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Original Article

Root Structure and Belowground Biomass of Hybrid Poplar in Forestry and Agroforestry Systems in Mediterranean France

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Abstract

In poplar, one of the most used species of forestry and agroforestry, below ground biomass allocation plays an important role in providing anchorage as well as efficient nutrient and water distribution channel. Available literature on this aspect is not enough in hybrid Poplar, *Populus euramaricana* I-214. Therefore, the study was aimed at finding how this species developed its root system and how much belowground biomass was allocated in Forest System (FRS) and Agroforest System (AFS). This was done using soil excavation and root coring methods. Coarse roots were distributed in all directions but their number and proximal cross section area (CSA) were not uniform. In the case of AFS tree maximum CSA was distributed in the south and south-west direction while in FRS it was in the north-east and south-east direction. Fine roots were observed throughout the rooting zone along with coarse and medium roots up to a maximum depth of 2.4 m in FRS and 2.8 m in AFS. Total belowground biomass was higher in AFS tree (130 kg tree^{-1}) than FRS tree (120 kg tree^{-1}). But on hectare basis FRS accumulated (24.5 Mg ha^{-1}) more biomass than AFS (18.1 Mg ha^{-1}). However, if practiced in surplus agriculture area and considered the system as a whole, AFS allows grain production in lieu of some biomass deficit.

Keywords: I-214 clone, excavation and coring, *Populus euramaricana,* root orientation, rooting depth

Introduction

Poplars have consistently been part of the agriculture and forest resource sectors in temperate regions as well as tropical country like India where cotton wood has been introduced substantially as block plantation and extensively as agroforestry crop (Jha, 1999; Block *et al*., 2006; Chauhan *et al*., 2012; Gera, 2012). Immediate and long-term needs in both the agriculture and forest resource sectors have created a niche for the production of wood from managed plantations of native poplar species and their hybrid varieties (Jha, 1999; Block *et al*., 2006). In agricultural landscapes, the implementation of agroforestry systems has the potential to provide a high carbon sequestration capacity compared to other greenhouse gas mitigation strategies (Jose and Bardhan, 2012).

Short rotation forestry crops are currently assuming growing importance in many countries where surplus agriculture and other land is becoming available and poplar stands are expanding on them, for example, Bulgaria, Canada, China, Germany, Serbia, Spain, USA etc. (Calfapietra *et al*., 2010). The aim is to benefit from the goods directly and services like carbon sequestration indirectly. This system has covered thousands of hectares in Europe alone to generate renewable energy, mostly using poplars and willows (Herve and Ceulemans, 1996; Venendaal *et al*., 1997; Verwijst, 2001; Langeveld *et al*., 2012). European farmers are increasingly attracted to energy crops following the most recent changes in the common agricultural policy and rapid development of the bioenergy sector (Spinelli *et al*., 2008). Wider use of poplar can contribute to European Union goals to ensure 20% of its energy consumption from renewable resources until 2020 and continue further in the future (Jansons *et al*., 2014). Poplar based agroforestry has the capability of enhancing soil organic carbon up to 83% (Singh *et al*., 1989).

Longer duration carbon locking role is played by the root system of the vegetation (Kumar *et al*., 2006; *Nair et al*., 2009) which has some other roles, like nutrient and water acquisition, anchoring etc. Fine and coarse roots are key contributors to belowground net primary productivity, and play critical roles in the biogeochemical cycling of forest and woodland ecosystems (Clark *et al*., 2001; Brunner and Godbold, 2007; Malhi *et al*., 2011; Smith *et al*., 2013; Raich *et al*., 2014). The storage capacity and the rate of carbon sequestration in this biogeochemical cycle depend on various factors such as the climate, soil type, tree species used for afforestation, current forestry practices, pre-afforestation management and land use history (Post and Kwon, 2000; Paul *et al*., 2002).

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Among all roots, fine roots represent only a small fraction of total tree biomass, but fine root production and turnover are significant components of the biomass turnover (Amthor, 1986; Lambers *et al.*, 2000; Chen *et al.*, 2004; Al Afas *et al.*, 2008). Coarse roots are multifunctional tree components providing key functions such as transport (nutrients, photosynthate, water), storage (sugars and nutrients), biomechanical stabilization, as well as the framework upon which fine root develop and connect (Resh *et al.*, 2003; Guo *et al.*, 2013; Cook and Weigh, 2005).

Aboveground biomass in poplar plantations or forestry system (FRS) and agroforestry systems (AFS) has been widely studied around the world (Laureysens *et al.,* 2004; Zabek and Prescott, 2006; Fang *et al.*, 2007; Christersson, 2010; Fortier *et al.,* 2010; Truax *et al.,* 2012;). In spite of crucial role of belowground parts for woody biomass production and carbon sequestration in soil (Berhongaray *et al.,* 2015), fewer or disproportionate studies have evaluated the belowground biomass of these systems (Fortier *et al.,* 2013). In other words, the poplar root system still remains the most poorly studied and understood portion of the tree (Friend *et al.,* 1991). Therefore, the objectives of the present study conducted in AFS and FRS in Mediterranean region of France was to assess and compare (i) distribution of belowground biomass to fine, medium and coarse roots, (ii) orientation of coarse roots around the stump root, (iii) extent of vertical and horizontal spread of roots in soil and (iv) the advantage of one system over the other.

Materials and Methods

Study sites

Two experimental plots, Forestry (Plantation) System (FRS or PLS) and Agroforestry System (AFS), were located side by side in the vicinity of Vezenobres township (Longitude 4º9' E, Latitude 44º2' N, elevation 138 m a.s.l.) in the Mediterranean region of France. The soil was sandy alluvial fluvisol with 8% clay, 42% silt and 50% sand. Pure sand and gravel layers occurred at different depths, about 1.1-1.3 m and 2.5-2.9 m. The climate is sub-humid with an average temperature of 14.8 ºC and an average annual rainfall of 1172 mm. Potential evapotranspiration (580 mm) was higher than average rainfall (267 mm) during the main growing season, May to August. Water table fluctuation was also common in the area (Mulia and Dupraz, 2006).

The AFS and FRS plots were established in 1996 using better performing I-214 and I-4551 clones of hybrid poplar (*Populus euramericana*). AFS trees were spaced 16 m (alley) x 4.5 m (row) while FRS trees had spacing of 7 m x 7 m. The trees were pruned at 6 m and 10 m following a block design. Durum wheat was grown in AFS keeping fallow every 3 or 4 years. *P. euramericana* I-214 clone with 6 m pruning was selected for the present study in 2009. For the last 3 years the AFS plot was devoid of agriculture.

Tree sample selection

Tree harvesting and dry matter estimation method was selected for structure and biomass estimation of roots. Since harvesting method is time and resource consuming but more accurate, a trade-off was made and instead of multiple trees, single tree harvesting (Fang *et al.*, 1999) was done in both AFS and FRS during summer 2009. Tree selection was done on following parameters: (i) tree was representative of the plantation having average diameter at breast height of all the trees in the plantation, (ii) it was from inner area not the border of the plantation, (iii) it's neighbouring trees had normal form and vigour and (iv) both the trees were of same clone (I-214) and same treatment (6 m pruning). Selected AFS tree matched all these qualifications *in toto*, but FRS tree was of little higher girth (1.41 m) than average (1.36 m) of the plantation. Therefore, biomass calculation for FRS was normalized by a factor 0.93 (square of the ratio of average tree and harvested tree) in this case (Jha, 2017).

Root harvesting

Stump and different types of roots were harvested at different depth and breadth in soil. Although multiple methods of belowground biomass harvesting have been recommended (Addo-Danso *et al.*, 2016), excavation method was used for harvesting of roots to capture lateral root variability in larger volume of soil (Berhongaray *et al.*, 2015). One quarter of the rooting zone of a single tree from both the plantations was selected randomly for excavation (Fortier *et al.*, 2015b). This zone was divided into 2D voxels (volume elements of soil, analogous to pixels of 1m length x 1m breadth x 0.5m depth) by marking squares (1m^2) on the ground. All the voxels were given unique identification number, for example first voxel with the tree stump in the centre had 0,0,0 identity and adjacent voxels had 1,0,0 on X axis (row), 0,1,0 on Y axis (alley) and 0,0,0.5 on Z axis.

Harvesting was done from selected voxel columns (Fig. 1) starting from the farthest one near the excavation trench so that the task of removal of cut soil remains easy. These voxel columns were dug carefully using soil pick (MBW, Slinger, WI, USA) releasing high pressure air (125 PSI). Roots collected from each voxel were brought to the laboratory and categorised into three groups based on size. Although roots are categorized and named differently (Lodhiyal *et al.*, 1995; Laclau, 2003; Tufekcioglu *et al.*, 2003; Das and Chaturvedi, 2005; Fortier *et al.*, 2015a), three categories viz., fine roots (< 2 mm), medium size roots (2 mm to 10 mm) and coarse roots (>10mm) were adopted in the present study.

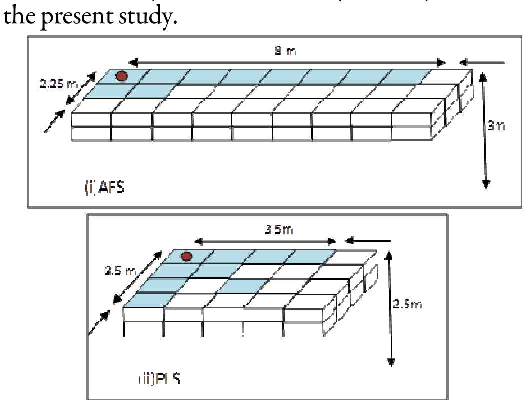

Fig. 1. The upper layer voxels and cellules (1.0 m x 1.0 m x (0.5 m+0.5 m) in one quarter of root growing volume in (i) AFS and (ii) FRS (PLS). Blue boxes are root harvested cellules and brown ellipse is the stump position

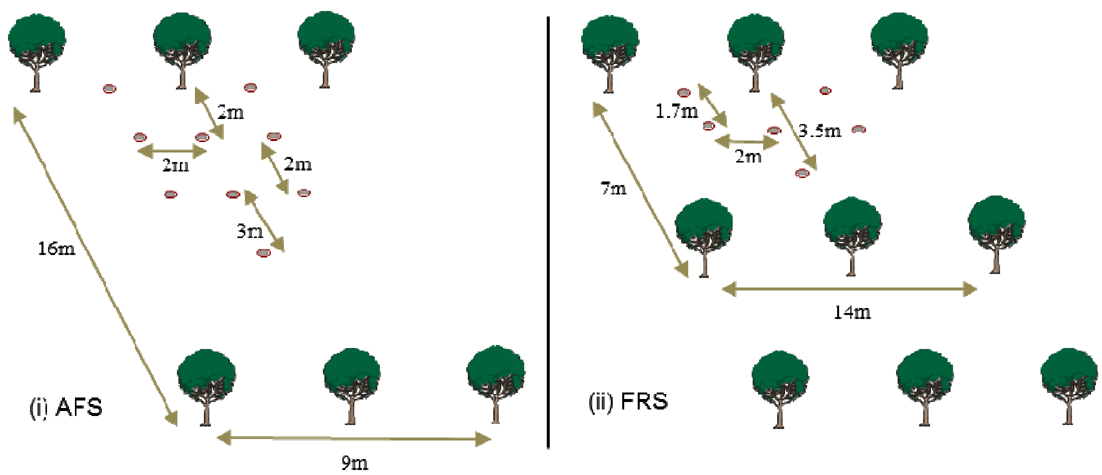

Fig. 2. Soil coring spots (brown ellipse between tree rows and close to the tree to be harvested) in (i) AFS and (ii) FRS of *Populus euramaricana* I-214. Distance in the drawing is not to the scale. Tree line, north-south, is the X axis and Alley is the Y axis

The stump root was excavated along with the proximal roots from first voxel column. All the secondary roots on the stumps were numbered and their proximal diameter or girth was recorded with reference to north, north east, east, south east, south, south west, west and north west directions using metal callipers or tailor's tape in order to determine their cross section area (CSA).

Soil coring method was also used in the present study for getting another set of fine root data since soil excavation method is reported to under estimate fine roots due to its loss during excavation (Friend *et al.*, 1991) and recommendation of coring method for uniformly distributed fine roots (Mulia and Dupraz, 2006; Levillain *et al.*, 2011). Nine and six well spread coring points were selected in the alley of AFS and FRS trees, respectively (Fig. 2). Coring was done using micro-caterpillar driller (Sondeuse EMCI 300C with core size 1.1 m by 0.1 m). Soil cores were drilled out from maximum penetrable depth. The cores were divided into sub-cores of 0.2 m length and broken into two halves to observe presence of living and dead, fine and coarse roots. The live roots were smooth, light coloured and non-friable as compared to the dead roots. Roots were counted on both the faces of core breaks for further use.

Root biomass estimation

Harvested roots were cleaned, weighed and their samples were dried at 90 °C temperature in oven till constant weight. Fresh and dry weight ratio was used to calculate the biomass for harvested voxels. For remaining voxels biomass was extrapolated mathematically. As per site observation and trend in cellules' biomass, exponential decrease in root growth was assumed and exponential regression relationship between biomass and distance from the tree (along Y axis) was developed. Linear decrease was adopted along X axis for want of enough of data and indicative trend with distance in AFS. Values of non-sampled cellules were calculated using the exponential decay equation constants (Sigma plot software). Weightage was applied to them cellule wise, since contribution of these were different for a quarter of the scene. Exponential decrease was used for both the axes X and Y in FRS. The biomass values calculated so far were corrected by using distance matrix, representing the voxels. In this case also weightage was applied in biomass calculation for the cellules. Quarter root biomass was arithmetically extrapolated to determine total underground biomass.

Fine root biomass by coring method was estimated using fine root number, density constant (143.55), specific root length (17.86 m g^{-1}) and rooted volume in following formula (Mulia, 2005):

$$\text{Root biomass} = \frac{\text{Average root number x Rooted volume x Density constant}}{\text{Specific root length}}$$

Results

Root structure and distribution

Soil excavation showed that roots were growing horizontally as well as vertically. Secondary roots in both the trees grew on the stump root in all the directions (Fig. 3), but the orientation of these roots was not uniform in any of the quarters as opposed to the counterpart quarters in the azimuth. Their number, thickness and orientation by depth varied within the two trees. Total number of secondary roots was higher in FRS (140) than AFS (54) while total CSA of these roots were more in AFS (3,243 cm^2) than FRS (3,082 cm^2). Growth of stump root terminated bluntly before 1.5 m in FRS while it extended beyond 2.0 m in AFS giving the appearance of a tap root. The horizontal roots radiated farther beyond 7.0 m in AFS and 3.0 m in FRS. Vertical and oblique roots were also seen in some voxels far from the tree base.

The pattern of coarse root orientation on the stump root revealed that north-south orientation had more root CSA than east-west in both the trees. When intermediary orientation, north-east and north-west, and south-east, and south-west were combined, root area distribution stood lopsided. In the case of AFS tree, maximum distribution was in south and south-west direction while in FRS it was north-east and south-east direction (Fig. 3 a & b). The voxel-wise CSA distribution was 64%, 10% and 26% in 0-50 cm, 51-100 cm and 100-150 cm depth, respectively, in

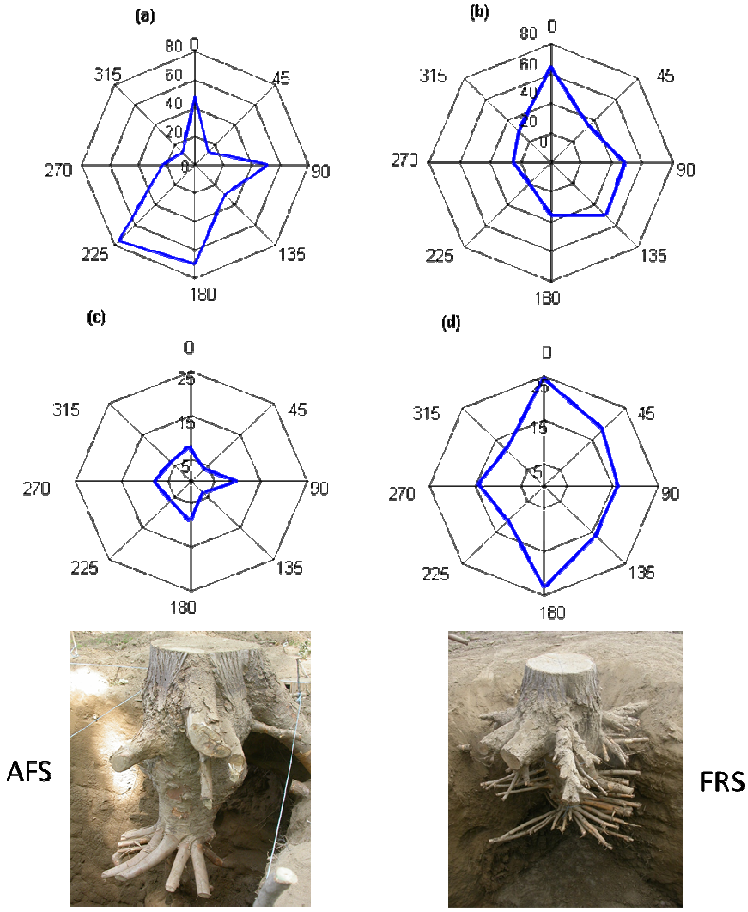

Fig. 3. Graphic and pictorial presentation of root profile in stump voxel column of AFS and FRS trees. Root cross section area is represented in (a) and (b), and Root number is represented in (c) and (d), respectively of AFS and FRS trees. 0 degree symbolizes north direction

the case of AFS while it was 73%, 17% and 10% in FRS. However, morphological observation of root orientation indicated that secondary roots were prominently coming out of stump root in two tiers in AFS tree with a gap of 60-70 cm, first tier closer to the ground and second at the bottom of stump root. There were very few secondary roots growing on the stump root between the two tiers (Photos in Fig. 3). In FRS no such tier differentiation was evident since the secondary roots were growing in continuity all along the stump root.

Fine roots were observed throughout the rooting zone along with coarse and medium roots. They were excavated from sub-surface (10 cm) up to a maximum depth of 2.4 m in FRS and 2.8 m in AFS. However, rooting depth was variable along the horizontal distance from the tree. It seemed to be increasing from tree line up to 1.7 m -2.0 m distance and afterwards there was decrease in rooting depth with increase in distance. Fine root density also varied at different depths without showing any trend of increase or decrease (Fig. 4).

Belowground biomass distribution

Tree height, girth, and density in AFS and FRS were 30.7 m, 1.39 m and 139 tree ha^{-1} and 30.7 m, 1.41 m and 204 tree ha^{-1}, respectively. Other results related to biomass are recorded in Table 1. The assessment of different components of root biomass was based on regression equations developed from root biomass (RB) and voxel distance (Y) from the tree. All the six equations (RB=a*exp(-bY) related to trend-lines presented in Fig. 5 were highly significant (r^2 = 841** to 999**). Total belowground biomass was higher in AFS tree (130 kg $tree^{-1}$) than FRS tree (120 kg $tree^{-1}$). The pattern was similar in other components also like fine roots, medium roots, coarse roots and stump root. Dry root mass allocation into different components like fine root, medium root, coarse root and stump root was 4%, 10%, 45% and 41%, respectively in AFS tree. In the case of FRS tree, fine root and coarse root contribution remained same but medium root was 1% lower and stump root 1% higher. The two methods of fine roots' biomass estimation resulted in varied quantity. Coring (7.7 kg $tree^{-1}$, AFS; 5.9 kg $tree^{-1}$, FRS) yielded higher biomass than excavation (5.4 kg $tree^{-1}$, AFS; 4.6 kg $tree^{-1}$, FRS) in both the trees.

Biomass accumulation in rooting space of tree through fine roots depended on its density and length. However, density of fine roots was not consistent through depth of soil or distance from tree in both the cases of AFS and FRS (Fig. 4). AFS stored fine root biomass in to 2.8 m soil depth while in FRS storage depth was restricted to 2.4 m. Fine root biomass storage (Fig. 6) in AFS varied from 0.96 kg (0-0.2 m) to 0.05 kg (2.6-2.8 m) while in FRS it varied from

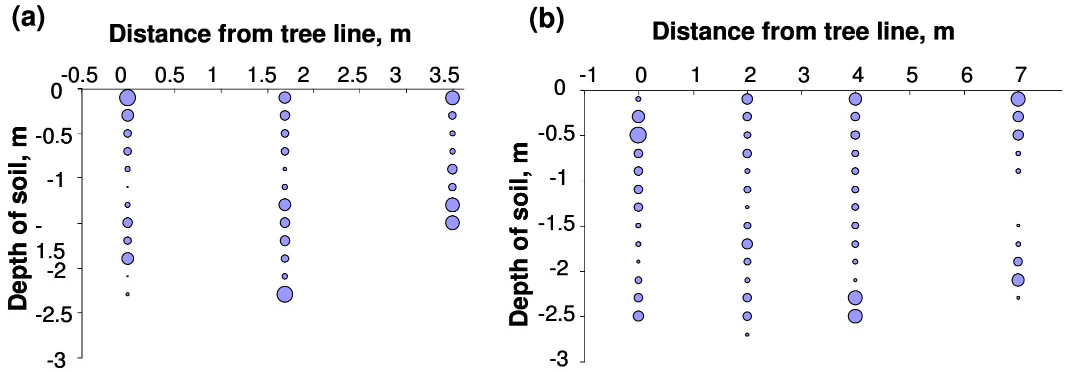

Fig. 4. Fine root density (note the size of the blue bubbles) at different depth and distance from tree in FRS (a) and AFS (b) trees

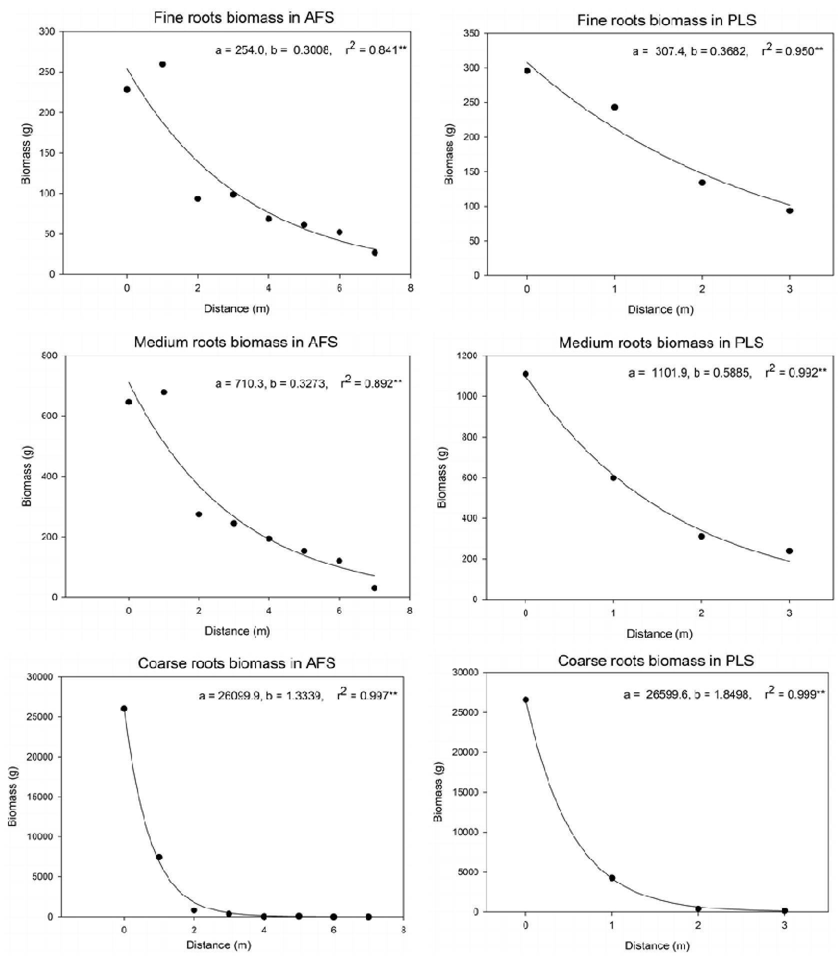

Fig. 5. Charts displaying biomass regression curve (exponential decay) along with corresponding intercept and slope values in AFS and PLS (FRS). X axis: distance from the tree and Y axis: root biomass

1.07 kg (0-0.2 m) to 0.15 kg (2.0-2.2 m). However, generalization showed that there was maximum fine root biomass storage in first meter (48% in AFS and 45% in FRS) followed by second meter (27% in AFS and 40% in FRS) and then third meter (26% in AFS and 15% in FRS).

Discussion

Root excavation method

Possible reason of higher fine root quantity estimation by coring than excavation in both the tress, AFS and FRS, could be explained by a hypothesis that excavation method results in sampling error since roots break off and get lost during excavation (Millikin and Bledsoe, 1999; Niyama *et al.*, 2010). Bledsoe *et al.* (1999) also found that complete recovery of entire deep rooted system was difficult even under ideal condition. Similar to this, Friend *et al.* (1991) observed in *P. trichocarpa* x *P. deltoides* clones that field excavation failed to recover at least 68% of fine root

Table 1. Synthesis of the biomass results in Agroforestry (AFS) and Forestry (FRS) Plantations

Tree parameters	Unit	Plantation Systems	
		AFS	FRS*
Fine roots (excavation)	kg	5.4	4.6
Fine roots (coring)	kg	7.7	5.9
Medium roots	kg	12.4	10.8
Coarse roots	kg	58.7	54.3
Stump root	kg	53.2	50.3
Below ground tree^{-1} (excavation)	kg	130	120
Below ground ha^{-1} (excavation)	Mg	18.1	24.5

FRS * is factorized value (0.93) for average tree (see tree sample selection sub-section)

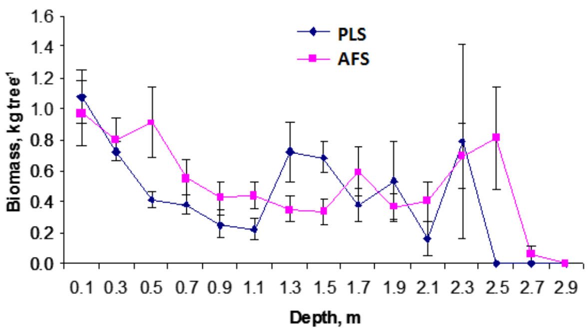

Fig. 6. Fine root biomass at different depth in AFS and PLS (FRS) trees

biomass. This loss appeared to be very high as compared to the present study where there was 70-77% recovery of fine roots in relation to coring method.

Root harvesting depth

Most of the workers, owing to resource and time consumption factor coupled with assumption of root presence in that area only, used excavation method and explored fine roots to limited depth, for example, 0.4 m (Ostonen *et al.*, 2005), 0.5 m (Bayala *et al.*, 2004), 0.3-0.5 m (Jiangen *et al.*, 2008), 0.6 m (Tomlinson *et al.*, 1998), 0.8 m (Moreno-Chacon and Lusk, 2004), 0.6-0.9 m (Misra *et al.*, 1998), 1.0 m (Purbopuspito and Rees, 2002; Dowell *et al.*, 2009), 1.5 m (Smith *et al.*, 1999) and 2.0 m (Moreno *et al.*, 2005) in different species. In the case of Poplar, few studies like, Puri *et al.* (1994), Fang *et al.* (2007) and McIvor *et al.* (2009) explored 0.3 m, 1.0 m and 1.4 m depth, respectively. However, in the present study, excavation was extended to 3.0 m depth since roots were observed up to 2.4 m to 2.8 m during coring. This finding is supported by Mullia and Dupraz (2006) and Heilman *et al.* (1994) who also recorded poplar roots up to 3.0 m and beyond this, respectively.

Hansen *et al.* (2003) and Rosengren *et al.* (2006) reported that 95% of all fine roots were located within 1.0 m in temperate and boreal forest ecosystems. Callesen *et al.* (2016) suggested this depth as pragmatic 'effective rooting depth' which is not in conformation with plantation systems in Mediterranean condition where medium roots and coarse roots were found much below this depth. Simple indication of present finding was that effective rooting depth should be beyond 1.0 m, otherwise there could be omission of substantial amount of root recovery (52-55 %) since its distribution in first, second and third meter depth, respectively, was 48%, 27% and 25% in AFS and 45%, 40% and 15% in FRS. As such estimation of these deeper layer roots, being out of the ploughing layer, are very important from the view point that they have longer residence time in the soil since they are better protected and undisturbed (Nair *et al.*, 2009).

Fine and coarse root distribution

Fine roots were distributed in the deeper layer also but its concentration was higher in first layer (0-10 cm) in both AFS and FRS systems. Quite a few workers in Poplar (Dickman *et al.*, 1996; Lukac *et al.*, 2003; Al Afas *et al.*, 2008) and other species like scot pine, Japanese cedar, Khasi pine etc. (Friend *et al.*, 2000; John *et al.*, 2001; Janssens *et al.,* 2002; Konopka *et al.*, 2005 & 2006) also reported concentration of fine roots in upper layer. This variation of root concentration may be due to varied presence of coarse root, nutrient and moisture availability, soil structure, temperature and microbial activity in different soil layers. Interaction among these factors are more dynamic in subsoil region in comparison to deeper layer (Block *et al.*, 2006; Konopka *et al.*, 2006). Uneven distribution of roots in different directions or rooting quarters may have similar reasons.

Many researchers (Kellman, 1979; Watson and O'Loughlin, 1990; Puri *et al.*, 1994, Abernathy and Rutherford, 2001; McIvor *et al.*, 2005) concluded that structural roots are largely confined to top 0.3 m of soil profile in Poplar and other species. This understanding does not hold well in the present case since more than 50% of root biomass was distributed beyond this depth. However, there are a few more reports of deep seated coarse root distribution in cottonwood (Rood *et al.*, 2011), loblolly pine (Albaugh *et al.*, 2006), and dehesa vegetation (Moreno *et al.*, 2005).

Root orientation and growth

Root number and CSA in *Populus x euramericana* (Tasman variety) varied between different depths but not in different directions (McIvor *et al.*, 2005). Contrary to this, these two varied with change in direction as well in the present study (*Populus euramericana* I-214). Although Smith (2001) and Kalliokoski *et al.* (2008) observed strong assumption of symmetrical dimension of root system, Puri *et al.* (1994) and McIvor *et al.* (2009) recorded highly asymmetric roots in poplar and other species owing to the effect of non-symmetrical mechanical stress and heterogeneous nutrient availability in soil (Coutts *et al.*, 1999; Casper *et al.*, 2003).

Root growth is essentially opportunistic in its timing and its orientation. It takes place whenever and wherever the environment provides water, oxygen, minerals, support and warmth (Perry, 1989). Variation of number in secondary roots and their proximal CSA in different directions in two different systems and even within the same tree of present investigation indicated that distribution of resources was not uniform. Substantial variation in root system has been previously reported in clonal plants of same age growing in uniform soil and site condition (Harrington and DeBell, 1996). Therefore, exploring the limited or one quarter of the rooting space of a tree (Fortier *et al.*, 2015b), and extrapolation of the value from it may not give accurate estimation and lead into either overestimation or underestimation of root growth. Henderson *et al.* (1983) had also confirmed in *Picea sitchinensis* that no reliable estimate can be obtained from measuring only one quarter of the space.

Two tiered root orientation in the AFS tree, probably due to damage of upper layer roots during ploughing of inter-row space for agriculture, was reported earlier also in sandy location by Perry (1989) in *Pinus* and other trees. This was done strategically to absorb water and nutrients from surface layer by first tier. Deep seated second tier allowed survival under drought or other adverse condition. Rood *et al.* (2011) also observed that in drier regions the cottonwood becomes phreatophytic and produces deeper root system to access moisture from ground water.

Belowground biomass

Total root biomass (18.1 Mg ha^{-1} in AFS and 24.5 Mg ha^{-1} in FRS) was within the reported range (14.8 Mg ha^{-1} to 29.6 Mg ha^{-1}) of hybrid poplar buffer (Fortier *et al.,* 2013) but fine root biomass (0.75 Mg ha^{-1} in AFS and 0.94 Mg ha^{-1} in FRS) was very low (1.86 Mg ha^{-1} to 2.62 Mg ha^{-1}; Fortier et al., 2015a). The condition was similar as compared to other systems like, young tree plantation (6 Mg ha^{-1} to 42 Mg ha^{-1}; Lukac *et al.,* 2003 and Block, 2004) and mature forest (5 Mg ha^{-1} to 52 Mg ha^{-1}; Steele *et al.*, 1997 and Pinno *et al.*, 2010). Though the edapho-climatic factors govern biomass production, the reason for higher fine root biomass could be higher plantation density as hypothesised by Berhongaray *et al.* (2013). This was confirmed in present study also as FRS had higher density and fine root biomass than AFS.

However, higher fine root or total root biomass on per tree basis in AFS than FRS could be due to different management regime. FRS trees got only post-planting silvicultural treatment like pruning while AFS got additional advantage of environment manipulation like irrigation and fertilizer application to the alley crop. Latter had also lesser inter-tree competition for underground resources like nutrients and moisture. Jha and Gupta (1991) and Banerjee *et al.* (2009) have also suggested that providing extra irrigation, fertilizer doses, weeding and hoeing during the early age of intercropping enhanced tree growth resulting in more biomass accumulation (Singh and Sharma, 2007). Corroborating results were found in other studies like, agrisilviculture (Pingale *et al.,* 2014), fruit trees (Raizada *et al.*, 2013), young *Populus deltoides* plantation (Kern *et al.*, 2004) and *Acacia mangium* (Danial *et al.*, 1997).

Forest and agroforest systems

The root system of two differently nurtured trees was different on accounts of coarse root orientation and resource allocation in spite of being same clone, age and locality. AFS showed more plasticity due to changed culture regime. This is in line with the hypothesis of Mulia and Dupraz (2006) that trees grown in association with annual winter crops develop a different rooting pattern as compared to trees grown in pure forestry stands. Root depth and architecture are partly controlled by physical and agronomic factors (Bishopp, 2009; Fukaki and Tasaka, 2009) but substantially by the genotype and age (Wullschleger *et al.*, 2005; Kell, 2012). But in the present case genetic control hypothesis for biomass variation could be ruled out (both trees same clone and age), and be assigned to soil structure and nutrient availability. Additional factor for deep rooting could also be the available moisture in water table around 3.0 m level. There is indirect support from Hallgren (1989) that poplar is an opportunistic rooter and does not produce deep roots if water table is at higher level.

As discussed earlier coarse and fine roots of poplar in plantation and agroforestry system are located near soil surface (Tufekcioglu *et al.*, 1999; Douglas *et al.*, 2010 etc.) with 1.0 m as effective rooting depth (Callesen *et al.*, 2016) may have some limitation. Contrasting to this much deeper roots in the present case had an advantage of extracting nutrients and moisture from larger area as well as acting as safety net for trapping leachable nutrients from upper layer (Allen *et al.*, 2004; Dougherty *et al.*, 2009). On this account AFS is more useful than FRS since it had root spread more deep and wide. Plasticity of AFS roots, an adaptation feature (Perry, 1989), get support from Gary (2000) who speculated that ploughing effected pruning of lateral roots could be the reason to drive down the coarse root to deeper layer since they were damaged and could not grow laterally beyond this in the tilled space. It is also possible that the presence of roots of agriculture crop played its role in this plasticity (Yocum, 1937; Mulia and Dupraz, 2006).

Conclusions

The hybrid poplar had deep seated root system in fluvisol in Mediterranean region. Coarse roots occupied the available space in all the directions but their orientation in a section may not be the mirror image of any of the quarter or the half of the rooting zone, possibly because of uneven soil structure and uneven nutrient availability. Differences were found in the trees of same species/clone at the same age but grown under two different systems – monoculture (FRS/PLS) and agrisilviculture (AFS). Secondary root orientation was tiered in the latter, possibly because of ploughing of tree inter-row space and presence of crop roots. Belowground allocation of biomass was higher in different root components – fine, medium and coarse roots in AFS tree. On hectarage basis it was more in FRS mainly due to higher tree density and optimum use of available nutrients. If introduced in agriculture land AFS has the advantage of grain production with some compromise on biomass vis a vis FRS.

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