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Tree Root Dynamics: An Essential Tool to Combat Root Competition in Agroforestry

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ABSTRACT

Tree crop competition in agroforestry systems prevails in unmanaged, improper planned agroforestry systems. Due to reduced crop yield in the system farmers regarded many agroforestry systems as economically non-viable. Mechanical measures are effective in reducing competition between trees and crops because of their high initial investment farmers are unable to take suitable measures. The aim of this paper is to signify the importance of knowledge on root dynamics, which helps a lot in reducing the root competition in the agroforestry systems. This paper discusses the selection of trees with complementary character to the crop, effects of irrigation, fertilization, cultural and tending operation on tree root growth.

***Key words**: Tree crop competition, Root dynamics, Complementary character*

Introduction

Roots are the hidden half part of a plant that has always been given lesser emphasis in the management of a crop as compared to the shoot. Root dynamics can be described as the changes which take place in the growth and architecture of the roots; it includes changes in root length, diameter, biomass, angle of rooting, root turnover, *etc*. Based on the size of roots tree roots are classified into Course roots (>2mm) and fine roots (< 2mm diameter). Fine roots are the dynamic portion of the belowground biomass, which forms a significant part of net primary production in any ecosystem (Hendrick and Pregitzer, 1993). These roots are held responsible for the absorption of water and nutrients from the soil also these fine roots of trees are involved in the competition held between the crops in the soil.

Agroforestry is a sustainable land-use system involving trees, crops and or animal components. Tree roots play a phenomenal role in conserving soil and enhancing soil fertility in agroforestry systems. The basic assumption behind agroforestry systems is that the tree and the crop absorb nutrients and water from a different depth of soil (root stratification) (Schroth, 1998) but in reality, it is not so, as >90% of plants in the world have at least 50% of all roots in the upper 0.3 m of the soil profile (including organic horizons) and 95% of all roots in the upper 2m (Schenk and Jackson, 2002).

The reduced yield of agriculture crops in intercropped systems is a result of root competition between tree and crop for water and nutrients especially near the trees; which accounts for at least 10% loss of agriculture yield (Malik and Sharma, 1990; Gao *et al.*, 2013). Root competition in the tree-based intercropping system is quite common in arid regions (Singh *et al.*, 1989; Corlett *et al.*, 1989), apparently in the drier months of other regions (Singh and Singh, 2016). Because of root competition between

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the components agroforestry system, farmers found this as an economically non-viable system from the production point of view.

Plant competition is an interaction that includes the effect of one plant on a resource and the response of another plant to the change in resource availability. Resource availability to competitors can be affected through resource depletion (scramble competition) and by mechanisms that inhibit access of other roots to resources (allelopathy) (Schenk, 2002). Mechanical measures such as installation of root barriers at 0.3m away from the tree rows at both the sides and pruning the tree roots to a ploughing depth in a biweekly interval are effective in reducing the root competition in agroforestry (Singh *et al*., 1989; Schroth, 1989). But these mechanical measures are costly to install or practise.

The root growth attributes among trees vary with each other and also with site conditions which is a boon for agro-foresters to design an agroforestry model with minimum root competition. A tree having complementary root growth character with the agriculture crops in that specific site should be chosen for the agroforestry land-use system. But it is difficult to find such trees everywhere and trees having complementary roots would not have good economic value in the local market. As the tree management practices and site factors influence the tree root growth, those can be used in addressing the root competition in agroforestry systems with comprehensive planning and less cost. The use of techniques in order to adjust the tree root interaction and function in tree-based cultivation systems is called "root management" (Bowen, 1984; Schroth, 1989).

Complementarities of tree roots with crop

The maximum active roots of agriculture crops are restricted to the depth of 20cm from the soil surface. Minimum horizontal spread, lower rooting angle, maximum rooting depth, non-allelopathic are the favorable tree root characters for agroforestry. The selection of agricultural crops should be based on the tree species planted in the system as like choosing drought-tolerant crops in the case of fast-growing trees. Since fast-growing trees have more fine root biomass near the surface than the slow-growing species they absorb more water and nutrients from the upper surface. Even though *Casuarina* is a fast-growing species and has more roots in upper layers of soil it seems to have favorable traits for agroforestry as its most root biomass is concentrated near the stem (George *et al.*, 1996).

In the case of Western Himalayan regions Verma *et al*., (2014) studied the root characteristics of some multipurpose tree species. They concluded that *Bauhinia variegate* has got minimum root spread, the angle between primary and secondary angle and maximum root depth which is 1.1m, 71.81° and 4.78m respectively. Whereas, a maximum root spread of 7.33 and more branching angle of 85.39° is found in *Robinia pseudoacacia* species (Verma *et al*., 2014). Therefore, *Bauhinia variegate* is a good option for agroforestry tree species in the western Himalayan region.

As discussed earlier the maximum root biomass in temperate trees is located within 20cm depth of the soil (Borden *et al.,* 2017; Raz-Yaseef *et al*., 2013). Among temperate agroforestry trees, *Populus* species have shown competitive stratification of the root zone with the agriculture crops (Borden *et al*., 2017); therefore, proper management has to be taken while intercropping with *Populus* species. Apple trees have a highly elastic root system, their root growth changes rapidly with the changing environment. Apple tree root zone strata can be shifted to the subsoil region by intercropping them with the competitive deep-rooted grasses (Lucerne, Corn) (Yocum, 1937).

Selecting tree with less branching is the thumb rule while selecting species for agroforestry by looking at its external appearance as the trees with less branching habit have their maximum concentration of its active roots near the stem, the root pruning or tillage operations don't affect the tree much (Korwar and Radder, 1994). But in the case of heavy root branching habit trees, most of the active roots are concentrated away from the trunk (Atger and Edelin, 1994).

Irrigation

Irrigation does not influence the overall production of root biomass but somehow it influences the vertical distribution of roots in the soil profile (Contador *et al*., 2015; Goode *et al*., 1978), in this support Goode *et al.* (1978) reported that irrigation to apple trees increased root density in the top 15 cm by decreasing root density in the 15-30 cm soil depth; whereas, irrigation in walnut induced more roots in the 23-42cm soil depth than in the 63-82 cm (Contador *et al.*, 2015). Hence irrigation induces trees to accumulate more roots near the surface while non irrigated trees accumulate the root biomass in deeper layers of the soil in search of water.

Method of irrigation affects the root distribution only in moisture deficient conditions of the soil. By supplying water through a well-managed drip irrigation system near the tree trunks root growth can be localized this may be because the depth of wetting in drip irrigation would more than other irrigation methods so it would have influenced the rooting depth (Cullen *et al.*, 1972). The root distribution was restricted to the soil surface in flood irrigated areas while low volume sprinkler irrigation system resulted in uniform vertical root distribution in apple trees (Huguet, 1976). In contrast to this Abdullah *et al.* (2010) observed a uniform pattern of root distribution with different methods of irrigation (drip, surface and subsurface drip, and under-tree micro-sprinkler) in apple trees.

Fertilizer application

In fact, in nutrient-limited soil practicing agroforestry should be avoided for tangible benefits, but once any agroforestry system is laid out, ultimately it enriches the soil nutrients over some time and enhances overall productivity. Plants require 17 essential elements for their growth and development. Among them, 14 nutrients required for the plant are obtained from the soil. Generally, root competition is observed in soils with low fertility. Wilson and Tilman (1993), observed the decreased root competition as the fertility level of the land increases.

Nitrogen application affects less on root growth as compared to shoot growth. N_2 application increases the surface area of the roots by producing more branches of thinner roots, so that roots will absorb more nutrients required for rapid shoot growth (Lynch *et al.*, 2011). But this effect of fertilizer on root growth may depend on the age of the crop and the general nutrient level of the soil. In the case of Eucalyptus of 18 to 32 months old, Jourdan *et al.* (2008) reported slightly reduced mean fine root biomass as nitrogen application level increased. It could be due to sufficient existence of nitrogen in the soil before the nitrogen application and on the addition of more nitrogen the overdose might have declined fine root production; as fine root production decreased in the citrus due to over fertilization with nitrogen (May *et al.*, 1964).

Singh and Singh (2016) carried an experiment in Ludhiana on fine root biomass production in Poplar with different nutrient treatments. They found a direct relationship between nutrient concentration applied to the plant and the fine root biomass production in Poplar (*Populus deltoids* Bartr.). The maximum biomass production was found in the treatment given with 625g of N and 400g of P_2O_5 (cumulative nutrients given for five years) for trees than in other treatments (Table 1).

Phosphorus availability in the soil is the main factor that controls root growth and development; application of phosphorus in deficient soil is much effective in proliferation of plant roots especially in early plant growth stage (Lynch *et al.*, 2011). Almost 143 per cent more fine root production as compared to controlled condition in *Acacia mangium* was recorded when 600 kg ha^{-1} yr^{-1} of phosphorus fertilizer was added (Thang *et al.*, 2020).

Table 1. Fine root biomass (0-75 cm depth) of poplar under different nutrient levels in alley cropping systems during various months of year (Singh and Singh, 2016).

Nutrient levels (N: P_2O_5)	Fine root biomass (gm^{-2})				
	April	July	October	January	Mean
T1(0:0), non intercroppped	28.1	34.4	37.8	34.5	33.7
T2(0:0)	39.1	47.6	42.7	35.6	41.3
T3(375:0)	41.6	50.7	59.2	43.2	48.7
T4(375:300)	44.4	57.5	63.0	50.8	53.9
T5(500:0)	48.6	59.3	72.5	50.9	57.8
T6(500:300)	52.5	80.2	74.6	60.6	67.0
T7(500:400)	51.8	85.4	79.4	71.8	72.1
T8(625:0)	55.5	85.5	95.5	88.5	81.3
T9(625:300)	51.9	90.4	112.4	102.4	89.3
T10(625:400)	59.2	101.7	127.2	94.5	95.7
Mean	47.3	69.3	76.4	66.3	

Table 2. Root activity pattern of two-year-old *Acacia mangium* as influenced by tree spacing and spatial distance (Kunhamu *et al*., 2010).

Spatial dimensions (cm)		Root activity (%) under different density regimes					
		High density (2m x 1m)		Medium density (2mx2m)		Low density (2mx4m)	
Lateral distance (cm)	Depth (cm)	Pruned	Unpruned	Pruned	Unpruned	Pruned	Unpruned
25	30	33.8	37.58	23.34	23.27	24.68	11.08
	60	15.85	15.49	20.7	11.53	9.25	11.98
	Subtotal	49.65	53.04	44.04	34.8	33.93	23.06
50	30	21.07	24.7	11.09	24.44	17.15	24.01
	60	16.74	5.07	9.96	12.11	7.36	10.53
	Subtotal	37.81	29.77	21.05	36.55	24.51	34.54
75	30	5.94	9.7	13.68	12	24.69	29.32
	60	6.6	7.48	21.23	16.65	16.87	13.09
	Subtotal	12.54	17.18	34.91	28.65	41.56	42.41

Cultural operation

Nowadays zero tillage or minimum tillage is followed for crops for conservation of soil but in the case of agroforestry, this conservation technology has a bad impact on the yield of agricultural crops especially when agricultural crops are grown with fast-growing trees species like *Leucaena leucocephala* (Ssekabembe, 1985). Deep ploughing is insisted near the rows of trees in agroforestry practices. 30cm deep ploughing along *L. leucocephala* hedgerows before sowing of agriculture crop increased grain and stover yields of alley cropped sorghum, and higher moisture contents in the alleys with tree roots pruned indicates reduced root competition (Korwar and Radder, 1994).

Tending operation

Pruning is an important management tool used in agroforestry practices to reduce both aboveground competition and belowground competition. The level of competition reduction cannot be the same in all species for shoot pruning (Schroth, 1998). Pruning reduces photosynthetic production in the canopy and exposes the soil beneath the canopy to direct sunlight which is the two main reasons why root growth is reduced due to canopy pruning.

Kunhamu *et al.* (2010), documented that maximum root activity was found in 25cm lateral distance from the tree trunk in closely spaced trees whereas more root activity was found in 75cm lateral distance in the case of widely spaced trees. In the meantime, they noticed that root activity was more at 60 cm depth in pruned trees while it was more near the surface in the case of un-pruned trees. This might be because the temperature in the surface soil increases due to canopy opening which does not favour surface root production (Table 2).

Tree root growth is opportunistic so, keeping appropriate spacing between alley and crop, and spot weeding around the trunk in alley reduces vegetation and keep the area free from competition which attracts the tree roots to concentrate near the trunk (Atkinson *et al.*, 1978).

Conclusion

Selection of appropriate tree species for specific site and crops grown with suitable spacing will reduce the root competition. Drip irrigation helps in water deficient area to restrict growth of roots near the tree trunk apparently, weeding around the tree trunk also can help in the same manner. Maintaining general status of nutrients in the soil at good condition prevents yield reduction of crops to a certain level and addition of nutrients in the soil; especially phosphorus, increases root biomass. This information can be used to train the roots in desired direction. Shoot pruning reduces the root biomass so this has to be judiciously practised for avoiding competition in intercropping situation without hindering tree growth.

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