass, N concentration, N accumulation, sampling months.

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Introduction

The farmers of Punjab and some other parts of north-western India have adopted poplar (*Populus deltoides* Bartr., family - Salicaceae) based agroforestry on a large scale. Poplar is raised on agricultural fields along with crops like wheat, potato, sugarcane, turmeric, pearlmillet, vegetables, etc.. Its popularity with the farmers is mainly due to its fast growing nature and easy propagation through cuttings. The characteristics like clean bole, deciduous nature during winters, pruning tolerant, multiple uses, soil enriching properties, compatibility with agricultural crops and high economic returns make this most ideal for adoption in agroforestry systems (Tewari 1995). The poplar based agroforestry systems have been proved to be economically viable and ecologically sustainable (Jain & Singh 2000; Khullar *et al.* 2010). For the diversification of traditional

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agriculture (rice-wheat rotation), there is shift in euphoria of farmers as well as government to grow more trees in Punjab which is primarily an agricultural state with 84 % area under highly intensive and mechanized agriculture. Poplar wood is in high demand for paper-pulp, plywood, match boxes, packing cases and light constructional timber (Singh & Negi 2001). Poplar has made significant contribution in meeting industrial requirements and occupies a unique and important position in rural economy.

An understanding of root distribution of trees in the soil profile leads to better management of agroforestry systems. Roots are an important source and sink for nutrients in agroforestry systems. Trees have higher proportion of fine roots in top soil which compete for resources with crop roots in agroforestry system (Dhyani & Tripathi 2000; Smith *et al.* 1999). On the other hand, roots of trees in general and the fine roots in particular enrich the soil with organic matter and nutrients by rapid turnover, intercept the leached nutrients from sub surface soil layers and recycle them to surface playing their safety net role in these systems (Allen *et al.* 2004; Valverde-Barrantes *et al.* 2007). The root production and turnover are the important processes in the overall cycling of nutrients. Fine root biomass and productivity vary under different spacings of trees (Singh 1994), seasons in the year (Cavelier *et al.* 1999), intercrops (Smith *et al.* 1999), nutrient levels (Nadelhoffer *et al.* 2002) and soil depths (Dhyani & Tripathi 2000; Raizada *et al.* 2013). Raizada *et al.* (2013) observed that nearly 80 % of fine roots were confined to the 0 - 20 cm soil layer in five fruit trees and three forest tree species. Nadelhoffer *et al.* (2002) had observed higher fine root production in the plots fertilized with N and P than the unfertilized plots in wet sedge and moist tussock tundras. The nutrient concentration of fine roots determines the nutrient return potential of the roots. Nutrient release from decomposing roots is a pathway of significant nutrient flux in agroforestry systems. Nutrient concentration in fine roots may be higher than those in tree foliage (Gordon & Jackson 2000). The amount of carbon and nutrients returned to the soil from fine roots was greater than above ground litterfall in the tropical broad leaved evergreen, cold temperate needle leaved evergreen forests and in heathland ecosystems having shrubs and grasses (Aerts *et al.* 1992; Vogt *et al.* 1986).

Poplar intercropped with pearlmillet-wheat rotation is one of the main agroforestry systems in Punjab. However, there is a lack of information on the influence of nutrients on the biomass and nutrient dynamics of fine roots of poplar which would be helpful in determining carbon and nutrient cycling from fine roots and evaluating the competition of tree roots with the roots of intercrops for various resources. Therefore, the present study was conducted to evaluate the spatiotemporal distribution of fine root biomass, N concentration and accumulation in the fine roots of poplar in response to different levels of nitrogen and phosphorus. Nitrogen concentration in leaves of poplar was also determined to envisage the standing state of nitrogen in trees during different months under increasing levels of nitrogen and phosphorus.

Materials and methods

Study site and climate

The investigation was carried out at the experimental area of Department of Forestry and Natural Resources and Department of Soil Science, Punjab Agricultural University, Ludhiana during 2009 - 2010. The experimental site is located in the Ludhiana district of Punjab at an elevation of 247 m above mean sea level and lies at 30^{o} 54′ N latitude and 75^{o} 40′ E longitude which represents the central agroclimatic zone of Punjab.

The geological location of Punjab is in the north-west Indian sub-continent with western Himalaya in the north and the Thar Desert in the south. In general, the climate is sub-tropical to tropical with a long dry season from late September to early June and wet season from July to early September. May and June are hottest months with intensive evapotranspiration losses, whereas December and January are the coldest months. Frost is not so common in the region. The experimental site received an annual rainfall of 837 mm, which was not evenly distributed and most of it (81 %) was received during the rainy season (July to September). The lowest mean monthly air temperature of 13.7 °C was attained in January and highest of 40.2 °C in May.

Experimental details

An agroforestry experiment on poplar was established at a spacing of 5 m x 4 m (500 tree ha^{-1}) with a net plot size of 4 trees $plot^{-1}$ (16 m x 5 m i.e. 80 m^2) in randomized blocked design (RBD) having three replications in January 2005. The agricultural crops i.e. pearlmillet (*Pennisetum*

Table 1. Applied levels of nutrients to poplar during five years in an agroforestry system at Ludhiana, Punjab.

	Nutrient levels (N: P_2O_5, kg ha^{-1})					
Treatment number	1st year	2nd year	3rd year	4th year	5th year	Total
T_1 (Uncropped)	0:0	0:0	0:0	0:0	0:0	0:0
T_2	0:0	0:0	0:0	0:0	0:0	0:0
T_3	25:0	50:0	75:0	100:0	125:0	375:0
T_4	25:20	50:40	75:60	100:80	125:100	375:300
T_5	50:0	75:0	100:0	125:0	150:0	500:0
T_6	50:20	75:40	100:60	125:80	150:100	500:300
T_7	50:40	75:60	100:80	125:100	150:120	500:400
T_8	75:0	100:0	125:0	150:0	175:0	625:0
T_9	75:20	100:40	125:60	150:80	175:100	625:300
T_{10}	75:40	100:60	125:80	150:100	175:120	625:400

americanum L., family - Poaceae) and wheat (*Triticum aestivum* L., family - Poaceae) were grown as intercrops in *kharif* (summer) and *rabi* (winter) season, respectively. Every year, pearlmillet was sown during first fortnight of July and harvested in end September whereas wheat was sown in first fortnight of November and harvested in end April. The nutrients recommended to pearlmillet and wheat were applied @ 100 kg ha^{-1} N and 125:62 kg ha^{-1} N:P_2O_5, respectively. Pearlmillet was grown during first four years of tree age whereas wheat throughout the study period. Therefore, no pearlmillet was grown under the trees in the year (2009 - 10) when the present study on root biomass and N dynamics was conducted.

There were ten treatments which included nine selected combinations out of twelve factorial combinations of four N and three P_2O_5 levels in addition to poplar trees without any crop (uncropped treatment) (Table 1). In uncropped poplar trees, irrigation was given similar to other treatments but no nutrients were applied whereas in the cropped (pearlmillet - wheat rotation) poplars, the plots got the respective nine combinations of N and P in addition to the uniform dose of nutrients applied to intercrops as given in the above paragraph. The N levels for poplar in 1st year varied from 0 to 150 g $tree^{-1}$ (75 kg ha^{-1}) whereas in 5th year, these varied from 0 to 350 g $tree^{-1}$ (175 kg ha^{-1}). The P levels varied from 0 to 80 g $tree^{-1}$ (40 kg ha^{-1}) in the 1st year and 0 to 240 g $tree^{-1}$ (120 kg ha^{-1}) in the 5th year (Table 1). The nutrients were applied on per plant basis. These were applied in 1 m diameter basin around the tree during 1st year, 2 m diameter basin during 2nd year and 3 m wide strip (1.5 m on each side of tree row) during 3rd, 4th and 5th year of tree growth. Nitrogen and phosphorus were applied in the form of urea and diammonium phosphate, respectively. The entire amount of P was applied in the month of May after harvesting of intercropped wheat. Nitrogen was applied in 3 splits; 1st in May, 2nd in July and 3rd in September i.e. during the growing period of trees every year (Singh & Sharma 2007).

Root sampling and analysis

Fine roots (< 2 mm diameter) of poplar were sampled in 5th year growth of trees during four months to cover the four main seasons in the region i.e. during April 2009 (spring), July 2009 (summer/rainy), October 2009 (autumn) and January 2010 (winter). For excavation of roots, depthwise (0 - 15, 15 - 30, 30 - 45 and 45 - 75 cm) soil cores were taken with a sharp edged steel augur of 12 cm diameter and 1 m length at 50, 100, 150 and 200 cm distance from four perpendicular directions from the base of the tree stem. Soil cores were taken around two trees in each plot. Each core was kept separately in polythene bag for root sorting. Each soil core was placed on a polythene sheet and roots were handpicked from the soil. The roots were distinguished into live and dead roots on the basis of appearance, colour, texture and friability. Live roots had characteristic appearance and colour, intact bark and were firm whereas the dead roots were dark and spongy. Only the live roots were collected as it was not possible to collect the dead and decomposing roots and the root fragments which were mixed as organic matter and not easily identifiable as roots. Diameter of the roots was measured and those having less than 2 mm diameter (fine roots) were separated. Roots of the same depth from different horizontal directions around the tree base were pooled. Each sample was firstly washed with tap water and then with distilled water to remove the adhering soil particles. The roots were oven dried at 65 ± 2 °C till their constant weight and the dry fine root biomass was recorded. The dry fine root biomass (FRB) was expressed as g m^{-2}. The roots were ground and the concentration (%) and accumulation (mg m^{-2}) of N in the fine roots were determined.

Nitrogen in the root samples was determined by Kjeldahl method (Jackson 1973). For the estimation of total nitrogen, 0.5 g portions of the root material were placed in the digestion tube and 1 g digestion mixture (400 parts of K_2SO_4, 20 parts of $CuSO_4$, 3 parts of HgO and 2 parts of SeO powder) was added along with 5 ml of concentrated H_2SO_4 in each digestion tube. The samples were digested in a block digestor at specific temperatures till these were clear. After the completion of digestion, the samples were cooled and volume made up to 50 ml with distilled water. Ten ml aliquot was taken in the Kjeldahl flask and 10 ml 40 % NaOH was added followed by steam distillation. NH_4-N evolved was absorbed in 4 % boric acid mixed indicator solution. The nitrogen concentration was determined by titration with N/70 H_2SO_4. The accumulation of N in the fine roots was calculated by multiplying the fine root biomass with N concentration of each sample.

Leaf and soil sampling

Leaves of poplar were collected from lower branches of the plants from each treatment during April 2009, July 2009, October 2009 and January 2010. Equal number of leaves were collected from lower, middle and upper parts of branches and pooled together. These leaves were washed first with tap water and then with distilled water. The leaves were dried under shade and placed in an oven at 65 ± 2 °C for 48 hours. The dried samples were ground in a mill and preserved for chemical analysis. The N concentration of the leaves was also determined by Kjeldahl method.

Three surface (0-15 cm depth) soil samples were collected from the experimental site before initiation of the study (January 2005) to have an idea about the soil properties. The samples were dried in shade, ground, sieved and analysed for soil organic carbon, available N, P and K by standard methods (Jackson 1973). The physico-chemical characteristics of the soil were: $pH_{1:2}$ - 8.1, $EC_{1:2}$ - 0.39 dS m^{-1}, organic carbon - 2.83 g kg^{-1}, available N - 125 kg ha^{-1}, available P - 11.5 kg ha^{-1}, available K -193 kg ha^{-1} and soil texture - loamy sand.

Statistical analysis

Analyses of fine root biomass and N accumulation in fine roots (0 - 75 cm soil depth), and leaf N concentration were conducted using analysis of variance (ANOVA) technique in split plot design (SPD) taking four months in the main plots and ten nutrient levels in the sub plots (degrees of freedom: replications - 2, months - 3, error a - 6, nutrient levels - 9, months x nutrient levels - 27, error b - 72 and total - 119) (Panse & Sukhatme 1985). Similarly, the effects of months and soil depths on fine root biomass, N concentration and N accumulation were determined in SPD taking four months in the main plots and four depths in the sub plots (degrees of freedom: replications - 2, months - 3, error a - 6, depths - 3, months x depths - 9, error b - 24 and total - 47). The treatment means were separated by least significant difference (LSD) test at 5 % level of significance ($P < 0.05$). Standard error of means (SEM) were computed. Correlation coefficients between different parameters were calculated and tested at 1 % level of significance ($P < 0.01$). All statistical analyses were performed using CPCS-1 statistical software developed by Punjab Agricultural University, Ludhiana.

Results

Fine root biomass

The fine root biomass (FRB) averaged over months (0 - 75 cm depth) was the lowest in uncropped trees and increased significantly ($P < 0.0001$, F = 359, df = 9) with the application of N and P (Table 2). The average FRB was the highest at the highest level of N and P (95.7 g m^{-2}) i.e. in T_{10}. The FRB of poplar averaged across nutrient levels increased significantly till October ($P < 0.0001$, F = 168.35, df = 3) and declined in January (Table 2). The interaction effects indicate that the total FRB in the month of April under various levels

Table 2. Fine root biomass (0-75 cm depth) of poplar under different nutrient levels during various months at Ludhiana, Punjab.

Nutrient levels	Fine root biomass (g m^{-2})				
	April	July	October	January	Mean
T_1	28.1	34.4	37.8	34.5	33.7
T_2	39.1	47.6	42.7	35.6	41.3
T_3	41.6	50.7	59.2	43.2	48.7
T_4	44.4	57.5	63.0	50.8	53.9
T_5	48.6	59.3	72.5	50.9	57.8
T_6	52.5	80.2	74.6	60.6	67.0
T_7	51.8	85.4	79.4	71.8	72.1
T_8	55.5	85.5	95.5	88.5	81.3
T_9	51.9	90.4	112.4	102.4	89.3
T_{10}	59.2	101.7	127.2	94.5	95.7
Mean	47.3	69.3	76.4	66.3	
SEM (±)	Months (M): 0.96, Nutrient levels (NL): 1.09, M x NL: 2.18				
LSD ($P < 0.05$)	Months (M): 3.31, Nutrient levels (NL): 3.07, M x NL: 6.14				

M: indicates SEM or LSD of months averaged over nutrient levels.
NL: indicates SEM or LSD of nutrient levels averaged over months.
M x NL: indicates SEM or LSD of interaction of months and nutrient levels.

of nutrients was significantly lower ($P < 0.0001$, F = 21.74, df = 27) than the FRB of other months (Table 2). The significantly lowest FRB was in uncropped poplars in April (28.1 g m^{-2}) and the significantly highest in T_{10} in October (127.2 g m^{-2}) ($P < 0.0001$, F = 21.74, df = 27). The magnitude of increase in FRB in July over the FRB in respective treatment in April was considerably greater at higher levels of nutrients than at the lower levels ($P < 0.0001$, F = 21.74, df = 27) (Table 2). Among depths, FRB was significantly highest in 0 - 15 cm and significantly lowest in 45 - 75 cm depth ($P <$ 0.0001, F = 9.28, df = 9) during all the months (Fig. 1a). Most of the FRB (35.2 % in October - 41.1 % in July) was confined to the 0 - 15 cm soil layer (Fig. 1a).

N concentration of fine roots

Nitrogen concentration varied significantly (P < 0.0001, F = 670.25, df = 3) over increasing soil depths over various months (Fig. 1b). The concentration of N was the highest ($P = 0.0458$, F = 2.35, df = 9) in April (1.29 %) in surface soil depth (0 - 15 cm) and the lowest in January (0.37 %) in 45 - 75 cm depth. The concentration of N averaged over depths was also significantly highest (P < 0.0001, F = 131.81, df = 3) in April (1.04 %) and the lowest in January (0.72 %) (Fig. 1b). Nitrogen concentration of fine roots increased significantly with application of nutrients (data not shown). It increased from 0.54 % without application (T_1) of nutrients to 1.13 % with the application of maximum dose of nutrients (T_{10}).

N accumulation in fine roots

The fine root N accumulation (0 - 75 cm depth) averaged over months was the lowest without application of nutrients (uncropped poplars) and increased significantly ($P < 0.0001$, F = 4394.20, df = 9) with nutrient application (Table 3). The N accumulation averaged over nutrient levels was the highest in July and decreased significantly till January ($P < 0.0001$, F = 323.75, df = 3). The interaction effects reveal that in most of the higher levels of nutrients, the fine root N accumulation in the month of July was significantly ($P < 0.0001$, F = 105.59, df = 27) higher than the N accumulation of other months (Table 3). The fine root N accumulation was lower in uncropped poplars during all the months (Table 3). The interaction effects indicate that nitrogen accumulation in the fine roots varied significantly ($P < 0.0001$, F = 63.39, df = 9) under different depths during various months (Fig. 1c). It was the highest in 0 - 15 cm and

Table 3. Nitrogen accumulation (0 - 75 cm depth) in poplar fine roots under different nutrient levels during various months at Ludhiana, Punjab.

Nutrient levels	N accumulation (mg m^{-2})				
	April	July	October	January	Mean
T_1	190	167	223	184	191
T_2	296	280	251	219	261
T_3	391	354	378	284	352
T_4	464	459	428	388	435
T_5	549	553	557	428	522
T_6	636	780	626	586	657
T_7	640	990	695	689	753
T_8	758	1038	854	938	897
T_9	771	1162	1174	1220	1082
T_{10}	932	1438	1399	1392	1290
Mean	563	722	659	633	
SEM (±)	Months (M): 3.7, Nutrient levels (NL): 5.5, M x NL: 10.9				
LSD ($P < 0.05$)	Months (M): 12.7, Nutrient levels (NL): 15.4, M x NL: 30.8				

M: indicates SEM or LSD of months averaged over nutrient levels.
NL: indicates SEM or LSD of nutrient levels averaged over months.
M x NL: indicates SEM or LSD of interaction of months and nutrient levels.

Table 4. Nitrogen concentration of poplar leaves during different months under various nutrient levels at Ludhiana, Punjab.

Nutrient levels	N concentration (%)				
	April	July	October	January	Mean
T_1	0.97	0.75	0.74	0.59	0.76
T_2	1.07	0.89	0.88	0.63	0.87
T_3	1.12	0.95	0.96	0.73	0.94
T_4	1.15	1.06	0.93	0.83	0.99
T_5	1.18	1.12	0.97	0.94	1.05
T_6	1.22	1.16	1.07	0.89	1.09
T_7	1.24	1.18	1.09	1.02	1.13
T_8	1.28	1.21	1.12	1.10	1.18
T_9	1.33	1.22	1.14	1.11	1.20
T_{10}	1.37	1.24	1.17	1.13	1.23
Mean	1.19	1.08	1.01	0.90	
SEM (±)	Months (M): 0.0006, Nutrient levels (NL): 0.0007, M x NL: 0.0139				
LSD ($P < 0.05$)	Months (M): 0.019, Nutrient levels (NL): 0.020, M x NL: 0.039				

M: indicates SEM or LSD of months averaged over nutrient levels.
NL: indicates SEM or LSD of nutrient levels averaged over months.
M x NL: indicates SEM or LSD of interaction of months and nutrient levels.

the lowest in 45 - 75 cm depth during all the months. More than 42 % of the total N was accumulated in the fine roots of 0 - 15 cm soil depth during various months. Nitrogen accumulation in the fine roots of 0 - 15 cm soil depth varied from 42.8 % in January to 50.4 % in July (Fig. 1c).

N concentration of poplar leaves

The leaf N concentration averaged over months increased significantly ($P < 0.0001$, F = 478.76, df = 9) with the application of nutrients (Table 4). The average leaf N concentration was the highest in April and the lowest in January.

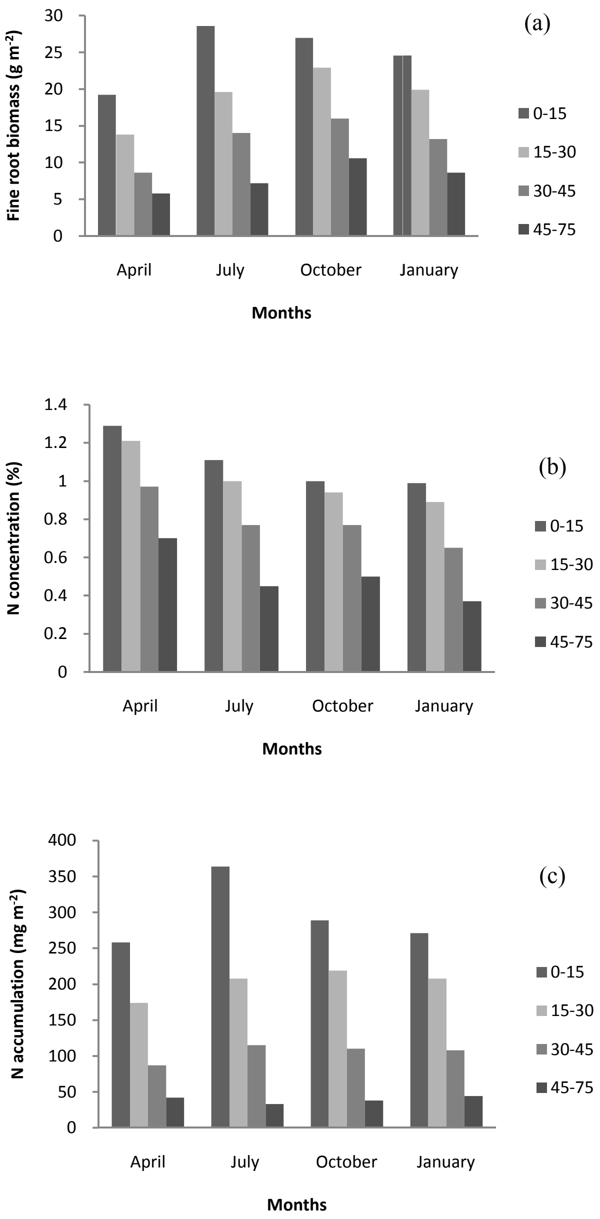

Fig. 1. Fine root biomass (a), N concentration (b) and its accumulation (c) in fine roots of poplar in different soil depths (cm) during various months in Ludhiana, Punjab.

The leaf N concentration in the month of April averaged over nutrient levels was significantly higher than the N concentration of other months (P < 0.0001, F = 486.72, df = 3). The leaf N concentration was lower in uncropped trees during all the months and significantly highest in T_{10} (P < 0.0001, F = 11.19, df = 27).

Table 5. Pearson's correlation coefficients (r) between different root and leaf parameters (n = 10).

Parameters	Months	Root N accu-mulation	Leaf N concentration
Fine root biomass	April	0.960*	-
	July	0.983*	-
	October	0.990*	-
	January	0.997*	-
Root N concentration	April	0.991*	0.988*
	July	0.978*	0.949*
	October	0.913*	0.944*
	January	0.913*	0.936*

*Significant at P < 0.01.

Relationship of root and leaf parameters

Fine root biomass during different months was significantly (P < 0.01) related to root N accumulation (Table 5). The correlation coefficient (r) between these parameters varied from 0.960 in April to 0.997 in January. Similarly, the root N concentration during various months was also significantly related to root N accumulation (r = 0.913 - 0.991) and leaf N concentration (r = 0.936 - 0.988).

Discussion

Fine root biomass

Fine roots are responsible for absorption of nutrients and water from the soil. Therefore, the increase in availability of N and P in the soil as a result of application of nitrogenous and phosphatic fertilizers and their absorption by fine roots might have increased FRB in fertilized treatments over the lower doses of N and P or unfertilized treatments. The site had light soil texture (loamy sand) and low content of inherent available N and P in the soil. Thus, the application of these nutrients on such site might have led to higher shoot biomass production. Therefore, there would be higher photosynthetic capacity as a result of increased leaf biomass leading to higher acquisition of carbon with excess carbon available to roots allowing root biomass to increase (Kern *et al.* 2004). Similarly, Danial *et al.* (1997) observed a significant increase in root biomass of *Acacia mangium* with P application.

The lowest FRB in April may be due to the initiation of growing season of the tree after the winter season (October - March). Hence, there is production of new leaves as well as roots. In July and October, the growth of roots and tree continued as a result of better availability of resources and favorable climatic conditions during these months (rainy season), which is the active growth period of poplars (Singh & Sharma 2007). But the initiation of winters after October and peak winter season in January might have led to decreased root growth in January. In addition, the low temperature in winters, leaf fall and pruning of poplars in December - January lead to shedding and dying of fine roots. Dhyani & Tripathi (2000) observed that in four tree species namely mandarin (*Citrus reticulata* Blanco, family – Rutaceae), alder (*Alnus nepalensis* D. Don, family – Betulaceae), cherry (*Prunus cerasoides* D. Don, family – Rosaceae) and albizia (*Paraserianthes falcataria* L., family – Fabaceae) in northeast India, the fine root biomass followed a unimodal growth curve by showing a gradual increase from spring (pre-rainy) to autumn (post-rainy) season. The maximum fine root biomass was observed in autumn and minimum during winters. Sundarapandian *et al.* (1996) had also observed that FRB was higher in rainy and autumn season than other seasons in a deciduous forest. Therefore, understanding the root growth pattern during different months may help in assessing the root competition between various components of an agroforestry system.

The higher FRB on the surface soil layer (> 35 %) coincides with more availability of nutrients, water and soil management on the top layer of soil (Dhyani & Tripathi 2000; Srivastava *et al.* 1986; Pandey *et al.* 2014). Raizada *et al.* (2013) observed that under six fruit and three forest tree species, > 80 % fine roots were confined to the 0 - 20 cm soil layer. Due to higher FRB on surface layer, higher competition for nutrients and moisture is expected between tree and intercrop roots.

N concentration of fine roots

The highest fine root N concentration in 0 - 15 cm depth and its decrease with increasing soil depth may be attributed to more availability of nitrogen and its absorption on the surface layer of soil (Fujimaki *et al.* 2004; Valverde-Barrantes *et al.* 2007). Appearance of new leaves in March - April (spring season) leads to higher N concentration of fine roots. Conversely, the pruning of poplar branches in December-January and due to peak winters, there is shedding of fine roots and retranslocation of N prior to shedding which corresponds to the lowest N concentration in fine roots in January (winters). Also in winters the N mineralization is slower as the winter season retards the bacterial growth, thus its uptake by plants may be lower. McClaugherty *et al.* (1982) had observed seasonal patterns of increase in nitrogen concentration during spring and decrease during winter in the fine roots of red pine (*Pinus resinosa*). Tripathi *et al.* (2009) had reported the highest nutrient concentrations in summer followed by winter and rainy seasons in mature bamboo savanna soils in dry tropical region in India. More absorption of N at higher levels of nutrient application might have led to increased N concentration (Raison *et al.* 1996). Higher concentration of nitrogen in fine roots with increasing levels of nutrient application is bound to increase the nitrogen return through roots under higher levels of nitrogen.

N accumulation in fine roots

Nitrogen accumulation in fine roots increased with application of nutrients due to increased absorption of N by fine roots at higher levels. After carbon, N is the major constituent of organic materials; thus, its accumulation has been found to increase with N application in various tree based systems (Fujimaki *et al.* 2004; Raison *et al.* 1996). The higher N accumulation in July and October may be due to higher fine root biomass as well as higher N concentration during these months. As N accumulation is a function of root biomass and N concentration in the fine roots, this was higher at higher FRB and N concentration. Higher accumulation of N in the surface soil layer (> 42 %) is ascribed to greater FRB and N concentration on upper soil layer than the lower layers (Fujimaki *et al.* 2004; Valverde-Barrantes *et al.* 2007).

N concentration of poplar leaves

Removal of applied N by roots and its translocation to leaves might have led to an increase in leaf N concentration with the application of nutrients (Prasad *et al.*1984). An investigation by Magill *et al.* (1997) has shown that foliar nitrogen concentration increased up to 25 % in hardwood stands (*Quercus velutina, Betula lenta, Acer rubrum* and *Fagus grandifolia*) and

67 % in the pines (*Pinus resinosa*) with the application of nitrogen fertilizer. The highest N concentration of leaves in April may be because of emergence of new leaves. During initiation of growth of leaves, the biomass is lower while the dilution effect of growth indicates that as the biomass increases, the nutrient concentration decreases (Gill *et al.* 1987). However, the total uptake may be higher when the biomass is more. Therefore, the leaf N concentration might have decreased in July as a result of growth of leaves and its dilution effect. However, on onset of winters in October, the N concentration decreased due to initiation of senescence of leaves and retranslocation of N to wood prior to leaf shedding (Gordon & Jackson 2000). In January the N concentration continued to decrease probably owing to higher N retranslocation from leaves before leaf fall (Lodhiyal & Singh 1995; Scherzer *et al.* 1998). Likewise, Negi & Singh (1993) had observed that nitrogen retranslocation during senescence ranged from 32.7 to 75.3 % across different species including *P. deltoides*.

Relationship of root and leaf parameters

The significant positive correlation coefficients of fine root biomass and root N concentration with root N accumulation indicate that return of N would be higher if the FRB is more. High correlation between root N concentration and leaf N concentration indicates positive relationship between these parameters and higher uptake of nitrogen at higher levels of N application.

Conclusions

The study indicates that the distribution of fine root biomass and N accumulation in fine roots of poplar was higher on surface soil layers and increased with application of nitrogen and phosphorus. These parameters were higher in July (summer/rainy season) and October (autumn) than January (winter) and April (spring). Therefore, the root competition for resources (nutrients and moisture) between the poplar and intercrop roots will be higher in summer season crops (sown in June/July and harvested in September/October) than the winter crops (sown in November and harvested in April). Application of N will lead to increased uptake of N by plant as described by increasing leaf N concentration under higher levels of applied N.

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