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# Distribution of fine root biomass of fruit and forest tree species raised on old river bed lands in the north west Himalaya

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**Abstract:** Biomass production and turnover of fine roots were estimated in six fruit and three forest stands that had been raised on old river bed lands in the Doon valley. Significant variations ($P < 0.05$) were observed among species, over seasons and distances from the stem. Nearly 80 % of fine roots were confined to the 0 - 20 cm soil layer in all species investigated. Fine root biomass and turnover was high at 1 m distance from the stem in moisture sensitive fruit species (mango, litchi and kinnow mandarin) due to annual addition of manure and fertilizers. In forest stands similar trends were observed except that turnover rates varied at increased distance from the stem and ranged between 0.326 and 0.884 at 1 m distance and between 0.613 and 0.811 at 2 m distance. The contribution of fine roots towards the build-up of soil organic matter and enrichment of nutrients can lead to conducive soil environment to assist natural forest recovery on these degraded sites over a period of time.

**Resumen:** Se estimaron la producción de biomasa y el recambio de raíces finas en seis rodales de árboles frutales y tres rodales de bosque cultivados en terrenos del antiguo lecho del río en el valle Doon. Se observaron diferencias significativas ($P < 0.05$) entre especies, así como entre estaciones y distancias desde el tallo. Alrededor de 80 % de las raíces finas estuvieron confinadas a la capa de suelo de 0 - 20 cm en todas las especies investigadas. La biomasa y el recambio de raíces finas fueron altos a una distancia de 1 m del tallo en especies frutales sensibles a la humedad (mango, lichi y mandarina kinnow) debido a la adición anual de abono y fertilizantes. En rodales de bosque se observaron tendencias similares, excepto que las tasas de recambio variaron al incrementarse la distancia desde el tronco, fluctuando entre 0.326 y 0.884 a una distancia de 1 m, y entre 0.613 y 0.811 a una distancia de 2 m. La contribución de las raíces finas a la acumulación de materia orgánica del suelo y el enriquecimiento de nutrientes puede generar un entorno edáfico propicio para asistir a la recuperación del bosque natural en estos sitios degradados después de un cierto periodo de tiempo.

**Resumo:** A produção de biomassa e o volume de renovação de raízes finas foram estimados em seis árvores de fruto e três povoamentos florestais vegetando em solos de um leito velho do rio no vale Doon. Observaram-se variações significativas ($P < 0,05$) entre as espécies, ao longo das estações e distâncias ao tronco. Quase 80 % das raízes finas encontravam-se confinadas na camada de 0 - 20 cm do solo em todas as espécies estudadas. A biomassa de raízes finas e e o seu volume foi elevado a 1 m de distância do tronco nas espécies frutíferas sensíveis à humidade (manga, lichia e tangerina kinnow) devido à adição anual de estrume e fertilizantes. Em povoamentos florestais observaram-se tendências semelhantes, exceto que as taxas de renovação variaram a uma maior distância do tronco no intervalo entre 0,326 e 0,884 a 1 m de distância e entre 0,613 e 0,811 a 2 m de distância. A contribuição das raízes finas na acumulação de matéria orgânica do solo e de enriquecimento em nutrientes pode contribuir para

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criar um ambiente no solo conducente à recuperação da floresta natural destes sítios degradados ao fim de certo período de tempo.

**Key words:** Fine roots biomass, fruit and forest trees, old river beds, North-west Himalaya.

## Introduction

Roots in general and fine roots in particular play an important role in enriching the soil with organic matter and nutrients by rapid turnover and by absorption of water and nutrients from the soil. Production and turnover of fine roots in forests have been studied by several workers (Carrera *et al.* 2008; Gill & Jackson 2000; Huang *et al.* 2008). In some cases nutrient input to soil through fine root was observed to be greater than the above-ground litter (Helmisaari *et al.* 2007). The role of fine roots in soil fertility maintenance in agro-forestry systems was emphasised by Young 1991 and Sanchez 1995. Their role in the uptake of water and nutrients and effect on crops in agro-forestry systems was studied by Smucker *et al.* (1995). Gower *et al.* (1995) reported that fine roots may account for 7 - 76 % of annual net primary productivity of forest trees.

In India, Arunachalam *et al.* (1996) investigated biomass production of fine and coarse roots during in the re-growth of a disturbed subtropical humid forest. Dhyani & Tripathi (2000) investigated fine and coarse root distribution in an agri-silvicultural system involving *Citrus reticulata*, *Alnus nepalensis*, *Prunus cerasoides* and *Paraserianthes falcataria* in Meghalaya, northeast India. Babu *et al.* (2001) investigated distribution and seasonal changes of fine and coarse roots in *Pinus kesiya* forest of three different ages in northeast India. Jha & Mohapatra (2010) reported fine root production and nutrient flux in the semi-arid ravines at Agra. They investigated leaf litter-fall, fine root mass, production and turnover rates in the 0 - 30 cm soil depth under *Leucaena leucocephala*, *Acacia nilotica*, *Azadirachta indica* and *Prosopis juliflora* and reported marked seasonal variations in all the four species. Barbhuiya *et al.* (2012) investigated fine root dynamics in a tropical wet evergreen forest in northeast India and reported significant variations in root biomass between disturbed and undisturbed sites.

The subtropical regions of the North West Himalayas occupy a significant area in the states of Jammu & Kashmir, Punjab, Himachal Pradesh and Uttarakhand. The primary forest vegetation consists chiefly of Northern tropical dry mixed deciduous forests, dry Shiwalik sal (*Shorea robusta* Gaertn.) forests and moist mixed deciduous forests. These forest ecosystems have undergone repeated damage both due to natural and manmade reasons (e.g. deforestation, cultivation on steep slopes, forest clearing and road construction). Climax *S. robusta* forests in several areas in the valley portions have retrogressed back to degraded seral stages of dry mixed deciduous forests dominated *Acacia catechu*, *Dalbergia sissoo*, *Erythrina suberosa*, *Wedlandia exserta* etc., accompanied with a decline in forest productivity and increased ecosystem disturbance. Inappropriate land use (in the upper reaches) and deforestation has led to high rates of soil erosion (Samra *et al.* 1999) that may range from 5 t $ha^{-1}$ in dense forests to 80 t $ha^{-1}$ in the Shiwaliks, along with landslides, land slips and slope forming material, carried down the slopes into river valleys and deposited as gravel bars along seasonal river courses. The area occupied by these gravel bars in the valley portions of the North West Himalayas is substantial, being estimated to be 2.73 million ha (Arora & Vishwanatham 1995). Due to the nature of the substratum these areas are not put to any productive use and are usually occupied by seasonal weeds and grasses.

Efforts to utilise these subtropical areas by establishment of various land use systems were initiated in the 1980's and some reports are available (Rathore *et al.* 2011; Saroj *et al.* 2004; Singh *et al.* 2008; Vishwanatham *et al.* 1999). However, information is lacking on the quantification of fine root biomass across the year, which can be useful in developing a better understanding of the processes occurring in the rhizosphere. This study aims to determine the spatial and temporal variability in fine root biomass in six fruit and three forest tree species which were raised as pure stands and pure orchard blocks for the purpose of utilizing these old river bed lands. We studied

**Table 1.** Typical physico-chemical characteristics of substratum in the river bed area.

| Characteristics | Depths (cm) | | | | |
|---|---|---|---|---|---|
| | 0 - 10 | 10 - 60 | 60 - 75 | 75 - 90 | 90 - 100 |
| Soil : stone ratio* (volume basis) | 70 - 30 | 20 - 80 | 45 - 55 | 30 - 70 | 15 - 85 |
| Mechanical analysis of soil | | | | | |
| Coarse sand (%) | 3 | 35 | 77 | 51 | 74 |
| Fine sand (%) | 60 | 50 | 7 | 13 | 15 |
| Silt (%) | 24 | 6 | 6 | 18 | 8 |
| Clay (%) | 13 | 9 | 10 | 18 | 3 |
| pH | 6.0 | 6.5 | 6.5 | 6.5 | 6.6 |
| Total N (%) | 0.07 | 0.04 | 0.08 | 0.07 | 0.02 |
| Available $P_2O_5$ (kg ha$^{-1}$) | 18.7 | 18.8 | 20.0 | 18.1 | 19.2 |
| Available $K_2O$ (kg ha$^{-1}$) | 176.4 | 172.8 | 144.0 | 130.4 | 120.7 |

*Soil particles < 2 mm; gravel/ stone > 2 mm size.

seasonal production, turnover and distribution pattern of fine roots in soil under different management practices.

## Material and methods

### *Study area*

The study was carried out during 2009 at the Research farm of the CSWCRTI, Dehra Dun (30° 19' N Lat. and 78° 02' E Long.) at an elevation of 517 m above msl. Annual rainfall (averaged from 1956 to 1998) is 1646 mm received in about 82 rainy days. The rainfall received during the study period averaged 1483.7 mm, with nearly 80 % received during the monsoon period (July to September) and the rest during December - January. Summer (April to June) is hot and dry. Winter is quite cold (average 4.4 °C) with occasional frost in January. Vegetative growth of almost all plants forms takes place during the rainy season (July to September). Plants remain dormant during the cold winter season (November to February).

### *Soil characteristics*

The experimental site is an old riverbed wasteland and soils have been classified as sandy skeletal typic Ustifluvent soils (Bharadwaj & Singh 1981). Infiltration rates at these sites are high (2.13 to 3.0 cm hr$^{-1}$) due to their sandy texture and a permeable stony layer at lower depths of the profile. Gravels ranging from 0.2 to 10 cm sizes constitute 60 % of the total weight of the contents excavated from a one cubic meter pit. A detailed description of the soil conditions has been provided in Table 1.

### *Establishment of fruit trees*

Orchard blocks of mango (*Mangifera indica* L.), litchi (*Litchi chinensis* Son.), guava (*Psidium guajava* L.), kinnow mandarin (*Citrus reticulata* Blanco.) sweet orange (*Citrus reticulata* Osbeak.) and amla (*Emblica officinalis* Gaertn.), which are usually grown in the region, were set up (during 1996-1997) in the dry river bed for evaluating their performance and utilization of the area for fruit production (Table 2). Kinnow mandarin, a popular fruit of the region, is a cross between *C. delicosa* and *C. nobilis*. After land clearing and removal of old root crowns, the area was levelled and pits of 1m x 1m x 1m were dug manually and filled with sieved soil mixed with farm yard manure (FYM) and recommended dose of fertilizers. One year old healthy seedlings were planted during July - August in the pits and tended regularly. Fertilizer was applied annually as per the recommended package of practices (Table 2). Fruit bearing was allowed from the 4th year and fruits were annually harvested.

### *Establishment of forest plantation*

Plantations of three important tree species of the subtropical N. W. Himalayas *Grewia optiva* (Drumm.) (Vern. - *Bhimal*) and *Bauhinia variegata* L. (Vern. - *Kachnaar*), *Dalbergia sissoo* Roxb. (Vern. - *Shisham*) were established in 1996. One year old seedlings were planted during the monsoons in pits manually excavated (60 cm x 60 cm x 60 cm). Annual tending and weeding were carried out. *Grewia* and *Bauhinia*, popular tree species of the region grow over a wide range of situations (subtropical to sub - temperate). These species, whose

**Table 2.** Land use history at different locations of sampling points.

| Description of stand | Age (years) | Spacing (m) | Soil type | Stems ha$^{-1}$ | Yield (t ha$^{-1}$) | Management practices followed |
|---|---|---|---|---|---|---|
| *D. sissoo* plantation* | 13 | 3 x 2 | Sandy | 1666 | - | Annual tending |
| *G. optiva* plantation* | 13 | 3 x 2 | Sandy | 1666 | - | Annual tending |
| *B. variegata* plantation* | 13 | 3 x 2 | Sandy-loamy | 1666 | - | Annual tending |
| Mango** | 15 | 8 x 8 | Sandy-loamy | 156 | 11 | a |
| Litchi** | 15 | 8 x 8 | Sandy-loamy | 156 | 7 | a |
| Kinnow** | 15 | 5 x 5 | Sandy-loamy | 400 | 20 | b |
| Amla** | 14 | 7 x 7 | Sandy-loamy | 204 | 14 | a |
| Guava** | 10 | 6 x 6 | Silty clay loam | 277 | 9.7 | c |
| Malta** | 15 | 5 x 5 | Silty clay loam | 400 | 15 | b |

*Forest species planted in pits of size 60 cm x 60 cm x 60 cm;
**Pure orchard blocks; fruit plants planted in pits of size 1m x1m x 1m;
a - application of 1 kg each of N & K, 0.5 kg of P and 30 kg FYM each year per tree after the 10th year;
b - application of 0.6 kg each of N & K, 0.3 kg of P and 30 kg of FYM each year per tree after the 6th year;
c- application of 0.7 kg each of N & K, 0.35 kg of P and 30 kg of FYM each year per tree after the 7th year.

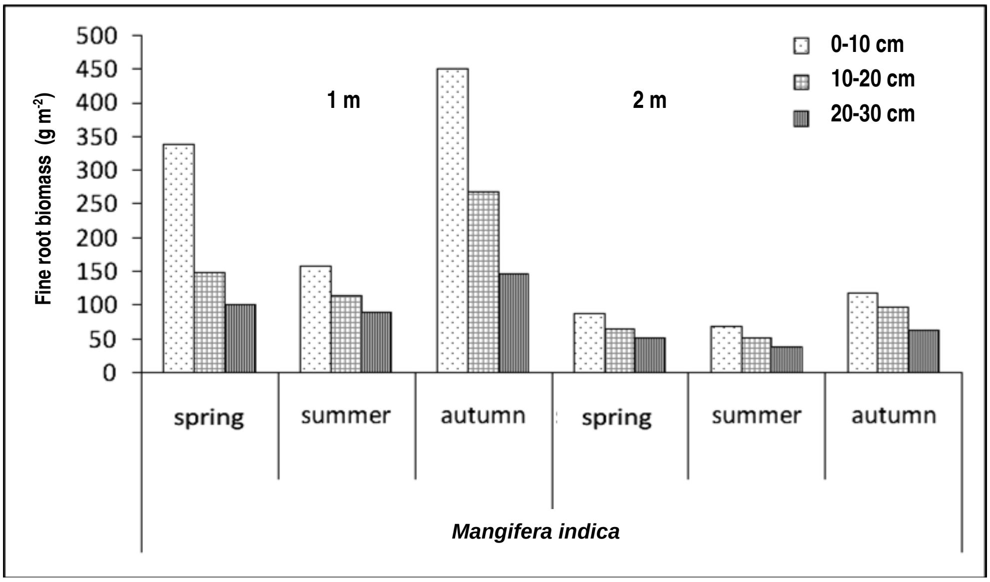
all parts are used, are usually retained on terraces formed on hill slopes. *Dalbergia sissoo,* another important species of the subtropical region, is a primary colonizer in riverine sites. Quality timber is obtained when the trees are > 60 years old; poor quality timber and poles are used as firewood and for agricultural implements. Young succulent leaves are eaten as fodder.

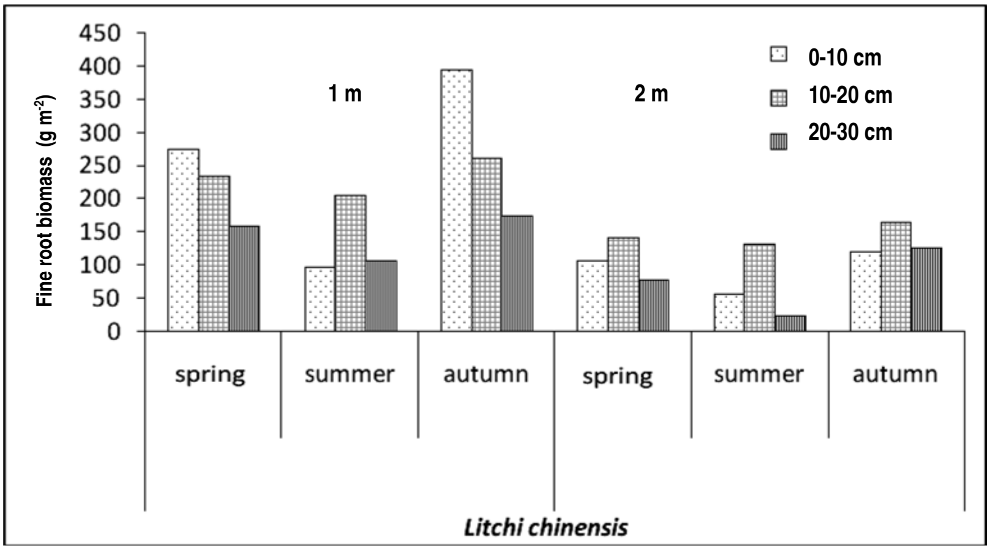
### *Sampling of fine roots and estimation of turnover rates*

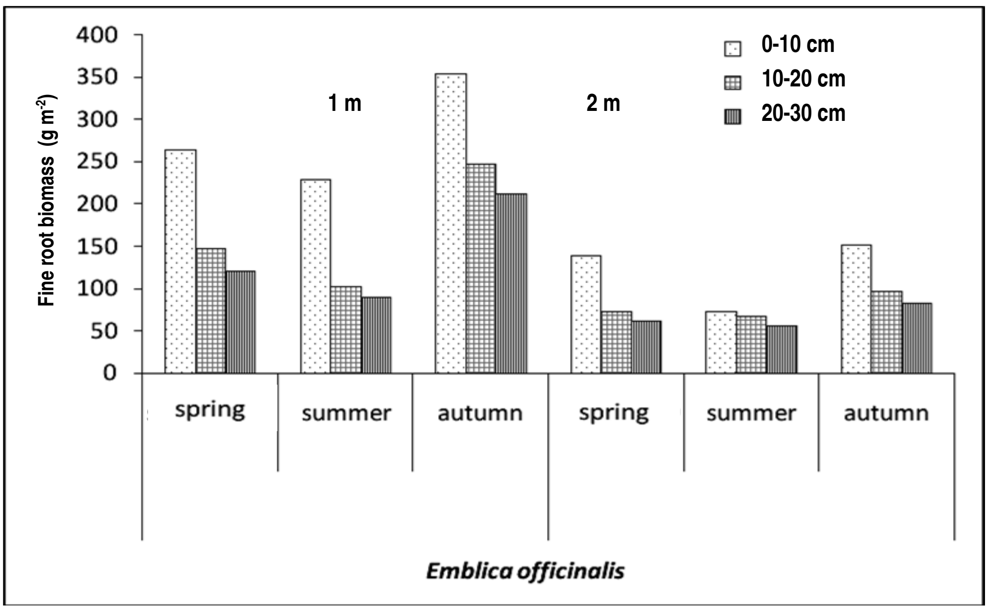
Sampling was carried out during 2009 by sequential soil coring in different blocks (Table 2) at three sampling intervals: March (covering the winter, December - February, when most vegetation is under winter induced dormancy), June and October (covering the beginning and end of monsoon period). This method of sampling may underestimate fine root production (Makkonen & Helmisaari 1998), but is a widely used method since it directly estimates fine root biomass. Due to nature of the underlying substratum, consisting of coarse sand and stones of various sizes and soil layer in some places, plants were randomly selected in each orchard block and forest stand. Soil cores were obtained using a sharp edged steel tube auger (9 cm diameter and 12 cm depth). Each core was kept separately in polythene bag and brought to the laboratory for washing and root sorting on the same day. Soil cores were sampled from three depths (0 - 10, 10 - 20, 20 - 30 cm) at 1 m and 2 m distance from the stem base. Coring spot was selected randomly around the base of the tree in any direction and two samples were collected from each soil depth. A total of 198 soil cores were sampled for all tree species (66 from each depth).

Roots were separated from soil by soaking the soil core in water and gently washing over sieves with mesh size ranging from 5 mm to 0.5 mm (Anderson & Ingram 1993). Roots < 2 mm in diameter were considered as fine roots (Dhyani & Tripathi 2000). These were handpicked using forceps and any sand or detritus particles adhering to the root were separated manually. Separation of live and dead roots was difficult, hence the root mass reported in the paper includes both dead and live roots. Fine roots collected from different depths were washed in clean water and dried at 70 $^0$C for 48 h and expressed in g m$^{-2}$.

Root production was estimated in 0 - 30 cm soil layer by sequential coring (minimum-maximum) method (Mc Claugherty *et al.* 1982). This method calculates the difference between minimum and maximum of fine root biomass during the measuring period and equates it with production. The rate of fine root production was expressed as g m$^{-2}$ yr$^{-1}$. Turnover rate of fine roots was calculated by dividing annual fine root production with the mean fine root mass and expressed as yr$^{-1}$ (Jha & Mohapatra 2010). Data were subjected to analysis of variance (ANOVA) test to analyse the effect of species and depths on fine root mass.


Fine root biomass (g m-2)
0
50
100
150
200
250
300
350
400
450
500
1 m
2 m
0-10 cm
10-20 cm
20-30 cm
spring
summer
autumn
spring
summer
autumn
Mangifera indica


Fine root biomass (g m-2)
0
50
100
150
200
250
300
350
400
450
1 m
2 m
0-10 cm
10-20 cm
20-30 cm
spring
summer
autumn
spring
summer
autumn
Litchi chinensis


Fine root biomass (g m-2)
0
50
100
150
200
250
300
350
400
1 m
2 m
0-10 cm
10-20 cm
20-30 cm
spring
summer
autumn
spring
summer
autumn
Emblica officinalis

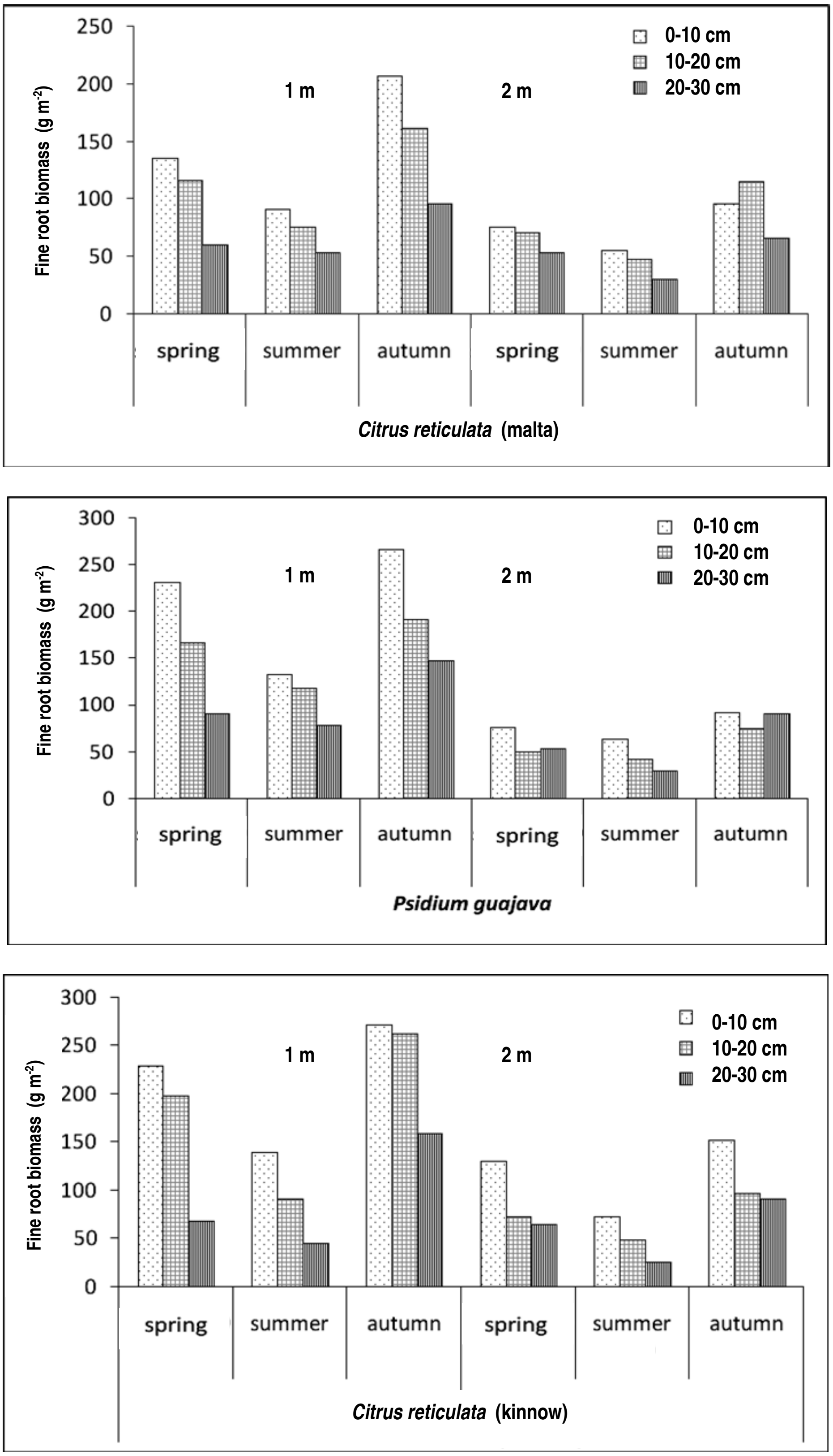



**Fig. 1**. Distribution of fine root biomass (g $m^{-2}$) at different soil depths at 1 m and 2 m distance from stem base of different fruit species.

## Results

### *Root biomass, production and turnover rates in fruit trees*

Fine root biomass (FRB) differed significantly in fruit species, over seasons, depths and distances from stem base (Fig. 1). At 1 m distance from stem base, nearly 43 % of the total FRB in all species was confined to the 0 - 10 cm layer, except in mango where 52 % of the FRB was confined to this layer. In the 10 - 20 cm layer FRB was higher in *Citrus* species and *L. chinensis* (by 37 %) followed by guava (33 %). On an average, nearly 78 % of FRB of all species was confined in the 0 - 20 cm layer. Across seasons and depths, FRB increased in the monsoon season and thereafter declined till the next summer. These variations were not significant in case of *E. officinalis* where only a 13 % decline was observed in FRB in the 0 - 10 cm layer and about 20 % in the 0 - 20 cm layer. However, at 2 m distance from the stem base, it was observed that nearly 40 % of the FRB was confined to the 0 - 10 cm layer, with FRB values being higher in *C. reticulata* by 47 %, in *E. officinalis* by 45.5 % and in *M. indica* by 43 %. The trends of change across seasons remained similar to the pattern at 1 m, variations being confined to the 0 - 10 cm layer except in case of *L. chinensis* and *C. reticulata*, where FRB increased more in the 10 - 20 cm layer in the monsoon season.

Fine root production rates were high within 1 m radius but declined significantly (by nearly 50 % on an average) at 2 m distance from the stem base. Production rates at 1 m distance were high (416 to 501 g $m^{-2}$ $yr^{-1}$) in mango, litchi and kinnow (Table 3) all three of which are nutrient demanding species and are sensitive to moisture and nutrient stress. On the other hand, production rates were lower, by nearly 32 % on an average, in *E. officinalis*, *P. guajava* and *C. reticulata,* all moderately hardy fruit species able to grow in stressed environments. Within these two broad groups, mostly seasonal maximum FRB differed indicating high rates of production during the peak growing season (monsoon season July - September) when vegetative growth and aboveground biomass accretion is highest.

Fine root turnover rates ranged from 0.580 to 0.852 $yr^{-1}$, the highest being in *C. reticulata* and lowest in *P. guajava* (Table 3) at 1 m distance. At 2 m distance the values were highest for *C. reticulata* (kinnow) (0.771 $yr^{-1}$) and least in *E. officinalis* (0.510 $yr^{-1}$).

### *Root biomass, production and turnover rates in forest trees*

FRB was significantly ($P$ < 0.05) different amongst the different species investigated, both over increasing soil depth and over seasons. Nearly 80 % of the total FRB was confined to the 0 - 20 cm layer at 1 m radius in all species. Within this distance, highest FRB in the 0 - 10 cm layer was observed (Fig. 2) in *B. variegata* (51 %) followed by *G. optiva* (47 %) and *D. sissoo* (29.4 %) but in the 10 - 20 cm layer, FRB was higher in *D. sissoo* (by 54 %) followed by *G. optiva* (30 %) and *B. variegata* (27 %). Across seasons, maximum biomass accretion in fine roots occurred in the 0 - 10 cm layer during the monsoon in case of *B. variegata* and *G. optiva* and in the 10 - 20 cm layer in case of *D. sissoo*. At 2 m spacing, nearly 77 % of the total FRB was confined to the 0 - 20 cm layer. Fine root biomass in the 0 - 10 cm layer constituted 64 % of the total FRB in case of *G. optiva* and 37 % in case of *D. sissoo*. In the 10 - 20 cm layer, 37 % of the total FRB of *D. sissoo* and 25 % of *G. optiva* was recorded.

Fine root turnover rates at 1 m distance were lower in stands of *G. optiva* (0.326; Table 4) but were much higher in stands of *D. sissoo* (0.865) and *B. variegata* (0.884). At 2 m distance, turnover rates increased significantly ($P$ < 0.05) in case of *G. optiva* (0.613) and decreased marginally in *B. variegata* (0.881) and *D. sissoo* (0.780).

## Discussion

Fine root biomass (FRB), production and turnover rates were consistent with the availability of water and nutrients in fruit trees which have been raised in artificially created root environments to ensure survival and establishment of plants in the harsh site conditions. In fruit trees (growing in nutrient enriched rhizosphere), FRB remains confined within the zone of application of FYM and fertilizers and there is a significant reduction in FRB at increasing distance from the stem base where nutrient stressed condition occur. Increased nutrient and moisture deficiency during the spring and summer seasons, beyond 1 m radius all round the trees led to reduced fine root ramification even during the monsoon when soil moisture was not limiting.

Availability of water and nutrients (FYM and fertilizers) within 1 m radius of the main stem led to higher FRB and turnover rates. At increased distance (2 m radius) FRB declined due to constraints in resource availability. In forest plan-

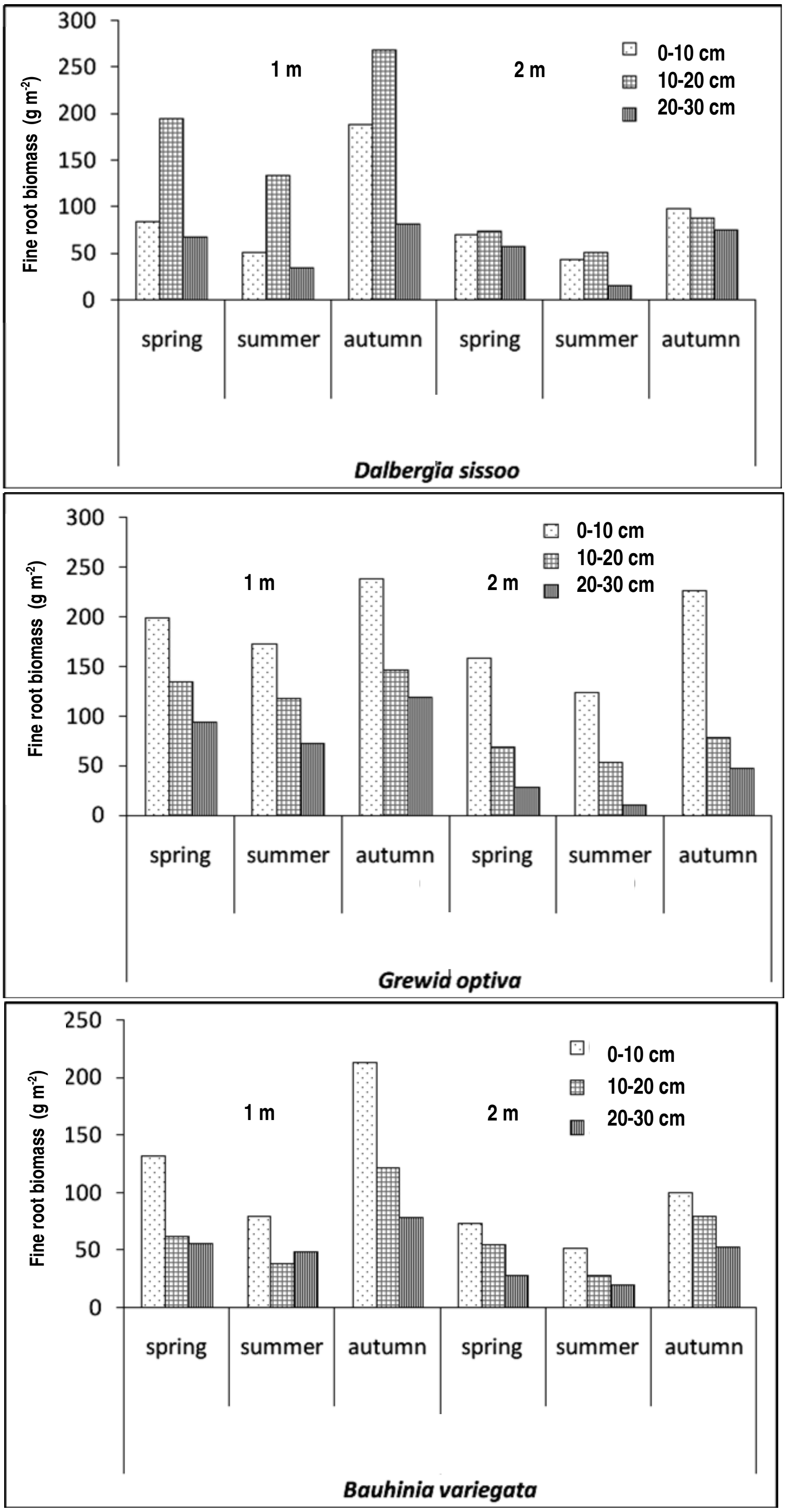



**Fig. 2.** Variations in fine root biomass (g $m^{-2}$) at different soil depths and seasons at 1 m and 2 m distance from stem base of different tree species raised on old river bed lands.

**Table 3**. Seasonal fine root biomass (mean ± SD), mean FRB, annual fine root production and annual fine root turnover rate in different fruit species in 0 - 30 cm soil depth at 2 distances from the stem base.

| Species/Distance from stem base | Seasonal Fine root biomass ($g\ m^{-2}$) | | Mean FRB ($g\ m^{-2}$) | Production ($g\ m^{-2}yr^{-1}$) | Turnover rate ($yr^{-1}$) |
|---|---|---|---|---|---|
| | Maximum | Minimum | | | |
| Distance 1.0 m | | | | | |
| *Mangifera indica* | 867 ± 18.2$^a$ | 366 ± 11.4$^a$ | 608 | 501 | 0.823 |
| *Litchi chinensis* | 834 ± 16.4$^a$ | 410 ± 8.6$^a$ | 637 | 424 | 0.665 |
| *Emblica officinalis* | 810 ± 19.4$^a$ | 419 ± 9.6$^a$ | 586 | 391 | 0.667 |
| *Citrus reticulata* (malta) | 465 ± 8.5$^a$ | 267 ± 10.4$^a$ | 332 | 245 | 0.737 |
| *Citrus reticulata* (kinnow) | 692 ± 9.2$^a$ | 276 ± 11.6$^a$ | 488 | 416 | 0.852 |
| *Psidium guajava* | 606 ± 10.6$^a$ | 330 ± 4.3$^a$ | 475 | 276 | 0.580 |
| Distance 2.0 m | | | | | |
| *Mangifera indica* | 282 ± 8.7$^b$ | 161 ± 6.8$^b$ | 217 | 121 | 0.556 |
| *Litchi chinensis* | 413 ± 9.6$^b$ | 216 ± 7.1$^a$ | 319 | 196 | 0.613 |
| *Emblica officinalis* | 328 ± 4.3$^b$ | 193 ± 6.2$^b$ | 264 | 135 | 0.510 |
| *Citrus reticulata* (malta) | 276 ± 4.2$^b$ | 132 ± 10.6$^b$ | 202 | 144 | 0.710 |
| *Citrus reticulata* (kinnow) | 340 ± 6.2$^b$ | 146 ± 10.2$^b$ | 251 | 194 | 0.771 |
| *Psidium guajava* | 259 ± 8.6$^b$ | 136 ± 6.2$^b$ | 192 | 122 | 0.634 |

FRB – Fine root biomass; Mean values with different superscripts of fruit types at increasing distance from the stem base are significantly different at $P$ < 0.05 between sampling points. Mean values with same superscripts at increasing distance from the stem base are not significantly different at $P$ < 0.05 between sampling points.

**Table 4.** Seasonal fine root biomass (mean ± SD), mean FRB, annual fine root production and annual fine root turnover rate in different forest species in 0 - 30 cm soil depth at 2 distances from the stem base.

| Species | Seasonal Fine root biomass ($g\ m^{-2}$) | | Mean FRB ($g\ m^{-2}$) | Production ($g\ m^{-2}yr^{-1}$) | Turnover rate ($yr^{-1}$) |
|---|---|---|---|---|---|
| | Max. | Min. | | | |
| Distance 1.0 m | | | | | |
| *D. sissoo* plantation | 538 ± 12.8$^a$ | 220 ± 6.2$^a$ | 368 | 319 | 0.865 |
| *G. optiva* plantation | 504 ± 14.2$^a$ | 363 ± 8.6$^a$ | 432 | 141 | 0.326 |
| *B. variegata* plantation | 414 ± 10.6$^a$ | 168 ± 10.2$^a$ | 278 | 246 | 0.884 |
| Distance 2.0 m | | | | | |
| *D. sissoo* plantation | 262 ± 8.6$^b$ | 111 ± 12.8$^b$ | 192 | 150 | 0.780 |
| *G. optiva* plantation | 352 ± 7.3$^b$ | 188 ± 18.3$^b$ | 265 | 163 | 0.613 |
| *B. variegata* plantation | 234 ± 6.4$^b$ | 100 ± 7.1$^b$ | 163 | 133 | 0.811 |

FRB - Fine root biomass; Mean values with different superscripts at increasing distance from the stem base are significantly different at $P$ < 0.05 between sampling points. Mean values with same superscripts at increasing distance from the stem base are not significantly different at $P$ < 0.05 between sampling points.

tations, trends were slightly different in case of *G. optiva* which was expected in young trees where actively foraging roots are spread out over greater distances from the main stem, but not so in *B. variegata* and *D. sissoo* where FRB remained high at 1 m and declined at 2 m distance from the stem.

The distribution of fine roots reflects the distribution of available nutrients within an ecosystem (Vitousek & Sanford 1986). Fine roots are more efficient in absorbing water (Eissenstat & Yanai 2000) and hence nutrients, which suggests an important role played by water in controlling FRB and production. Increase in FRB in the warm and humid months (July - September) was evident in this study during the post-monsoon season sampling. This increase coincides with the period of active vegetative growth immediately after a hot and dry summer induced dormancy. In subtropical and tropical India maximum FRB has been reported in the wet season (Khiewtam & Ramakrishna 1993; Upadhaya *et al.* 2005) which corresponds to periods of nutrients release. Decline in FRB during spring in nearly all locations studied can be attributed to the translocation of reserve food stored in the root system to the new shoots for a new flush of leaves, which has been reported from tropical regions in India (Khiewtam & Ramakrishnan 1993). In an earlier study on old river bed lands, Raizada *et al.* (2002) reported patterns of nutrient re-translocation prior to senescence and their storage in different plant components.

While seasonal turnover rates were not determined, annual turnover rates in fruit plants were high. Fine root turnover rates can be considered similar to other findings from tropical sites where turnover rates between 0.3 to 2.5 have been observed (King *et al.* 2002; Silver *et al.* 2005). The high values in fruit plants can be attributed to the annual addition of FYM and fertilizers (as per recommended rates of application) to the plants. High nutrient availability reduces average root life span and increases turnover because construction cost of roots are low relative to maintenance costs and uptake rates of young roots are high (King *et al.* 2002). This was observed within 1 m radius in fruit trees and in stands of *D. sissoo* and *B. variegata* both of which are nitrogen fixing and cycle nutrients efficiently.

## Conclusions

Our study indicates that utilizing old river bed lands for raising moderately stress tolerant fruit species and plantations of suitable forest species can lead to organic enrichment of soil layer by the high turnover rates of fine root biomass in close vicinity of trees. Eventually, the edaphic conditions of the site may improve allowing colonization and establishment of native plant communities consisting of annual grass and pioneer tree species. Distribution of large amount of fine roots during the monsoon season in the 0 - 10 cm depth even at 2 m distance from stem base in fruit species like *C. reticulata*, kinnow mandarin and *P. guajava* indicates that roots in these species forage longer distances for resources and make them more susceptible to moisture stress in the post-monsoon season. Further studies are required to determine patterns of decomposition and nutrient release from belowground parts in stressed environments.

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