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Litter fall quantity, root density, biomass and decomposition rate in *Dalbergia sissoo:* a nutrient cycling perspective

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Abstract

Plant litter decomposition plays a crucial role in the formation of soil organic material during nutrient cycling. This study determined the root density, biomass, decomposition rate and elemental composition of root and leaf litter in *Dalbergia sissoo*. Litter trappers were installed under the tree canopy and litter bag method was used to investigate the decay rate of roots and leaves. The study revealed significant difference ($P<0.001$) in leaves and roots decomposition over the time. It was revealed that root density and root biomass were 2.41×10^5 m ha^{-1} and 2 .0 t ha^{-1} respectively. The total litter production was 2.53 t ha^{-1} yr^{-1}. The mass loss/decomposition of fine, medium and coarse roots during the year was 23.84, 18.68 and 36.377% respectively. The total leaf decomposition/mass loss during the year was 36.83%. The initial elemental composition percentage of carbon was high in leaves than roots whereas, Nitrogen, Phosphorus and Potassium concentrations were significantly higher in roots as compared to leaves. The results are helpful for future studies gearing towards the nutrient budgets in *D. sissoo* plantations.

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Introduction

Litter decomposition takes part in nutrient cycling and phenomena is carried out by disintegration of complex organic matter into a simpler form by the action of microbial community and this process helps in mineralization of soil and also supply vital nutrients to the soil (Gessner *et al.,* 2010). Plants are fundamental carbon sinks that regulate carbon release and carbon storage within the soil (Martens, 2000). Some of the carbon is ingested by herbivore consumption and remaining carbon endures in the atmosphere in the form of debris and with the passage of time, remaining debris is decomposed by macro and micro fauna species present in the soil. Decomposition rate is affected by soil microbial community, chemical properties of litter and other abiotic factors (Gulis *et al.,* 2004).

The rate of decomposition and nutrient release pattern varies with the type of plant litter that may vividly influence the formation of soil organic matter (Zhang *et al.*, 2008). Root and leaf decomposition play a crucial role because it provides fundamental carbon sinks within the soil (Martens, 2000). It is also a major source of biogeochemical cycling, recycle essential nutrients and provide physical anchorage (Trumbore and Gaudinski, 2003).

Plant litter is the vital energy resource to soil microbes during the initial stage of decomposition (Graham and Haynes, 2005). Roots and leaf decomposes differently due to position difference and create diverse micro-macro fauna species in the forest floor (Osono *et al.,* 2006). Root litter decomposition primarily takes place in the soil, whereas leaf litter decomposition occurs above the soil surface. Leaves decompose more rapidly than roots and stems. According to (Vanholme *et al.,* 2010) leaves decompose 3.1 times faster than coarse stems, 2.1 times faster than fine roots and 1.6 times faster than fine stems. In literature, leaf bags were placed above the soil surface and root bags were buried within the soil (Cusack *et al.,* 2009). Decomposition rate vary specie to specie and within the same specie different plant organs exhibit different decomposability rate and the decay rate is also influenced by many physicochemical factors such as microbial community, litter quality, soil pH and soil moisture (Liu *et al.,* 2006).

D. sissoo is vernacularly known as Sissoo, Shisham, Indian rosewood or tali. It is native to Pakistan, India and Nepal. It naturally grows in tropical to sub-tropical climate and found throughout the sub-Himalayan tract. It belongs to family Fabaceae and it is a deciduous tree and show peak litter fall during winter season. It have certain ecological benefits; improves soil fertility, used for reclamation of sodic soil and reduce soil erosion (Mishra *et al.,* 2002). It also provides timber, fuelwood, fodder and have socioeconomic benefits (Shah *et al.,* 2010) and used as afforestation technique (CABI, 2005).

The main objectives of this study were to investigate total leaf litter fall, root density and biomass, their decomposition rate in Shisham dominated plant community. Moreover, the nutrient composition of roots and leaf of *D. sissoo* was also analyzed to know the amount of nutrient going into the soil after decomposition.

Materials and methods

Study site

This study was conducted in District Attock (Punjab, Pakistan) located between 72°40'50'' to 72°42'50'' E and 33°32'05'' to 33°33'05'' N (Shaheen *et al.,* 2008). Climate of an area is semi-arid during winter and sub-humid during summer season in winter. The average annual temperature of the area is 22.2 °C. *Olea cuspidata* and *Acacia modesta* are the dominant tree species and *Dodonaea viscosa* and *Ziziphus nummularia* are the dominant shrubs of the respective area.

Research design

The Litter bag technique was used in the respective site to determine the decomposition rate of roots and leaves of *D. sissoo*.

Root biomass and root density

Firstly, soil was excavated from the periphery of $25m^3$ (5m × 5m × 1m) around the tree bole. All the roots were cut with pruning scissor and soil debris were removed with distilled water and roots were then oven dried at 72°C for 48 hours. Length of the root was measured with the help of ruler to determine root density. Then, with the help of weighing balance, the weight of all roots was noted for estimation of root biomass. The digital vernier caliper was used for the determination of root diameter for each root class and then roots were categorized into three groups; fine roots having diameter of <2mm, medium roots diameter =2mm and coarse roots having diameter >2mm.

Collection of litter fall

Ten litter trappers were installed under the canopy of *D. sissoo* for the estimation of total annual litter production. Trappers dimension consisted of 1×1 m^2 and made up of nylon netted mesh size of 2mm and each trappers were installed at the height of 30cm, attached on four PVC pipes with the help of a rope. After 2 months interval, litter fall was collected from the trappers for one year.

Investigation on leaf litter decomposition

Leaf litter was collected from the site and air dried for 48 hours. The litter bag technique was used for the estimation of leaf decomposition. 10 g leaf litter was filled in nylon-net litter bag and bag size was 15cm × 20 cm having mesh size of 2mm (Pascoal and Cassio, 2004). Total 30 litter bags were filled and placed on the soil surface below the tree canopy of *D. sisso*. After every 2 month interval, 5 bags were retrieved from the site and brought to the laboratory and washed with deionized water for the removal of soil debris then oven-dried immediately at 75°C for 24 hours and finally weighed to estimate mass % loss. This mass loss % was considered to be the leaf decomposing litter which was added to the soil (Loranger *et al.,* 2002) and decay rate coefficient (k) was also calculated by using Olsen (1963) formula.

Root decomposition assessment

For root decomposition, litterbag decomposition experiments was conducted. Firstly, collected roots were carefully washed with distilled water to remove soil particles attached with roots then oven-dried at 80°C to determine the dry mass of roots (Koukoura, 1998). Roots were classified into three different diameter groups; fine (<2mm), medium (=2mm) and coarse (>2mm) roots (Camire *et al.,* 1991). For each root class different bags size made of nylon net (2mm mesh size) were prepared according to the root category and approximately 120 bags were made. 5g fine roots were placed into 10 × 10 cm (Fujii and Takeda, 2012) litter bag, 10g medium roots were filled into 10 × 15cm bag (Olajuyigbe *et al*., 2012) and 100g roots were put into 30× 30 cm into coarse roots bag (Lee *et al*., 2003) and then all the root bags were buried into the soil for decomposition. After 2 month interval 5 bags from each root category was randomly collected from the site and weight loss was calculated with the help of weighing balance. Decomposition rate (k) was also calculated and the rate at which root samples decayed exhibited the carbon quantity that added into the soil.

Litter mass loss of roots and leaf affected by decay process was determined by using the formula:

$M = (M_t - M_o) / W_o \times 100\%$

Where, M = the remaining litter mass as a percentage; M_o = the litter initial mass; M_t = the litter remaining mass

The value of the decay constant (k) was calculated by using the negative exponential decomposition model (Olsen, 1963) to evaluate the leaf and root litter decomposition rate for all root categories.

$X_t = x_o \times \exp^{(-kt)}$

Where, X_t = remaining litter mass after a given time period t; X_o = initial litter mass; k = decay rate co-efficient and t = time.

Elemental composition analysis for root and leaf litter

Oven-dried litter samples of both leaf litter fall and root litter at 80^o c and samples were ground for initial elemental composition of N, P, K and C. For N, 0.1 g sample of each root and leaf litter was digested in H_2SO_4 and H_2O_2 and mixed with distilled water to made 100 ml volume. Amount of total N was analyzed by using micro-kjeldahl method. P concentration was determined calorimetrically by the chloromolybdophosphonic blue method. Concentration of K was evaluated by atomic absorption spectrometry and C concentration was calculated by wet digestion technique with $K_2Cr_2O_7$.

Soil properties

Soil temperature was determined at the depth of 2ft by using thermometer. Soil moisture content and soil moisture % was also computed after every two month interval for one year. Soil moisture percentage was calculated by using the following formula.

Soil Moisture % = weight of fresh soil – weight of oven dried soil/ oven dried soil × 100.

Statistical analysis

One way analysis of variance (ANOVA) was applied for examining statistical differences among the mass loss for leaf and root decomposition at different time intervals. All statistical analysis was carried out at SPSS ver.16 and figures were prepared at sigma plot ver 12.5.

Results and discussion

Root biomass and root density

Total root biomass of *D. sissoo* was 2.00 t ha^{-1} and root density was approximately 2.41x10^5 m ha^{-1}. In literature the total length root length of *D. sissoo* mentioned as 2.75x10^5 m ha^{-1} (Chaturvedi & Das, 2002), therefore our results are consistent with their study. Estimation of below ground root biomass is important. According to Vogt *et al.* (1996) root production participate nearly half of the carbon being cycled and could generate annual production up to 33%.

Table 1. Amount of total litter fall (tonnes) including leaves, flowers and pods.

Months	Sampling interval (days)	Leaves (tonnes)	Flowers (tonnes)	Pods (tonnes)	Total litter fall (tonnes)
May-June	60	___	___	___	___
July-Aug	120	2.5x10^{-6}	___	___	2.5x10^{-6}
Sep-Oct	180	8.7x10^{-5}	2.7x10^{-5}	___	0.000114
Nov-Dec	245	9.025x10^{-5}	___	5x10^{-6}	9.525x10^{-5}
Jan-Feb	310	3.8x10^{-6}	3.32x10^{-5}	___	3.7x10^{-5}
March-April	363	4.4x10^{-6}		___	4.4x10^{-6}
Total	_	0.00018795	6.02x10^{-5}	5x10^{-6}	0.00025315

Litter fall

Litter fall was collected at 2 months interval and overall results showed a progressive trend. The amounts of litter were relatively less from May to September and from October to December litter accumulation showed a progressive trend because during this period heavy rainfall led to the defoliations. In the month of January no litter was collected because majority of leaves, branches, twigs fall down in December and minimum litter accumulated during February-April as germination and sprouting mostly began during spring. Total annual litter fall collected from the trappers was noticed as 2.53 t ha^{-1} for 1 year and one way ANOVA results of litter fall showed a significant positive relation of with 2 months interval (Table 1).

In present study annual litter production was 2.53t ha^{-1} that is relatively higher than the previous study of Singh *et al.* (1999) in which 1.35 t ha^{-1} annual litter produced by *D. sissoo*. Litter fall depends on environmental parameters. Our study indicated that during winter maximum litter accumulation occurred that might be related with natural senescence of tree organs stimulated by environmental factors such as temperature, moisture (Kumar and Deepu, 1992) and water effect on the litter production (Joergensen *et al.,* 1995).

Table 2. Initial elemental composition (%) of root and leaf litter in *Dalbergia sissoo*.

Elements	Leaf litter	Non-leaf litter		Root litter
	Leaves	Twigs	Flower	
C	49.34±1.39	49.861±1.92	47.132±2.54	36.17± 1.65
N	1.14 ± 0.11	1.16 ± 0.09	1.478 ± 0.14	2.383 ± 0.14
P	0.07 ± 0.005	0.07 ± 0.007	0.102 ± 0.03	1.16 ± 0.32
K	0.45 ± 0.021	0.38 ± 0.03	0.202 0.01	10.52±0.13

The total litter accumulation varies from specie to specie, growth pattern and age of the tree (Bray and Gorham, 1964). Tree canopy also have impact on litter fall production that control nutrient recycling (Prescott, 2002).

After 2 months interval, five leaf litter bags were removed from the site and weight loss pattern was determined. Initially, 0.001 t (10 g) mass of leaves were filled in the bag and rapid weight loss pattern was noticed as 0.000726, 0.00062, 0.000543, 0.000432, 0.000395 and 0.000374tonnes after 60th, 120th, 180th, 245th, 310th and 363th days respectively.

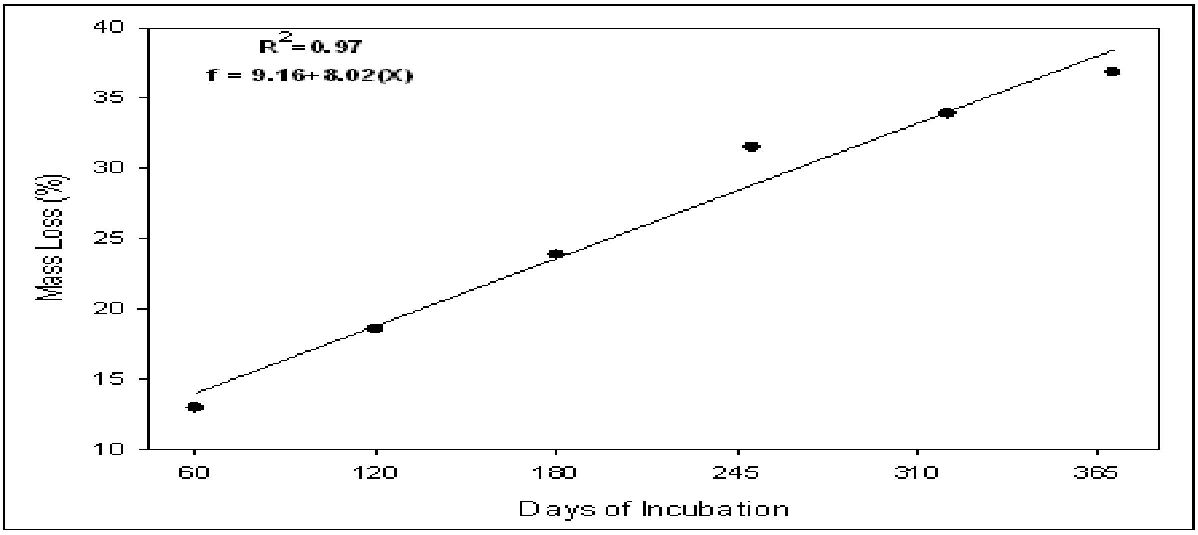

Fig. 1. Decomposition (R) % in leaves of *D. sissoo* with time (days).

Decomposition percentage (R%) was also evaluated for different collection period of leaf litter as 12.94%, 33.29% and 36.78 % for 60th, 310th and 363th days respectively (Fig. 1). One way ANOVA indicated a significant result (p= 0.0000) and decay rate co-efficient was also applied for calculation of constant weight loss throughout the year. Decay rate (k) for leaf litter was estimated as 3.68x10^{-8} t yr^{-1}.

Leaf decomposition

From an initial weight of 10g of leaves, the decrease in weight loss was 0.00072 t after 60 day, 0.000625t after 120 days, 0.000533t after 180 days, 0.000423t after 245 days, 0.0003850t after 310 days, 0.0003472 t after 363 days. Rapid mass loss trend was noticed throughout the year. One way ANOVA was used to examine the relation of leaf decomposition with two months interval. In first 60 days rapid decay took place. The decay rate coefficient k was used to calculate the constant weight loss. Leaf decay rate was 3.683x10^{-8} t yr^{-1}. Decomposition percentage (R%) also showed significant (p= 0.0000) results at different collection period in one year. The value of R% was 12.9515 for 60 days, 33.9206 for 310 days and 36.835 for 363 days (Fig.1).

Overall, leaf litter decomposition results were biphasic with an initial fast decomposition rate followed by slower decay rate.

Mass loss difference might be due to climatic factors and environmental differences. Temperature is the main cause that can affect leaf decomposition rate. Waring (2012) found that, leaf litter decomposition slowed down by cool temperatures and decomposition accelerated by warm temperatures and in return increase production of CO_2 and nutrient absorbance within the soil. Leaf decay process is also influenced by various actors, for instance soil water content, oxygen availability (Schuur, 2001), leaf litter composition, litter bag placements on above or within soil and community of decomposers.

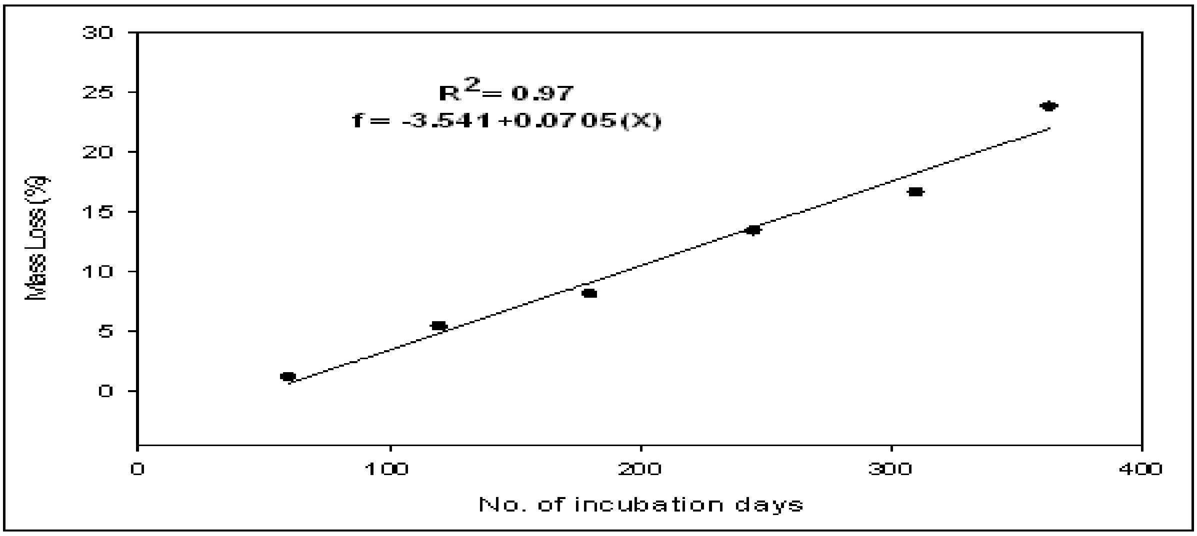

Fig. 2. Decomposition (R) % in fine roots with time (days).

Mass loss decomposition percentage (R%) pattern in various root classification

In the first 60 days, fast mass loss was noticed in all root categories and decay rate slow down after 245th, 310th and 363rd day. Quicker decomposition rate correspond to higher k value and vice versa. Hence Decay rate (k) is directly related to decomposition percentage (R%) and fine roots litter showed fast decay rate as compared to medium and coarse roots.

Fine root decomposition

Decrease in mass loss of fine roots was examined throughout the experiment. Initially 5g of fine roots was taken and the mass loss was high in the start of incubation and gradually it slowed down. The decomposition/mass loss (%) at 60th, 120th, 180th 245th, 310th and 363rd days of the year is shown in Fig. 2.

The ANOVA revealed significant difference (P<0.001) in monthly mas loss. Fine roots decayed at the rate of 2.3849x10^{-8} t yr^{-1}. When the relationship between mass loss % and incubation time was developed, it revealed linear relation with co efficient of determination as R^2=0.97 (Fig. 2).

Medium root decomposition

Continuous mass loss was studied in medium roots throughout the year. Initial weight of medium roots were 10g and the remaining mass left in the bags was observed as that 0.0009746, 0.0009279, 0.0008.951, 0.0008203, 0.0007368 and 0.0006.211 t after 60th, 120th, 180th, 210th, 245th, 310th and 363rd day of the year respectively. One way ANOVA revealed significant difference (P<0.001) in monthly mas loss.

Medium roots decayed at the rate of 1.86849x10^{-8} t yr^{-1}. When the relationship between mass loss % and incubation time was developed, it revealed linear relation with co efficient of determination as R^2=0.95 (Fig. 3).

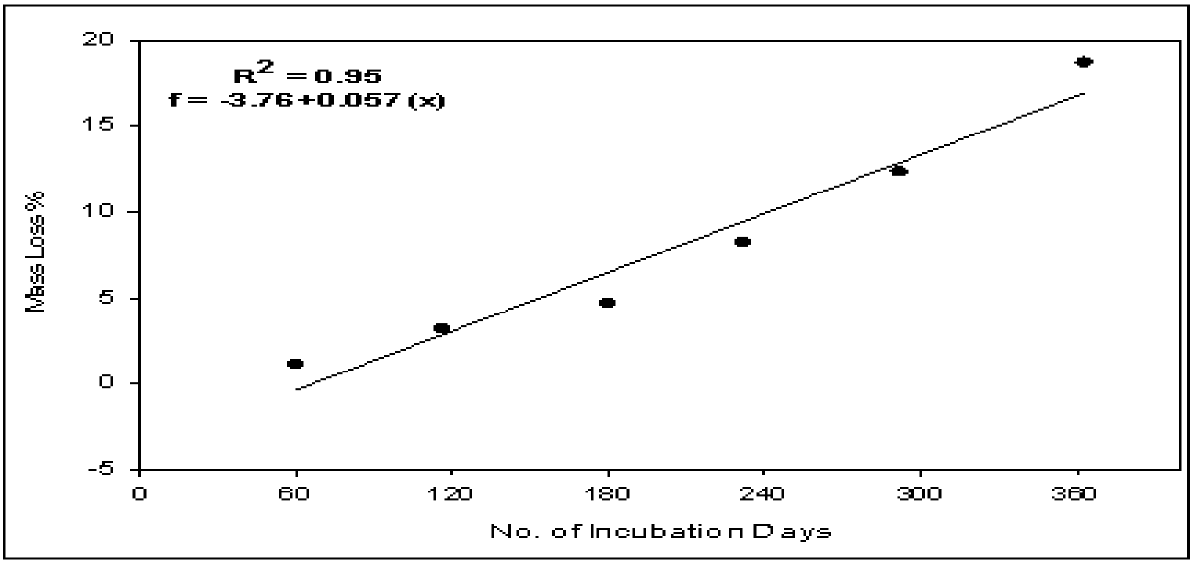

Fig. 3. Decomposition (R) % in medium roots with time (days).

Coarse root decomposition

Constant mass loss trend in coarse roots was examined throughout the year. Initially, 100g coarse roots were taken in the bags and mass loss trend was observed as 0.0091, 0.0079, 0.0069, 0.0063, 0.0054 and 0.0035 t after 60th , 120th 180th 245th and 363rd day of the year respectively.

One way ANOVA revealed significant difference (P<0.001) in monthly mas loss. Coarse roots decayed at the rate of 3.637735x10^{-8} t yr^{-1}. When the relationship between mass loss % and incubation time was developed, it revealed linear relation with co efficient of determination as R^2=0.94 (Fig. 4).

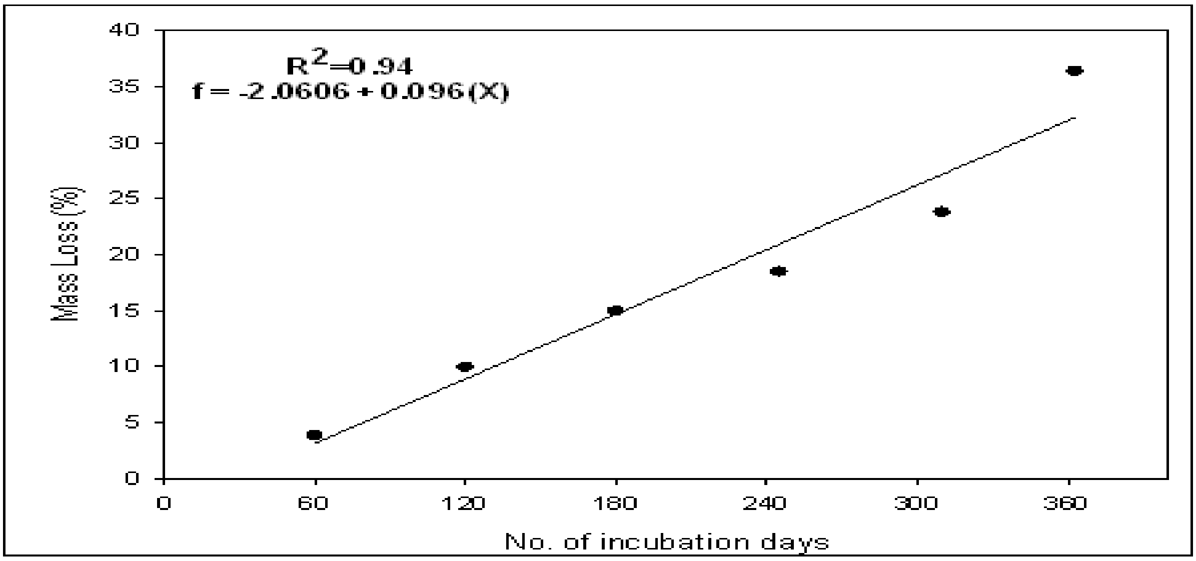

Fig. 4. Decomposition (R) % in coarse roots with time (days).

In all root categories, fast decomposition process was examined in the first 60 days and then decomposition slow down with the passage of time. Fine roots showed fast decay rate as compared to coarse roots. Decay rate (k) also directly related to R% means greater values of k correspond fast decomposition rate and smaller k values correspond to slow decomposition rate of roots.

In comparison to the previous studies of Edmonds and Thomas (1995), who worked on root and leaf litter decomposition and results showed that initially the decay rate was rapidly high. In winter litter decomposition rate was slow because of minimum temperature and delayed activity of soil micro-fauna (Tripathi and Singh, 1992) but at high temperatures soil microbial activity accelerated and litter decomposition also increased by increased in temperature (Waring and Schlesinger, 1985). Decay rate of root litter may slow down due to multiple factors such as abiotic factors and above and below ground litter bag placement. Mcclaughetry *et al.* (1982) examined decomposition of roots and their study showed that after one year roots bags having mesh size of 0.4mm decomposed up to 20% and medium root having mesh bags of 3mm decomposed as high as 47%.

Soil properties

Soil moisture content and soil temperature

Average soil temperature was 22.2 °C and average soil moisture content was recorded as 20.98%. The average monthly temperatures of respective area was also recorded as 29 °C in rainy season, 13 °C in winter season and 32.2 °C in summer season (Fig. 5).

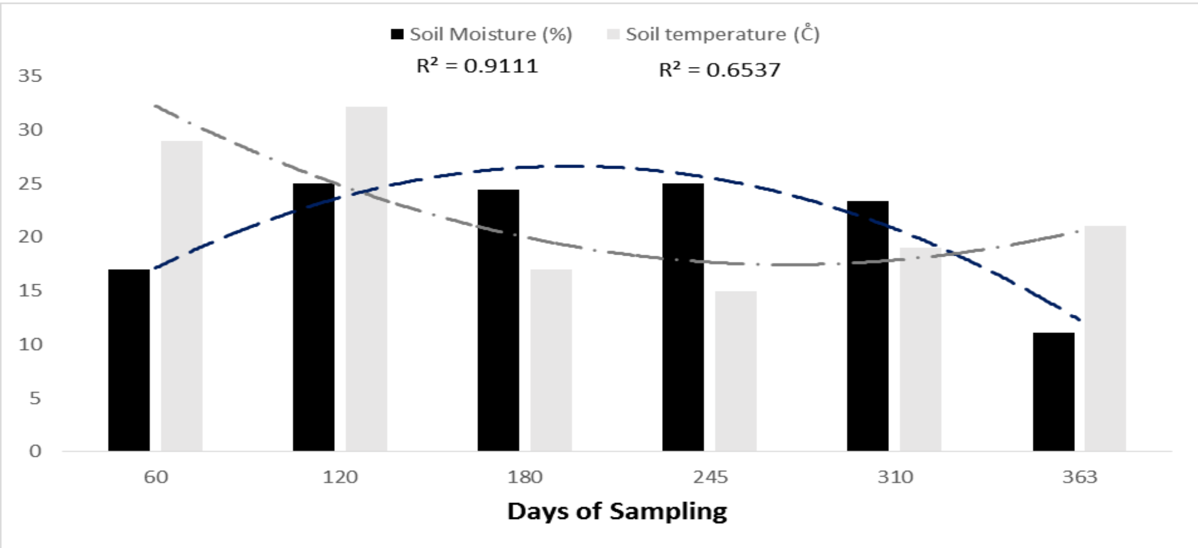

Fig. 5. Soil moisture (%) and soil temperature (°C) in study area during incubation period.

In summer season decay rate of roots and leaf was maximum as during this time period temperature of the site was maximum recorded as 32.2 °C, when temperature increases decay rate also showed maximum value of litter so decay rate of litter was directly related to each other whereas high soil moisture content minimizes decomposition rate and soil gas exchange in result it generate anaerobic condition. Serval studies have showed that litter layer act as a protecting layer that control soil properties, soil moisture content and conserve soil nutrients from leaching. According to Mo *et al.,* (2003) relatively low moisture content produced faster rate of litter decomposition during summer.

Elemental composition

Organic matter contains 58% organic carbon. Leaf decomposition improves the soil nutrient status without affecting the chemical properties of soil. C, N, P and K concentrations were significantly higher in reproductive part of *D. sissoo* and initial chemical composition of N, P, K and C showed significant results. Initial nutrient concentration differed both in roots and leaves. The level of N, P, K concentrations in roots were significantly higher than leaves but the carbon concentrations were significantly higher in leaves than roots (Table 2).

Elemental composition of the leaves is the greatest determining factor in the rate of leaching. Nutrient concentrations were higher in leaves and lower for roots (Hobbie *et al.* 2006).

The rate microbial activity is significantly dependent on the quality of litter (Flanagan and Van Cleve, 1983). Organic carbon release is essential nutrient for plant growth, contribute biochemical changes in the soil and control soil microbial activity (Briones *et al.*, 2010) Leaf litter generally contains low concentrations of N, P and soluble carbohydrates due to translocation. Janssens *et al.* (2010) reported that litter contain higher concentration of N decomposes at faster rate whereas plant litter with high concentration of lignin decompose at a slow rate.

Conclusion

The rate of decomposition/ mass loss % is highest at the start of incubation and then gradually it slow down. There are linear relationship exits in the decomposition rate of leaf litter, as well as roots of all categories. In the shisham plantation the decomposition of the leaf as well as roots have vital role. Among C, N, P & K, the rate of input of C is maximum from leaf and roots. The results are helpful for future studies gearing towards the nutrient budgets in shisham plantations.

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