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Carbon stock dynamics and physico-chemical properties of soils under farm plantations in mid-hills of Himachal Pradesh

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ABSTRACT

Impact of twenty five years old pure and mixed farm plantations of *Eucalyptus tereticornis*, *Populus deltoides*, *Quercus leucotrichophora* and *Eucalyptus tereticornis* plus *Pinus roxburghii* and *Quercus leucotrichophora* mixed with *Ulmus villosa* was studied on soil carbon density and other physico-chemical properties. The gain or loss of soil carbon stock from plantations was elucidated by comparing the soil properties under plantations with the adjoining area. The study indicated that plantations led to increase in soil organic carbon (SOC) and carbon density. Soil pH under plantations ranged from 5.74-6.41 as compared to 6.20-6.96 in control area. Percent SOC and total soil carbon density was highest in soils under *Eucalyptus tereticornis* (1.63% and 88.33 Mg ha^{-1}, respectively). Pure plantation of *Populus deltoides* resulted in maximum increase in actual soil carbon density (69.98%) as compare to area outside the plantations whereas, mixed plantation of *Eucalyptus tereticornis* plus *Pinus roxburghii* resulted in minimum increase of 14.19% in actual soil carbon density. Soil carbon density in various plantations followed the trend of *Populus deltoides* (30.45 Mg ha^{-1}) > *Quercus leucotrichophora* (22.42 Mg ha^{-1}) > *Quercus leucotrichophora* plus *Ulmus villosa* (22.02 Mg ha^{-1}) > *Eucalyptus tereticornis* (21.66 Mg ha^{-1}) > *Eucalyptus tereticornis* plus *Pinus roxburghii* (8.39 Mg ha^{-1}).

1. INTRODUCTION

Carbon sequestration is the removal of CO_2 from the atmosphere and its long term storage in oceans, soils, vegetation and geologic formations. Managed forests or plantations by storing carbon in biomass, soil and products provide significant pools for carbon sequestration. Conversion of lands covered with vegetation other than tree species to plantation forests occurs worldwide for timber production, soil conservation, restoration, recreation and other purposes. This shift in land use to plantation forests lead to increased rates of carbon sequestration as well as the mitigation of non-CO_2 greenhouse gases and therefore, tree plantations are being considered to generate environmental credits and increase land value (Jandl *et al.*, 2007).

Forest plantations witness an increase in soil carbon sequestration due to high above ground productivity, recalcitrant carbon inputs and deep rooting systems (Lal, 2005; Don *et al.*, 2010 and Laganiere *et al.*, 2010). In the long term, carbon sequestered in soils is more relevant for ecosystem functioning than carbon storage in above ground biomass. Soil carbon has been shown to increase under Eucalyptus plantations in the top 10 cm, but maintaining or increasing quantities of soil C has been shown to have variable effects on soil chemical properties (Nambiar and Harwood, 2014). The influence of tree species on forest soil properties has for a long time been studied by ecologists but the focus of these studies has not been directed toward effects on soil physico-chemical properties, organic carbon stocks and their dynamics for mitigation of greenhouse gases. Long-term, broad-scale studies are required to determine regional patterns of change in soil carbon that result from a suite of interactive factors, including land management (Cook *et al.*, 2016).

The quantitative estimates of tree species effects on SOC stocks are still scarce and the scientific basis for targeted use of tree species to maximize sequestration of SOC following afforestation is also limited to relatively few studies. In subtropical and sub temperate region of western Himalayas *Eucalyptus tereticornis*, *Populus deltoides*, *Quercus leucotrichophora*, *Pinus roxburghii* and *Ulmus villosa* are planted as important farm forestry trees. Large scale plantations of *Eucalyp tustereticornis* and *Populus deltoides* have been extensively raised in government and private farm lands and their potential to grow economically on farm and waste land is increasing. These farm plantations, despite playing important role in ecology and newly emerging carbon economy, has given very less attention in scientific researches.

Therefore, present study was conducted to quantify the impact of different farm plantations on carbon stocks and physico-chemical properties of soil in mid hills of Himachal Pradesh and to determine gain or loss of SOC under such plantations.

2. MATERIALS AND METHODS

Study Site and Climate

The study was carried out during 2012-13 at research farm of Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni situated at 30°50'30" to 30°52'0"N latitude, 77°8'30" to 77°11'30"E longitude. The site is located at an altitude ranging from 900 to 1350 m which falls in the transition zone between subtropical and sub temperate region of Solan district of Himachal Pradesh, India. The mean annual rainfall in the region is 1150 mm, whereas, mean annual temperature is approximately 19.2°C and relative humidity of the region remains about 57%.

Geology and Physiography

The area falls within the outer Himalayan range and the rocks belong to Shimla group of rocks overlain by intra karol and karol series as a result of karol thrust (Carboniferous lower Mesozoic period). Thinly bedded grayish shales and phyllitesn are exposed along the southern periphery of the area. Carbonaceous shales, Calcareous shales, dolomite limestones occurring within the thin band of intermittent shales and occasional sandstone and quartzite belong to karol series (Wadia, 1953).The physiography of the area is marked by an undulating topography dotted by elevations and depressions. The general gradient of the area is from NW to SE. Slopes are gently and excessively steep ranging from 3% in intensively cultivated area to more than 50% in pastures, plantations and forest area.

Selection of Plantations

Five 25 years old plantations of *Eucalyptus tereticornis*, *Populus deltoides* and *Quercus leucotrichophora* in pure stands and *Eucalyptus tereticornis* plus *Pinus roxburghii, Quercus leucotrichophora* plus *Ulmus villosa* in mix stands were selected for present investigation. Natural flora under each plantation type is given in Table 1. Each plantation was taken in four

Table: 1
Natural flora under various plantations

Plantation	Species
Eucalyptus tereticornis	*Setaria sphacelata var. conjungula, Cynodon dactylon, Pyrus pashia, Toona ciliata, Rubus ellipticus, Paspalum dilatatum, Oxalis corniculata, Lapidium rudrale, Rubus elipticus, Prinsepia utilis, Ficus palmata, Erigeron annus, Flueggea microcarpa, Ranunculus laetus, Bidens pillosa, Barleria cristata, Clematis spp, Elaeagnus umbellata, Artemisia roxburghiana, Trifolium repens, Achyranthus aspera.*
Populus deltoides	*Berberis lycium, Bidens pillosa, Elaeagnus umbellate, Sapium sebiferum, Toona ciliata, Cannabis sativa, Thalictrum foliolosum, Ficus palmata, Hedera helix, Smilax aspera, Rumex nepalensis, Artemisia roxburghiana, Melia azadirach, Solanum nigrum, Parthenium hysterophorus, Avena fatua, Physalis minima, Ranunculus laetua, Equisetum arvense, Verbena bonariensis, Panicum arundinella, Carissa carandas, Rosa moschata, Achyranthus aspera.*
Quercus leucotrichophora	*Elaeagnus umbellate, Melia azadirach, Cannabis sativa, Achyranthus aspera, Clematis spp, Murraya koenigii, Rondia tetrasperma, Pyrus pashia, Rhamanus variegitus, Fragaria viscose, Urtica dioca, Rubus ellipticus, Zanthoxylum arboreum, Berberis lyceum, Carissa carandas, Lantana camara.*
Eucalyptus tereticornis mixed with *Pinus roxburghii*	*Lantana camara, Zanthoxylum arboreum, Berberis lyceum, Murraya koenigii, Cannabis sativa, Rubus elipticus, Prinsepia utilis, Murraya koenigii, Ficus palmata, Punica granatum, Achyranthus aspera, Biden pillosa, Solanum nigrum.*
Quercus leucotrichophora mixed with *Ulmus villosa*	*Punica granatum, Melia azadirach, Ziziphus jujuba, Artemisia roxburghiana, Toona ciliata, Rubus ellipticus, Tagetus minuta, Lantana camara, Berberis lyceum, Carissa carandas, Rosa moschata, Caryopteris wallichiana, Meriandra strobilifera, Chrysopogon montanus.*

replications under randomized block design (RBD). Plantations were established on bare land during 1988-1989. Adjoining bare area outside each plantation was selected as control site. Effect of plantation type on soil carbon density and other physico-chemical properties was determined by comparing the status with the control sites. The plantations of uniform age, grown at iso-ecological situations were selected purposefully for the study.

Soil Sampling and Analysis

Samples were collected from 0-15, 15-30 and 30-45 cm depths from three sites from each replication and composite samples were prepared for each soil depth. Soil bulk density was determined using a core sampler (Singh, 1980). Soil samples were air-dried and passed through a 2 mm sieve to remove rocks and plant roots before analysis. Organic carbon was determined by Walkley and Black (1934) method . Soil pH and electrical conductivity (EC) were determined in 1:2.5 soil:water suspension by using digital pH meter and digital conductivity bridge (Jackson, 1973). Soil carbon density was calculated by following formula (Nelson and Sommers, 1996):

Soil Carbon Density (Mg ha^{-1}) = [Soil Bulk Density (g cm^{-3}) x Soil Depth (cm) x Organic Carbon] x 100

Statistical analysis

The Analysis of variance (ANOVA) was used to evaluate the influence of plantations on soil carbon stock and physico-chemical properties. The means were separated and compared through critical difference at 5% level of significance.

3. RESULTS AND DISCUSSION

Soil Organic Carbon (SOC)

SOC under different plantations ranged between 1.14-1.63% and exhibited a significant variation among different plantations and at soil depths (Table 2). SOC was significantly highest under pure plantation of *Eucalyptus tereticornis* (1.63%) followed by *Populous deltoides* (1.42%). Lowest SOC value of 1.14% was observed in *Eucalyptus tereticornis* mixed with *Pinus roxburghii* plantation which was statistically at par with *Quercus leucotrichophora* plus *Ulmus villosa* (1.16%) and *Quercus leucotrichophora* (1.19%). Significantly highest increase in SOC was observed in pure *Populus deltoides* plantation, which resulted an increase of 82% in the 0-45 cm soil depth followed by pure *Eucalyptus tereticornis* plantation (40.5%) over their control site, whereas mix plantation of *Eucalyptus tereticornis* and *Pinus roxburghii* registered with the lowest increase of 14% which was at statistically par with *Quercus leucotrichophora* and *Quercus leucotrichophora* plus *Ulmus villosa* plantation. In 0-45 cm depth, SOC was significantly higher in pure plantation as compared to mixed ones except *Quercus leucotrichophora* plus *Ulmus villosa* wherein the effect was statistically at par, probably due to high density. Among pure plantations lowest SOC (0.72%) under *Quercus leucotrichophora* was due to relatively poor tree densities and high human interferences as the foliage of the tree is commonly used as fodder in the region. Parrotta (1992) observed that organic carbon was significantly higher in plantation plots. Thakur *et al.* (2012) also reported higher SOC under plantations in the range of 1.50-1.95%.

As per standard trend under all plantations significantly highest SOC content was recorded in surface layer (0-15 cm) which was found to decrease depth wise. However, the increase in percent SOC concentration under plantations over control was the significantly highest (0.44%) in sub-surface (15-30 cm) soil depth whereas increase in 30-45 cm was lowest that was statistically at par with the surface (0-15 cm) depth. Higher built-up of SOC in the surface layers under

Table: 2
Depth wise percent SOC distribution in various plantations

Plantation species	Distribution under plantations			Mean	Distribution under control			Mean	Gain/Loss			Mean
	0-15 cm	15-30 cm	30-45 cm		0-15 cm	15-30 cm	30-45 cm		0-15 cm	15-30 cm	30-45 cm	
Eucalyptus tereticornis (T_1)	2.03	1.79	1.06	1.63	1.52	1.23	0.74	1.16	+0.51	+0.56	+0.32	+0.46
Populus deltoides (T_2)	1.80	1.46	0.99	1.42	1.28	0.60	0.47	0.78	+0.52	+0.86	+0.52	+0.63
Quercus leucotrichophora (T_3)	1.66	1.20	0.72	1.19	1.45	0.84	0.56	0.95	+0.21	+0.36	+0.16	+0.24
Eucalyptus tereticornis + *Pinus roxburghii* (T_4)	1.55	1.15	0.72	1.14	1.48	1.06	0.48	1.00	+0.07	+0.09	+0.24	+0.13
Quercus leucotrichophora + *Ulmus villosa* (T_5)	1.72	1.07	0.70	1.16	1.42	0.72	0.46	0.87	+0.30	+0.35	+0.24	+0.30
Mean	1.75	1.34	0.84	1.31	1.43	0.89	0.54	0.95	0.32	0.44	0.30	0.35
$CD_{0.05}$ T				0.09				0.15				0.11
D				0.07				0.12				0.08
T x D				0.16				0.12				0.18

tree species may be attributed to accumulation of litter fall of tree species on the soil surface. The subsequent decomposition and incorporation of litter into the soil would have helped in increasing the organic carbon content of the soil. The increase in organic carbon status under plantation with addition of organic matter through litter fall has been reported by Iovieno and Alfani (2007) for Pinus and Quercus and Singh and Sharma (2012) under different plantations. However, contrasting results were observed by Chirino *et al.* (2010) for Pinus and Eucalyptus who had recorded significant reduction in topsoil total carbon following afforestation of grassland.

Soil Bulk Density

The bulk density of soils under different farm plantations varied from 1.17-1.34 g cm^{-1}. All pure plantations showed a decrease in bulk density except pure plantation of *Quercus leucotrichophora* that has resulted in a decrease of 0.18 g cm^{-3} over control site. However all mix plantations resulted in increase in bulk density. The variation in the bulk density under different farm plantations can be owed to their varying rate of leaf-litter deposition. Among mix plantations, plantation of *Eucalyptus tereticornis* mixed with *Pinus roxburghii* showed highest 1.34 g cm^{-3} bulk density. Bulk density of soils under different plantations showed increase with the soil depth. This increase would have been due to decrease in organic carbon with increasing soil depth (Table 3).

Soil Acidity

Soil pH under the plantations was slightly acidic (5.74-6.41) due to decomposition of organic matter and release of organic acids. Mix plantation of *Quercus leucotrichophora* and *Ulmus villosa* showed highest pH (6.41) which was statistically at par with pure plantation of *Populus deltoides* (6.29), whereas the soils under mix plantation of *Eucalyptus tereticornis* and *Pinus roxburghii* showed minimum soil pH (5.74) which was statistically at par with pure plantation of *Eucalyptus tereticornis* (Table 4). Whereas, the highest pH in the control outside plantation was observed in *Eucalyptus tereticornis* (6.96) which was statistically at par with *Eucalyptus tereticornis* plus *Pinus roxburghii* and *Quercus leucotrichophora* mixed with *Ulmus villosa* plantation. However, the soil pH did not show any significant variation along with the soil depth in both plantation and the control sites. The results clearly indicated

Table: 3
Depth wise soil bulk density (g cm^{-3}) distribution in various plantations

Plantation species	Distribution under plantations			Mean	Distribution under control			Mean
	0-15 cm	15-30 cm	30-45 cm		0-15 cm	15-30 cm	30-45 cm	
Eucalyptus tereticornis (T_1)	1.19	1.21	1.23	1.21	1.24	1.28	1.32	1.28
Populus deltoides (T_2)	1.14	1.17	1.19	1.17	1.22	1.24	1.28	1.24
Quercus leucotrichophora (T_3)	1.31	1.35	1.37	1.34	1.11	1.16	1.22	1.16
Eucalyptus tereticornis + Pinus roxburghii (T_4)	1.31	1.34	1.37	1.34	1.28	1.32	1.38	1.33
Quercus leucotrichophora + Ulmus villosa (T_5)	1.28	1.29	1.31	1.29	1.15	1.24	1.30	1.23
Mean	1.25	1.27	1.29	1.27	1.20	1.25	1.30	1.25
$CD_{0.05}$ T				0.28				0.08
D				0.02				0.06
T x D				NS				0.06

Table: 4
Depth wise soil pH distribution in various plantations

Plantation species	Distribution under plantations			Mean	Distribution under control			Mean
	0-15 cm	15-30 cm	30-45 cm		0-15 cm	15-30 cm	30-45 cm	
Eucalyptus tereticornis (T_1)	5.82	5.84	5.87	6.84	6.89	6.99	7.03	6.96
Populus deltoides (T_2)	6.22	6.29	6.35	6.29	6.49	6.58	6.62	6.56
Quercus leucotrichophora (T_3)	6.04	6.14	6.21	6.13	6.12	6.17	6.31	6.20
Eucalyptus tereticornis + Pinus roxburghii (T_4)	5.72	5.74	5.77	5.74	6.69	6.72	6.73	6.71
Quercus leucotrichophora + Ulmus villosa (T_5)	6.33	6.40	6.50	6.41	6.63	6.72	6.75	6.70
Mean	6.02	6.08	6.14	6.08	6.56	6.63	6.68	6.63
$CD_{0.05}$ T				0.18				0.33
D				NS				NS
T x D				0.15				0.27

that the pure as well as mix plantations of *Eucalyptus tereticornis* increased the soil acidity as compare to other plantations. Thakur *et al*. (2012) also observed slightly acidic pH (5.8-6.42) under Eucalyptus plantation. Similar trends of soil pH were reported by Raina and Kumar (2000) for soils of Himachal Pradesh.

Soil EC

The EC of soil in plantations ranged from 0.10 to 0.30 dS m^{-1} and decreased significantly after plantation of pure as well as mix stands (Table 5). Highest EC was recorded under mix plantation of *Quercus leucotrichophora* and *Ulmus villosa* (0.30 dS m^{-1}) which was statistically at par with pure plantation of *Eucalyptus tereticornis* (0.25 dS m^{-1}). However in control outside respective plantations significantly highest soil EC of 0.44 dS m^{-1} was observed under pure plantation of *Eucalyptus tereticornis* followed by *Quercus leucotrichophora* plus *Ulmus villosa* (0.33 dS m^{-1}), *Eucalyptus tereticornis* plus *Pinus roxburghii* (0.29 dS m^{-1}), *Quercus leucotrichophora* (0.28 dS m^{-1}) and *Populus deltoids* (0.27 dS m^{-1}) which were statistically at par with each other. Mix plantation of *Eucalyptus tereticornis* mixed with *Pinus roxburghii* resulted in decrease in soil EC by 65.51% followed by pure plantation of *Eucalyptus tereticornis* (43.10%). Mix plantation of *Quercus leucotrichophora* mixed with *Ulmus villosa* resulted in minimum decrease of 9.09% in soil EC after 25 years. Decrease in soil EC with establishment of plantations was also observed by Shankarnarayan *et al.* (1987) and Demessie *et al.* (2012) under eucalyptus plantation.

Soil Carbon Density

Mean soil carbon density in farm plantation ranged from 22.52 to 29.44 Mg ha^{-1} (Table 6). It was significantly higher under pure plantation of *Eucalyptus tereticornis* and followed the trend of *Eucalyptus tereticornis* (29.44 Mg ha^{-1}) >*Populus deltoides* (24.65 Mg ha^{-1}) > *Quercus leucotrichophora* (23.66 Mg ha^{-1}) > mix plantation of *Quercus leucotrichophora* and *Ulmus villosa* (22.96 Mg ha^{-1}) > *Eucalyptus tereticornis* mixed with *Pinus roxburghii* (22.52 Mg ha^{-1}). Significantly highest soil carbon density was observed in 0-15 cm soil depth whereas it was significantly lowest in 0-45 cm soil depth. Similar results were also reported by Sharma *et al*. (2011) in different

Table: 5
Depth wise electrical conductivity (dS m^{-1}) distribution in various plantations

Plantation species	Distribution under plantations			Mean	Distribution under control			Mean
	0-15 cm	15-30 cm	30-45 cm		0-15 cm	15-30 cm	30-45 cm	
Eucalyptus tereticornis (T_1)	0.29	0.23	0.24	0.25	0.42	0.46	0.44	0.44
Populus deltoides (T_2)	0.22	0.17	0.18	0.19	0.32	0.26	0.12	0.27
Quercus leucotrichophora (T_3)	0.23	0.18	0.11	0.17	0.30	0.28	0.28	0.28
Eucalyptus tereticornis + Pinus roxburghii (T_4)	0.11	0.10	0.09	0.10	0.31	0.28	0.28	0.29
Quercus leucotrichophora + Ulmus villosa (T_5)	0.31	0.30	0.29	0.30	0.36	0.34	0.30	0.33
Mean	0.23	0.19	0.18	0.20	0.34	0.32	0.31	0.32
$CD_{0.05}$ T				0.07				0.15
D				NS				0.01
T x D				NS				0.12

Table: 6
Depth wise soil carbon density (Mg ha^{-1}) distribution in various plantations

Plantation species	Distribution under plantations			Mean	Distribution under control			Mean	Gain/Loss			Mean
	0-15 cm	15-30 cm	30-45 cm		0-15 cm	15-30 cm	30-45 cm		0-15 cm	15-30 cm	30-45 cm	
Eucalyptus tereticornis (T_1)	36.16	32.56	19.61	29.44	28.39	23.71	14.56	22.22	+7.77	+8.85	+5.05	+7.22
Populus deltoides (T_2)	30.78	25.67	17.51	24.65	23.33	11.14	9.04	14.50	+7.45	+14.53	+8.47	+10.15
Quercus leucotrichophor (T_3)	32.60	23.94	14.44	23.66	23.94	14.38	10.24	16.18	+8.66	+9.56	+4.20	+7.47
Eucalyptus tereticornis + Pinus roxburghii (T_4)	30.21	22.73	14.63	22.52	28.40	20.80	9.94	19.71	+1.81	+1.89	+4.69	+2.80
Quercus leucotrichophora + Ulmus villosa (T_5)	33.59	21.22	14.08	22.96	24.57	13.24	9.06	15.62	+9.02	+7.98	+5.02	+7.34
Mean	32.67	25.22	16.05	24.65	25.73	16.65	10.57	17.65	+6.94	+8.56	+5.49	+7.00
$CD_{0.05}$ T				1.89				3.21				2.10
D				1.46				2.49				1.63
T x D				3.27				2.60				3.65

plantations. Upper soil layer remains in dynamic equilibrium with biological and anthropological activities and is generally richer in carbon than lower layers. Similar results were also reported earlier by Shrestha *et al.* (2004) in mountain watershed of Nepal. The growth and function of vegetation depends on availability of plant nutrients in the soil, while SOC input depends on the input received from the vegetation grown. Thus, there is an interrelationship between vegetation and carbon dynamics in an ecosystem. The input can be from above ground leaf litter and/or the below ground fine roots and their decomposition rates are governed by microbial activity.

It is clear from that all plantations resulted increase in soil carbon density when compared with the area outside the respective plantations (Table 7). Soil carbon density was significantly highest in pure plantation of *Eucalyptus tereticornis* (88.33 Mg ha^{-1}). However, pure plantation of *Populus deltoides* resulted in significantly highest increase of 10.15 Mg $ha^{-1}$and depicted a gain by 69.98% in soil carbon density as compared to respective control area followed by the mix plantation of *Quercus leucotrichophora* and *Ulmus villosa* (46.98%), pure plantation of *Quercus leucotrichophora* (46.17%) and pure plantation of *Eucalyptus tereticornis* (32.50%). Mix plantation of *Eucalyptus tereticornis* and *Pinus roxburghii* resulted in significantly lowest increase by 14.19% in soil carbon density.

4. CONCLUSIONS

The study revealed that all plantations resulted in significant increase in soil carbon density as compared to control site outside the plantations. Pure plantation of *Populus deltoides* has highest potential of accumulating organic carbon in soil than other plantations. The order of carbon sequestration in the soil under different farm plantations followed *Populus deltoides* > *Quercus leucotrichophora* mixed with *Ulmus villosa* > *Quercus leucotrichophora* > *Eucalyptus tereticornis* > *Eucalyptus tereticornis* mixed with *Pinus roxburghii*. Plantations also helped in reduction of soil bulk density thus improved the physical structure of the soil. Thus these small scale plantations in addition to fulfilling the demand of fuel, fodder, wood and other products can also ameliorate the poor quality sites and by sequestering carbon in biomass and these soils can play significant role in mitigating climate change.

Table: 7
Depth wise actual carbon density (Mg ha^{-1}) distribution in different plantations

Plantation	P	P_0	Actual value	% Value
Eucalyptus tereticornis (T_1)	88.33	66.66	+21.66	32.50
Populus deltoides (T_2)	73.96	43.51	+30.45	69.98
Quercus leucotrichophora (T_3)	70.98	48.56	+22.42	46.17
Eucalyptus tereticornis + *Pinus roxburghii* (T_4)	67.57	59.14	+8.39	14.19
Quercus leucotrichophora + *Ulmus villosa* (T_5)	68.89	46.87	+22.02	46.98
$CD_{0.05}$	9.52	13.57		

P- Planted area; P_0- Unplanted area (Control)

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