

LEAF LITTER AND FINE ROOT DECOMPOSITION IN POPLAR BASED AGROFORESTRY SYSTEMS

BY

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*Thesis submitted to the Chaudhary Charan Singh Haryana
Agricultural University in the partial fulfillment of the
requirement for the degree of:*

**MASTER OF SCIENCE
IN
AGROFORESTRY**



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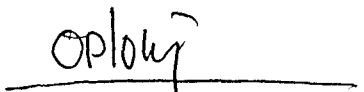
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My Parents

CERTIFICATE – I

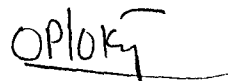
This is to certify that this thesis entitled “**Leaf litter and fine root decomposition in poplar based agroforestry systems**”, submitted for the degree of Master of Science in the subject of Agroforestry, of the CCS Haryana Agricultural University, Hisar, is a bonafide research work carried out by Sushil Kumar, under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.


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CERTIFICATE – II

This is to certify that this thesis entitled “**Leaf litter and fine root decomposition in poplar based agroforestry systems**”, submitted by Sushil Kumar to the CCS Haryana Agricultural University, Hisar, in partial fulfilment of the requirements for the degree of Master of Science, in the subject of Agroforestry has been approved by the student’s advisory committee after an oral examination on the same.



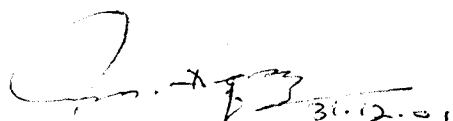
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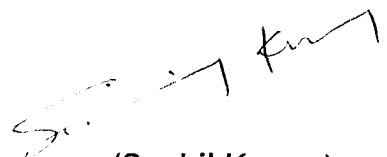
I am sincerely obliged to Sardar Surender Singh Hara (Owner, Hara Farm) and Sardar Iqbal Singh (Manager, Hara Farm), for their possible help and support throughout the span of my project carried out at Hara farm located in Amadulpur village of Yamunanagar district in Haryana state.

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Hisar

November 16, 2001


(Sushil Kumar)

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LIST OF ABBREVIATIONS

°C	Degree celcius
CD	Critical difference
cm	Centimeter
DBH	Diameter at breast height
<i>et al.,</i>	Et alia = and others
<i>etc.</i>	Et cetera
Fig.	Figure
g	Gram
ha	Hectare
<i>i.e.</i>	That is
kg	Kilogram
%	Percent
t	Tons

INTRODUCTION

Large number of farmers in north-western parts of India, in the recent past, have been adopting poplar based agroforestry systems due to the economic reasons. Poplar is a fast growing short rotation tree (6-8 years) having high industrial value for plywood and pulp and this tree is compatible with agricultural crops providing good income to the growers. Sugarcane is intercropped in younger plantations of 1-2 years old due to small canopy of the trees, wheat is grown during winter in middle aged plantations (3 - 5 years old) due to deciduous nature of trees, while turmeric cultivation is most suitable under the canopy of older plantations of 5 to 8 years due to its shade-loving nature.

Intensive studies on nutrient cycling have been carried out in natural forests (Edwards and Grubb, 1982; Toky and Ramakrishnan, 1983) and agroforestry systems in the tropics (Toky et al., 1989; Rasool, 1996; Mugendi, 1999; De Costa and Attapattu, 2000). However, little work has been done on industrial agroforestry systems such as poplar based systems of fertile and well irrigated plains of north-western India. Such studies are important from the ecological point of view as a large amount of biomass including leaf litter and fine roots of trees as

well as crop residues is available after every 4 to 12 months to meet out the nutrient requirements of tree as well as the crops, and at the same time huge quantity of nutrients is lost through harvest of timber after a period of 6-8 years, and annually through harvest of edible parts of crops.

A major challenge towards the long-term sustainability of these high nutrient demanding systems is to ensure that nutrients released through biomass of one crop/tree are efficiently utilized by subsequent growth of crops/trees. Synchronizing release of nutrients from decomposing biomass with demand (uptake) by crops/trees leads to increased nutrient use efficiency of the incorporated biomass and in turn minimizes the opportunity of nutrient loss.

Understanding decomposition and nutrient release pattern of plant materials is an important first step to better management of organic inputs in agroforestry systems (Palm, 1995; Mafongoya et al., 1998). These in turn depend to a large extent on chemical composition of plant tissue (Constantinides and Fownes, 1994). Initial N content of the biomass, C:N ratio, lignin content, lignin : N ratio, and polyphenol and its ratio with N and lignin have been shown to be important chemical qualities affecting the rate of decomposition and mineralization (Palm, 1995; Mafongoya et al., 1998).

The present study focuses on the pattern of litter decomposition, release of N, P and K and its synchronization with the nutrient demand by associated crops/trees. It has an important consideration in management of nutrients for crops

such as wheat, turmeric and sugarcane grown underneath trees of poplar. The present study, therefore was designed to achieve the following objectives :

- (i) To estimate the rate of decomposition of leaf litter and fine roots of poplar, sugarcane, wheat and turmeric in poplar based agroforestry systems.
- (ii) To estimate the mineralization/immobilization of N, P and K from decomposing leaf litter and fine roots of poplar, sugarcane, wheat and turmeric in poplar based agroforestry systems.

REVIEW OF LITERATURE

The review of literature has been discussed under the following headings :

- (i) Leaf litter and fine roots decomposition
- (ii) Nutrient dynamics

(i). Leaf litter and fine roots decomposition :

The importance of litter decomposition has been recognised by many workers (Singh, 1969; Berg and Staff, 1981; Upadhyay, 1984; Bahuguna *et al.* 1990; Rasool, 1996) due to the fact that litter decomposition increases the nutrient availability in the system and consequently the productivity of the system is increased.

Swift *et al.* (1981) studied decomposition and mineral nutrient dynamics of plant litter in a regenerating secondary rain forest at Ibadan Nigeria and observed that dry season was characterised by a high rate of litterfall, negligible decomposition and hence, the accumulation of reservoir of N, P, K, Ca and Mg in litter layer; while the rainy season led to rapid decomposition of leaf litter and releasing the nutrients into the soil reservoir.

Singh *et al.* (1993) studied the rate of decomposition in 'sal', *Eucalyptus* and poplar plantations in Uttar Pradesh in India, and reported that the annual litter decomposition was the highest in 'sal', 87 per cent followed by teak 72 per cent, poplar 65 per cent and least in *Eucalyptus* 50 per cent. Singh *et al.* (1994) reported that litter decomposition per year in *Dalbergia sissoo* and *Bombax ceiba* plantations in Uttar Pradesh was 73 per cent and 81 per cent, respectively.

Singh (1969) studied decomposition of 10 important tropical deciduous forest trees at Varanasi, and observed that with the onset of rains in the last week of June, the litter is rapidly decomposed and the rate slows down in winter due to lack of moisture.

A litterbag study of leaf litter decomposition in a plantation of 'sobabul' (*Leucaena leucocephala*) at Madurai, Tamil Nadu showed a reduction in the dry mass of 'sobabul' by 70 per cent after one year of exposure (Ilangovan *et al.*, 1996)

Bhardwaj *et al.* (1992) reported that the concentration of nitrogen, lignin and water-soluble components had a major control on the decomposition rates. Upadhyay and Singh (1985) concluded that the decomposition rate decreased with an increase in altitude and was inversely related with lignin content. Linear combination of lignin content with rainfall and with temperature indicated significant interactive influence on decomposition.

Bahuguna *et al.* (1990) reported that the litter decomposition of *Eucalyptus camaldulensis* was faster than *Shorea robusta*, probably on account of high initial

leachability of the potassium. The rate of decomposition of *S.robusta* showed a steady pattern of weight loss.

The differences in the rate of decomposition of litter of different species due to physical factors of different sites have been reported by Weigert and McGinnis (1975), Maclean and Wein (1978), Meentermeyer (1978), Pandey and Singh (1982), Nagy and Macauley (1982), Seastedt *et al.* (1983) and Upadhyay (1984). Singh and Gupta (1977) argued that the nitrogen rich broad leaf litter decomposed at a faster rate than nitrogen poor needle litter. Berg and Staaf (1981) from a variety of litter types concluded that there is a general tendency towards higher critical N levels at higher weight loss rates and lower critical N levels at lower weight loss rate.

Taylor *et al.* (1989) reported that decomposition rates of leaf litter could be predicted from the lignin or nutrient (N or P contents). Gupta and Singh (1981) concluded that the litter species characterised by high concentration of nitrogen, ash, acid detergent cell wall component and low concentration of carbon cellulose and lignin, decomposed rapidly, Upadhyay *et al.* (1985) reported that there was a significant inverse relationship between the percentage original mass remaining and the nitrogen concentration of the residual matter.

Mohsin *et al.* (1996) worked on poplar trees, intercropped with *Mentha* and *Cymbopogon*, in 'tarai' belt of U.P and concluded that the plantation intercropped with *Mentha* produced more litter than pure plantations or those intercropped with

Cymbopogon species. The litter of trees having crops beneath had higher N, P and K contents than the pure stands.

Usman *et al.* (2000) found that litter with greater root diameter tended to be lower in nutrient concentration.. Monthly mean temperature, rainfall and humidity could account for 54-56% of monthly mass loss for forest sites. Ash free mass loss of fine roots decreased with increasing root diameter. Material with higher C/N ratios had a longer duration of immobilisation and in turn a slower release phase.

(ii). Nutrient dynamics :

Fresh litter carries large amount of readily oxidisable carbon and comparatively small amount of total nitrogen, and hence its C/N ratio is high. When the decay of litter starts, carbon is released and large part of it escapes from the soil in the form of carbon dioxide. On the other hand, most of the nitrogen released during decomposition is taken up by micro-organism for synthesis of their cell substance. Hence, as the decomposition proceeds relatively greater amount of carbon is lost than nitrogen.

Rates of release of different nutrients were measured in decomposing leaf tissue from yellow birch, sugar maple and beech by Gosz *et al.* (1973). The rate of nutrient release from decomposing leaf litter appears to be correlated with nutrient concentration in current litter fall precipitation and leaf wash. The concentration and absolute weight of N and P in the leaf litter of all species increased with time. These studies also indicated that P levels can influence the mineralisation or immobilisation of other important nutrients. P and Mg were rapidly released from

the litter by leaching, calcium was released in such a way which indicated it is a structural component primarily released by decomposition.

The rate of loss of P, Mg, Ca, K and Na during decomposition of plant materials were studied in mature *Eucalyptus obliqua* forest in south-eastern Australia by Attiwill (1968). He observed that the loss of element follows the order of $\text{Na} > \text{K} > \text{Ca} > \text{Mg} > \text{P}$ and can be largely explained by the behaviour of these elements in terms of both mobility within the living biomass and of leaching from the forest canopy.

Pandey and Sharma (1988) in their study on litter nutrient dynamics of some plantation at New Forest, Dehra Dun found that in general, nutrients release followed the order $\text{Ca} > \text{K} > \text{N} > \text{Mg} > \text{P}$ for pines and *Eucalyptus*, and $\text{Ca} > \text{N} > \text{K} > \text{Mg} > \text{P}$ for 'sal' and 'teak'.

Laskowski *et al.* (1995) reported that on an average the elements could be ordered by decreasing mobility as $\text{K} > \text{Mg} > \text{Ca} > \text{S} > \text{Cu} > \text{Na} > \text{Mn} = \text{N} > \text{Cd} > \text{Pb} = \text{Fe}$. Instead of two presupposed factors controlling litter decomposition, biological and chemical, three factors were specified: (i) biological, dominated by decay of organic matter and dynamics of N, Ca, Mg, Mn and S; (ii) Physical, dominated by leaching and atmospheric deposition, and (iii) controlling the dynamics of organic matter, K, Na, Pb, Cd and Zn, Pb and Cd through the fixation of metal ions to humid substances.

Lodhiyal and Lodhiyal (1997) reported that nutrient cycling of vegetation is influenced by its retention values, i.e., net nutrient uptake and return of litter

nutrients. They observed that the nutrients requirement of the vegetation not only depends upon soil nutrient levels and stand age but also the nutrient concentration of foliage.

Nutrient concentration varied considerably between the tree tissues and was the highest in the needles, lowest in the stem and intermediate in bark and branches. Kadeba (1991) suggested that because tissue nutrient concentration exhibited relatively little change with the stand development, total aboveground nutrient content followed the dynamics of the biomass expansion and increased with stand age

Wang *et al.* (1995) and James and Smith (1977) reported that distribution and concentration of nutrients within tree component follow the order of leaves > twigs > lateral branches > trunk. Negi and Tandon (1997) reported that the percentage contribution of particular nutrient for a particular component of poplar did not show any trend or relationship with the age.

Singh (1998) reported that nutrient concentration of woody components of the trees had little variation in root, stem and branches. However, nutrient concentration was the highest in leaf tissue as compared to woody tissue and decreased considerably in leaf litter component due to the retranslocation of nutrients.

George and Varghese (1992) observed that leaf had the highest percentage of all nutrient (1.6% N, 0.11% P and 0.96% K) followed by branches (0.8% N, 0.1% P

and 0.85% K), bark (0.7% N, 0.05% P and 0.74% K) and wood (0.6% N, 0.04% P and 0.31% K) and the lowest percentage was found in roots.

Lodhiyal and Lodhiyal (1997) reported that annual transfer of litter nutrients to the soil by vegetation was 19-184 N, 8-15 P and 70-99 K kg ha⁻¹ yr⁻¹. The turnover rate for different nutrient ranged between 0.83-0.92 kg ha⁻¹ yr⁻¹. The nutrient use efficiency of poplar plantation ranged from 151 – 174 kg ha⁻¹ yr⁻¹ for N, 1338-1566 kg ha⁻¹ yr⁻¹ for P and 313 – 318 kg ha⁻¹ yr⁻¹ for K.

The annual return of N, P and Ca was higher than annual retention in *Populus deltoides* plantations in 'tarai' regions except at the age of 3 years and N at 5 year, while the retention except at the age of 3 year and N at 5 years, while the retention of K and Mg was much higher at all ages (Tandon *et al.*, 1991).

Singh *et al.* (1993) in their studies on production and decomposition of leaf litter in "sal", teak, *Eucalyptus* and poplar stand in Uttar Pradesh found that sal (*Shorea robusta*) released 0.79 per cent N, 0.019 per cent P, 0.20 per cent Ca and 0.60 per cent Mg. Similarly, teak (*Tectona grandis*) released 1.26 per cent N, 0.020 per cent P, 0.16 per cent Ca and 0.29 per cent Mg, and *Eucalyptus* hybrid released 1.10 per cent N, 0.012 per cent P, 0.16 per cent K, 1.50 per cent Ca and 0.31 per cent Mg. Poplar (*Populus deltoides* – ONDA clones) released 1.64 per cent N, 0.018 per cent P, 0.11 per cent K, 2.50 per cent Ca and 0.30 per cent Mg. Singh *et al.* (1994) studies on leaf litter production and decomposition in *Delbergia sissoo* and *Bombax ceiba* plantations and reported a total release of 0.67 per cent

nitrogen, 0.02 per cent phosphorus, 0.35 per cent potassium, 1.25 per cent calcium and 0.34 per cent magnesium in leaf litter.

Bahuguna *et al.* (1990) while studying leaf litter decomposition and nutrient release in *S. robusta* and *E. camaldulensis* plantations observed that in the beginning the initial N content was comparatively low in case of 'sal' (0.57%) than *E. camaldulensis* (1.12%) while at the end it was high in case of 'sal' (2.0%) and low in case of *E. camaldulensis* (0.94%).

Rasool (1996) reported that the annual return of nutrient through leaf litter was in order of N 39.67, P 8.19 and K 20.06 kg ha⁻¹ under 4-years old poplar plantation and N 29.34, P 5.72 and K 14.6 kg ha⁻¹ under 3-years old plantation.

Singh (1998) reported that the nutrient input from the decomposition and mineralisation of leaf litter primarily depends on substrate, quality and quantity of micro-organisms and they also stated that nutrient return to soil was N 20.6, P 3.1 and K 10.8 kg ha⁻¹ at 10 years old poplar plantation.

Sharma *et al.* (1998) observed the effect of nitrogen application with or without mulch on wheat plants under poplar trees planted at 5 m x 3 m spacing the reported that out of 0, 37.5, 50 and 75 kg N ha⁻¹ with or without poplar leaf mulch, the grain yield was highest with 75 kg N ha⁻¹ with or without poplar leaf mulch.

MATERIALS AND METHODS

Experimental site :

The study was conducted at a private farm in village Amadulpur, which is situated 10 km away from Yamunanagar town (30° 10' N, 77° 18' S) in Haryana state of north-western India. It is an intensively managed farm having poplar plantations of different ages. The farm (50 ha) is situated in between the basin of river "Yamuna" and "Yamuna canal" having sandy-loam soil. The climate is sub-tropical with rainfall of 1200 mm, and most of it is received as monsoons during June to September. Tubewell is another important source of irrigation.

Plantations of *Populus deltoides* clone G₄₈ (spacing of 5 m x 5 m) of 1-, 3- and 7-year old were selected. In 1-year old plantations, the canopy of the trees is not developed, the farmer prefers to grow light demanding perennial crop such as sugarcane, in 3-year old plantations, the canopy of the tree is well developed and the trees attain a DBH of approximately 20 cm and a height of 20 m, which does not allow a good growth of the grain/legume crops during summer however, during winter the trees of poplar become leafless and hence, a good wheat crop is

possible underneath the trees. At advance stage of tree growth after 6 years, a perennial shade-tolerant crop, such as turmeric is grown in the interspaces of trees. Turmeric is crop of 2-years, and builds up high biomass (11 t/ha/year) beneath poplar trees. Detail studies on decomposition of leaf litter and fine roots, and patterns of nutrient release were studied in plantations of 1-, 3-, and 7-year old plantations.

2. Study materials

Leaf litter and fine roots (< 2 mm diameter) from poplar, sugarcane, wheat and turmeric were collected. Freshly fallen dry leaves of poplar were collected randomly from surface of 1-year, 3-year and 7-year old plantations during the peak litterfall in December. Leaf litter of sugarcane, wheat and turmeric were collected immediately after harvesting of these crops in late-January, early-April and early-January grown in the interspaces of 1-, 3- and 7-year old plantations of poplar, respectively.

Fine roots (having diameter < 2 mm) of poplar were collected by simple excavation method, manually digging out roots of 10 randomly selected trees, from different age plantations during the January. Roots of wheat, sugarcane and turmeric were also collected immediately after harvesting of these crops from their respective fields during early-April, late-January and early-January.

Root materials were separated from extraneous material, which included other plant material or soil aggregates sticking on the surface. Particles from the

fine roots were separated by putting them in a sieve having size 1 mm and passing the water through the sieve. These were oven dried at 60 °C and stored for chemical analysis.

3. Estimation of decomposition rates :

To estimate the rate of decomposition, litterbag technique (Olson, 1963; Upadhyay and Singh, 1989; Usman et al., 2000) was used. Litterbags of size 20 x 20 cm, consisting of nylon net (mesh size 1 mm) were used. A total of 30 x 4 = 120 bags were prepared. Twenty grams of oven dried material was filled in each litterbag.

Litterbags containing fine roots were placed in the soil 10 cm below the surface, while those of leaf litter were placed on the surface of the soil. The placement of litterbags in respective fields for different species was done as coinciding the period of litter production *in situ* as described below :

Poplar : A total of 10 litterbags containing leaf litter and fine roots (5 each) were placed randomly in 1-year old plantation having sugarcane. Same numbers of litterbags were also placed in the 3-year and 7-year old plantations having wheat and turmeric, respectively. Placements of litterbags was done in the end of December 1999, which is period of maximum leaf fall of poplar.

Sugarcane: Fifteen bags each of leaf litter and fine roots, were placed randomly in 1-year old plantation having sugarcane, in the beginning of February.

Wheat : Similarly as mentioned above, the leaf litter and fine roots bags were placed in 3-year old plantation having wheat, at the end of April.

Turmeric : Leaf litter and fine roots were placed randomly in the 7-year old plantation having turmeric, in the month of February.

Three bags of each species and of each material type were picked up at monthly interval from the date of placement. The bags were brought to the laboratory after removing the extraneous material, which included other plant material or soil aggregates sticking on the outside surface of mesh bags. The litter was further cleaned carefully in the laboratory and placed in the oven at 60 °C for measurement of weight and chemical analysis.

Annual decomposition co-efficient (k) was calculated by using the decomposition model given by Olson (1963) :

$$x_t/x_0 = e^{-kt}$$

where,

x_t = mass at time t ;

x_0 = initial mass;

k = the annual exponential decay constant.

t_{50} values were calculated following Olson (1963) as :

$$t_{50} = 0.693/k$$

4. Nutrient analysis :

All samples used for dry weight loss were individually analysed for N, P and K concentration. Nitrogen was analysed by the micro-Kjeldahal method (Jackson, 1967), P by colorimetry (Jackson, 1958) and K by flame emission (Issac and Kerber, 1971).

5. Statistical analysis :

Factorial CRD was employed to study the different treatments (Panse and Sukhatme, 1961).

For analysis of the design, we used the linear model :

$$Y_{ij} = \mu + T_i + e_{ij}$$

Where,

Y_{ij} = Value of j^{th} replicate for i^{th} treatment

μ = General mean effect

T_i = Effect due to i^{th} treatment

e_{ij} = Random error which is independently, normal distributed with mean zero and variance σ^2e

Let there be t -treatment and the i^{th} treatment be replicated r_i times then the data can be arranged as below:

	1,	2	i	t	
	$Y_{11},$	$Y_{21}.....$	Y_{i1}	Y_{t1}	
	$Y_{12},$	$Y_{22}.....$	Y_{i2}	Y_{t2}	
	$Y_{1r1},$	$Y_{2r2}.....$	$Y_{ir1}.....$	Y_{tr1}	
Total	$Y_{1.}$	$Y_{2.}$	$Y_{i.}$	$Y_{t.}$	$Y_{..}$
Mean	Y_1	Y_2	Y_i	Y_t	

Let Y_i be the total of the i^{th} treatment and $Y_{..}$ be the Grand total (GT), i.e.

$$Y_{j.} = \sum_j Y_{ij} \quad Y_{..} = \sum_i \sum_j Y_{ij} \text{ and}$$

Total number of observations $n = \sum_{i=1}^t r_i$

$H_0 : T_1 = T_2 = \dots + T_t$ against the alternative hypothesis that T_j are not equal (any two are different). The following formulas were employed for the analysis of variance.

$$\text{Correction factor (CF)} = \frac{(GT)^2}{\sum r_i} = \frac{(Y_{..})^2}{n}$$

$$\text{Total sum of squares} = \sum \sum y_{ij}^2 - CF$$

$$\text{Sum of squares due to treatments} = \sum_{i=1}^t \frac{Y_i^2}{r_i} - CF$$

$$\text{Sum of squares due to error} = \text{Total SS} - \text{Treatment SS}$$

Analysis of variance

Source	d.f.	S.S.	M.S.	F_{cal}
Between treatment	$(t - 1)$	$\sum Y_i^2/r_i - CF = SST$	$SST/(t-1) = MST$	MST/MSE
Within treatment (error)	$(n - 1)$	$\sum \sum Y_{ij}^2 - \frac{\sum Y_i^2}{r_i} = SSE$	$SSE/(n-t) = MSE$	
Total	$(n - 1)$	$\sum \sum y_{ij}^2 - CF$		

The critical difference (C.D) was calculated as :

$$C.D. = SE (d) \times t [\alpha, (n-t)]$$

Where t_x is the tabulated value of t at α level of significance at error degree of freedom i.e. $(n-t)$. The level of significance was chosen at 5%.

The estimated standard error of any treatment means, say i -th treatment mean was calculated as :

$$SE_m = \sqrt{MSE/r_i}$$

The estimated standard error of the difference between any two means was

$$SE_d = \sqrt{MSE (1/r_i + 1/r_j)}$$

Where r_i and r_j are the number of replication for the i^{th} and j^{th} treatment.

$$\text{If } r_i = r_j = r \text{ then } SE (d) \sqrt{2 MSE/r}$$

EXPERIMENTAL RESULTS

1. Leaf litter and fine root decomposition

In leaf litter, the most rapid weight losses were observed in case of poplar, followed by sugarcane, turmeric and wheat (Table 1). The rate of decomposition was very fast during the initial 90 days for poplar, turmeric and sugarcane losing more than 50% material from litterbags, but subsequently the rate became slow. Wheat litter showed a different trend as compared to other species, losing only 30% weight during initial two months but from third month onwards, the rate increased sharply.

A 100% weight loss was observed in poplar at the end of five months. Maximum undecomposed material remained, 27% of initial amount was in wheat followed by turmeric (23%) and sugarcane (19%). Wheat roots showed faster rate of decomposition as compared to other species, and a weight loss of 87% was observed after five months. Maximum undecomposed roots, 30 % of initial weight was in sugarcane followed by poplar (27%) and turmeric (16%) (Table 1).

For exhibiting the pattern of decomposition, the \log_e %weight remaining was regressed against time elapsed. It was observed that there existed a highly significant ($P < 0.01$) negative relationship between % weight remaining and time

Table 1. Weight loss (g) of leaf litter and fine roots of poplar, sugarcane, wheat and turmeric in poplar agroforestry systems

Time elapsed (days)	Replication	Poplar		Sugarcane		Wheat		Turmeric	
		Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots
0	I	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	II	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	III	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
30	I	11.1	18.2	13.3	18.0	16.9	12.4	15.5	17.2
	II	10.9	17.1	13.9	16.9	18.2	14.1	17.1	16.4
	III	11.6	17.2	15.7	20.9	18.9	13.4	16.3	15.6
60	I	6.3	13.3	10.9	15.7	16.2	11.0	11.7	13.5
	II	5.4	12.8	11.3	17.3	13.6	9.0	12.6	13.1
	III	7.2	14.7	9.5	17.5	12.5	8.8	17.5	13.0
90	I	2.1	9.4	7.6	12.7	13.2	9.6	9.2	7.9
	II	1.9	11.4	8.4	13.7	12.9	8.2	8.4	9.5
	III	3.2	10.4	8.5	13.5	10.4	4.1	10.7	12.3
120	I	2.8	8.8	5.8	9.8	9.3	4.9	7.2	6.8
	II	0.6	7.7	7.2	7.9	9.4	5.2	6.7	8.3
	III	1.1	9.3	7.3	(14.6)	9.1	7.1	4.7	5.1
150	I	(0.8)	(8.6)	(6.8)	(10.8)	(9.3)	(5.7)	(6.2)	(6.7)
	II	5.4	5.4	2.1	6.1	5.9	1.8	3.7	3.9
	III	-----	4.5	3.8	7.1	6.1	3.1	5.2	3.2
Time elapsed	I	6.3	5.3	4.2	2.9	2.9	2.7	2.7	2.7
	II	(5.4)	(3.7)	(5.4)	(2.6)	(4.5)	(3.3)	(4.5)	(3.3)
	III	(5.4)	(3.7)	(5.4)	(2.6)	(4.5)	(3.3)	(4.5)	(3.3)
Factor	C.D. at 5%		S.E.(d)		S.E.(m)		S.E.(m)		
Time elapsed	0.719		0.362		0.256		0.256		
Decomposing material	0.830		0.418		0.296		0.296		
Time elapsed x Decomposing material	2.033		1.024		0.724		0.724		

Values in parenthesis are means of replications

elapsed for all the species. The regressions explained more than 92% and 94% variability in percent weight remaining on account of time elapsed for leaf litter and fine roots, respectively. The intercept value however, was around 4.7 for both leaf litter and fine roots (Table 2) indicating that equations although statistically significant, did not describe correctly the decomposition rate especially during the initial segment $t = 0$. Nevertheless, since the relationship is significant, it perhaps characterised the overall long term fractional weight loss for different species and therefore, could be used to test differences in decomposition pattern.

The highest decomposition rate constant (k) was observed in poplar leaf litter (4.23) and minimum in wheat leaf (1.36). However, in contrast to leaf litter, roots of wheat showed the maximum value (2.10), and minimum was observed for sugarcane (1.20). t_{50} values showed that poplar leaves had taken minimum time of 60 days, while the sugarcane roots had taken maximum time of 210 days for 50% decomposition of material in the litter bags (Table 2).

2. Changes in nutrient concentration

i) Nitrogen : The initial content of nitrogen in leaf litter was the highest in poplar (1.22%) being more than 2-fold higher than that of wheat and turmeric, and 1.5-fold higher than sugarcane (Table 3). The concentration of N increased significantly ($P < 0.05$) in all the four species as the time elapsed. Maximum increase in N concentration in leaf litter at the end of 5 months, was observed in poplar (110%), followed by wheat (61%), sugarcane (28%) and turmeric (20%).

Table 2. Relationship between \log_n % weight remaining and days elapsed for leaf litter and fine roots of poplar, sugarcane, wheat and turmeric ($Y = a + bX$)

Species	Intercept (a)	Slope (b)	Correlation co-efficient (r^2)	Decomposition rate constant (k)	t_{50} (days)
Poplar :					
Leaves	5.381	-0.041	0.93	4.23	60
Roots	4.709	-0.009	0.98	1.36	186
Sugarcane :					
Leaves	4.611	-0.010	0.99	1.74	145
Roots	4.750	-0.007	0.94	1.20	210
Wheat :					
Leaves	4.721	-0.008	0.97	1.36	186
Roots	4.621	-0.012	0.98	2.10	120
Turmeric :					
Leaves	4.709	-0.010	0.99	1.53	165
Roots	4.759	-0.011	0.97	1.86	136

All significant at $P < 0.01$

The increase in concentration of N in decomposing roots was much lower as compared to leaf litter. In contrast to leaf litter, maximum increase was observed in wheat (60%) and almost negligible in poplar (3.5%) (Table 3).

All the species had a significant ($P < 0.05$) positive relationship between N concentration in residual material and percent weight loss. Correlation co-efficient ranged from 0.849 to 0.950 for leaf litter and 0.308 to 0.733 for fine roots (Fig. 1, 2), which suggested that as the concentration of N in the residual material increased, the % weight loss also increased leading to a faster rate of decomposition.

ii) Phosphorus : In all the species, initial concentration of P was much lower than that of N in both types of material. The initial P concentration was also maximum in case of poplar leaf (0.24%) and minimum in sugarcane (0.09%). In roots however, the maximum initial P content was observed in turmeric (0.38%), being greater than 2-fold as compared to that of other species (Table 4).

The concentration of P also increased significantly ($P < 0.05$) similar to N in all the species as the time elapsed (Table 4). The maximum increase was observed in leaf litter of turmeric being 4-fold higher of the initial concentration at the end of 5 months; the increase in other species was also much higher being 3-fold in poplar, 2-fold in sugarcane and 1.5 fold in wheat. The P concentration in fine roots also showed significant increase in all types of material.

Table 3. Changes in N concentration in decomposing leaf litter and fine roots of poplar, sugarcane, wheat and turmeric in poplar based agroforestry systems.

Time elapsed (days)	Replication	Nitrogen concentration (%)													
		Poplar		Sugarcane		Wheat		Turmeric		Sugarcane		Wheat		Turmeric	
		Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots
0	I	1.07	1.95	0.73	1.41	0.27	1.11	0.63	3.10						
	II	1.17	1.87	0.91	1.25	0.33	0.82	0.47	2.98						
	III	1.42	2.18	1.00	1.33	0.54	0.86	0.58	3.04						
30	I	1.58	0.96	1.13	1.00	0.43	0.66	0.36	2.60						
	II	1.61	1.17	0.95	0.91	0.40	0.73	0.32	2.45						
	III	1.55	1.11	0.80	0.79	0.19	0.71	0.46	2.48						
60	I	(1.58)	(1.08)	(0.96)	(0.90)	(0.34)	(0.70)	(0.38)	(2.51)						
	II	1.80	0.90	1.21	1.25	0.36	0.87	0.42	2.80						
	III	2.20	1.26	0.93	1.15	0.53	0.77	0.39	2.99						
90	I	1.94	1.53	1.31	1.17	0.37	1.33	0.45	3.12						
	II	(1.98)	(1.23)	(1.12)	(1.19)	(0.42)	(0.99)	(0.42)	(2.97)						
	III	2.36	1.53	1.19	1.21	0.46	1.18	0.61	3.07						
120	I	2.24	1.38	1.12	1.25	0.58	0.87	0.49	3.14						
	II	2.39	1.44	0.69	1.23	0.55	1.16	0.52	3.06						
	III	(2.33)	(1.45)	(1.00)	(1.23)	(0.53)	(1.07)	(0.54)	(3.09)						
150	I	2.72	1.75	1.18	1.36	0.45	1.17	0.52	3.15						
	II	2.55	1.81	1.13	1.45	0.63	1.02	0.50	3.07						
	III	2.56	1.57	0.90	1.12	0.63	1.20	0.57	3.11						
150	I	(2.61)	(1.71)	(1.07)	(1.34)	(0.57)	(1.13)	(0.53)	(3.11)						
	II	2.11	2.11	1.15	1.49	0.70	1.32	0.61	3.20						
	III	2.00	2.00	0.93	1.41	0.59	1.30	0.69	3.15						
150	I	2.10	2.10	1.28	1.48	0.54	1.19	0.71	3.16						
	II	(2.07)	(1.12)	(1.46)	(1.46)	(0.61)	(1.27)	(0.67)	(3.17)						
	III	-----	-----	-----	-----	-----	-----	-----	-----						

Values in parenthesis are means of replications

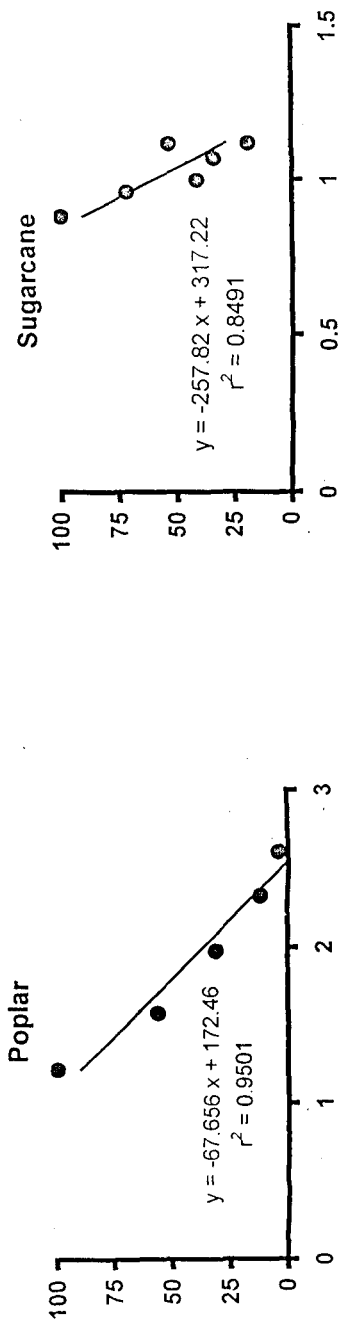
Factor	C.D. at 5%	S.E.(d)	S.E.(m)
Time elapsed	0.074	0.037	0.026
Decomposing material	0.086	0.043	0.031
Time elapsed x Decomposing material	0.210	0.106	0.075

Table 4. Changes in P concentration in decomposing leaf litter and fine roots of poplar, sugarcane, wheat and turmeric in poplar agroforestry systems.

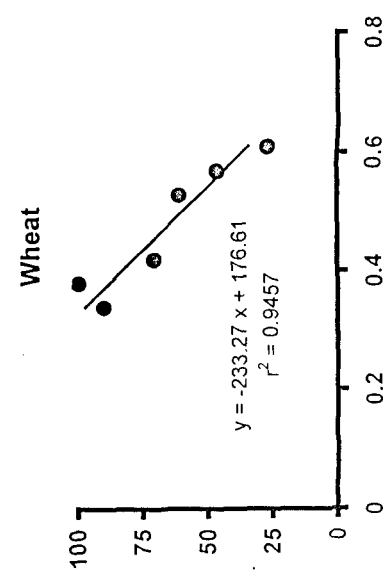
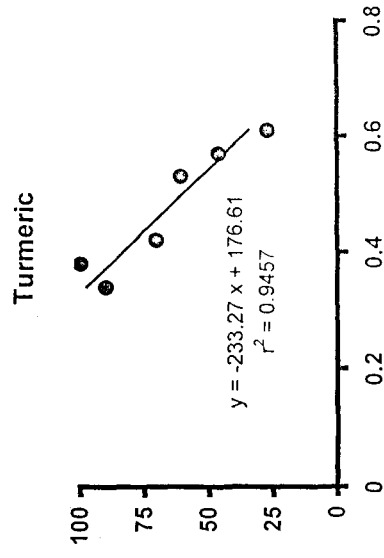
Time elapsed (days)	Replication	Phosphorus concentration (%)											
		Poplar		Sugarcane		Wheat		Turmeric					
		Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots				
0	I	0.26	0.17	0.11	0.19	0.20	0.01	0.21	0.40				
	II	0.30	0.11	0.09	0.15	0.15	0.10	0.19	0.39				
	III	0.16	0.17	0.08	0.20	0.13	0.11	0.08	0.35				
30	I	0.31	0.14	0.15	0.20	0.15	0.02	0.21	0.41				
	II	0.25	0.09	0.10	0.22	0.10	0.03	0.23	0.44				
	III	0.22	0.25	0.14	0.15	0.08	0.04	0.19	0.44				
60	I	0.41	0.20	0.21	0.22	0.20	0.04	0.27	0.53				
	II	0.36	0.17	0.37	0.10	0.14	0.03	0.25	0.55				
	III	0.32	0.20	0.17	0.35	0.17	0.04	0.29	0.45				
90	I	0.49	0.27	0.28	0.22	0.20	0.085	0.31	0.59				
	II	0.41	0.19	0.31	0.29	0.18	0.095	0.35	0.55				
	III	0.42	0.23	0.13	0.18	0.19	0.090	0.36	0.57				
120	I	0.63	0.23	0.20	0.31	0.25	0.17	0.42	0.61				
	II	0.58	0.16	0.23	0.24	0.19	0.09	0.45	0.65				
	III	0.62	0.21	0.38	0.32	0.22	0.10	0.42	0.63				
150	I	0.61	0.20	0.27	0.29	0.22	0.12	0.43	0.63				
	II	-----	0.23	0.35	0.33	0.21	0.20	0.55	0.69				
	III	-----	0.25	0.30	0.29	0.17	0.11	0.53	0.63				
				0.28	0.31	0.28	0.11	0.45	0.69				
				0.22	0.31	0.22	0.14	0.51	0.67				

Values in parenthesis are means of replications

Factor	C.D. at 5%		S.E.(d)		S.E.(m)	
Time elapsed		0.028		0.014		0.010
Decomposing material		0.032		0.016		0.011
Time elapsed x Decomposing material		0.078		0.039		0.028



% weight loss



% weight loss

N concentration

Fig.1. Relationship between % weight loss and % N concentration of leaf litter during five months of decomposition period.

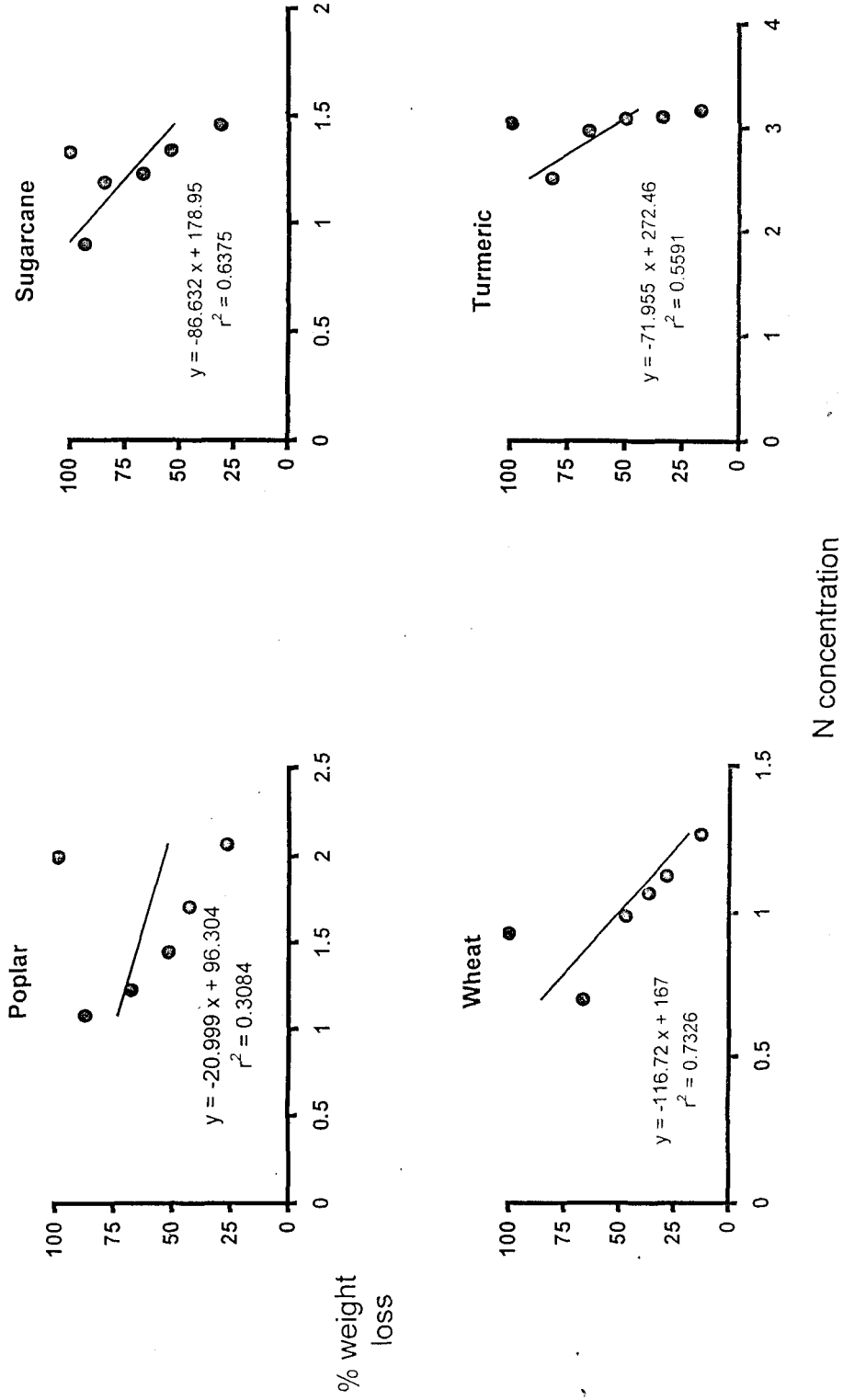


Fig.2. Relationship between % weight loss and % N concentration of fine roots during five months of decomposition period.

ranged from 0.849 to 0.985 for leaf litter and 0.653 to 0.996 for fine roots; all the correlation co-efficients were significant ($P < 0.05$) (Fig. 3, 4).

ii) Potassium : Initially, the highest concentration was present in leaves of poplar (2.19%) followed by turmeric, wheat and sugarcane. In roots, the highest concentration was in turmeric (2.00%), being almost 4-fold higher than sugarcane and wheat, and almost 2-fold higher than that in poplar. During the course of litter decomposition, K showed a contrasting trend to that observed for N and P. After 5 months of decomposition, maximum decline in K concentration occurred in leaf of poplar (90%), followed by that of wheat (87%), sugarcane (85%) and turmeric (64%). The roots also showed a significant decrease in concentration with a maximum decline in poplar and minimum in wheat (Table 5).

Highly significant inverse relationships ($P < 0.05$) between % weight loss and % K concentration were observed for all the species. Correlation co-efficients ranged from 0.859 to 0.976 in leaf litter and 0.868 to 0.952 in roots indicating that as the concentration of K decreased, the weight loss increased significantly ($P < 0.05$) (Fig. 5, 6).

3. Mineralization and immobilization

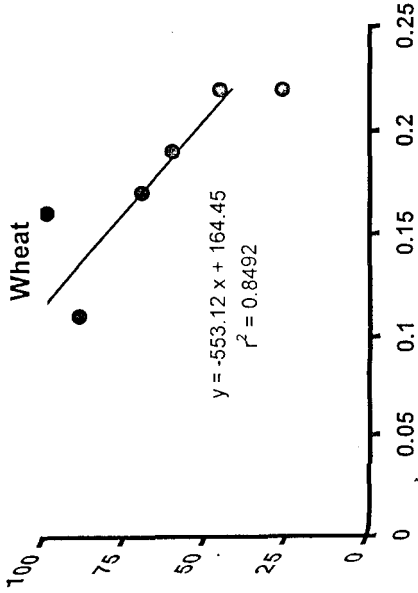
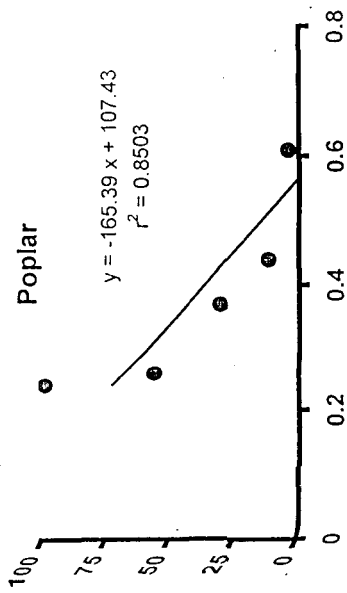
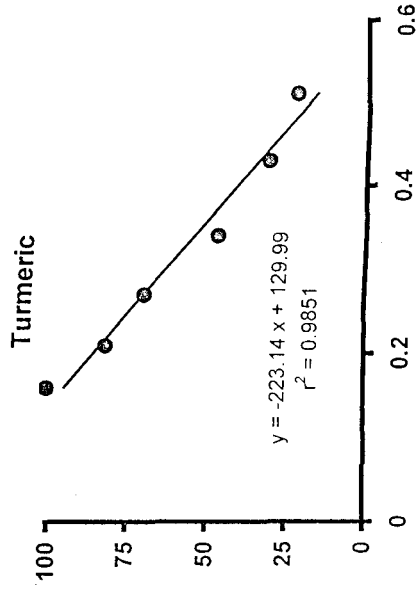
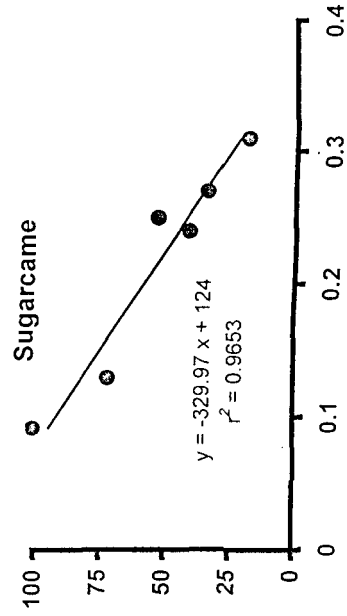
i) Nitrogen : Although, the concentration of N in all types of decomposing litter increased, the overall content (calculated on the basis of weight remaining) decreased sharply. Turmeric leaves and roots of all the species showed a sharp rate of mineralization during initial 30 days, releasing nearly 50% of initial content but

Table 5. Changes in K concentration in decomposing leaf litter and fine roots of poplar, sugarcane, wheat and turmeric in poplar agroforestry systems.

Time elapsed (days)	Replication	Potassium concentration (%)											
		Poplar		Sugarcane		Wheat		Turmeric					
		Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots				
0	I	2.13	1.09	0.65	0.40	1.12	0.41	1.57	2.06				
	II	2.19	0.94	0.69	0.38	1.06	0.38	1.61	2.00				
	III	2.25	0.79	0.73	0.35	1.00	0.35	1.59	1.94				
30	I	(2.19)	(0.94)	(0.69)	(0.38)	(1.06)	(0.38)	(1.59)	(2.00)				
	I	1.80	0.23	0.51	0.22	0.79	0.33	1.13	1.97				
	II	1.05	0.31	0.37	0.36	0.65	0.21	1.21	1.81				
60	III	1.30	0.72	0.25	0.19	0.88	0.40	1.17	1.65				
	I	(1.38)	(0.42)	(0.38)	(0.26)	(0.77)	(0.31)	(1.17)	(1.81)				
	I	0.22	0.19	0.22	0.27	0.31	0.33	0.91	1.12				
90	II	0.22	0.13	0.25	0.31	0.25	0.27	1.05	1.04				
	III	0.16	0.27	0.27	0.31	0.14	0.33	0.98	0.96				
	I	(0.20)	(0.20)	(0.25)	(0.30)	(0.23)	(0.31)	(0.98)	(1.04)				
120	I	0.27	0.33	0.15	0.31	0.20	0.39	1.14	0.75				
	II	0.11	0.24	0.30	0.25	0.17	0.27	1.26	0.69				
	III	0.18	0.31	0.19	0.29	0.33	0.25	1.20	0.67				
150	I	(0.19)	(0.29)	(0.21)	(0.26)	(0.23)	(0.28)	(1.20)	(0.69)				
	I	0.23	0.09	0.14	0.14	0.09	0.22	0.77	0.39				
	II	0.16	0.15	0.31	0.08	0.19	0.19	0.97	0.41				
180	III	0.19	0.14	0.12	0.09	0.14	0.25	0.87	0.43				
	I	(0.19)	(0.13)	(0.19)	(0.10)	(0.14)	(0.22)	(0.87)	(0.41)				
	I	0.07	0.07	0.11	0.04	0.08	0.17	0.65	0.27				
210	II	0.06	0.06	0.09	0.05	0.06	0.09	0.73	0.23				
	III	0.06	0.06	0.08	0.03	0.06	0.12	0.69	0.19				
	I	(0.06)	(0.06)	(0.10)	(0.04)	(0.13)	(0.13)	(0.69)	(0.23)				

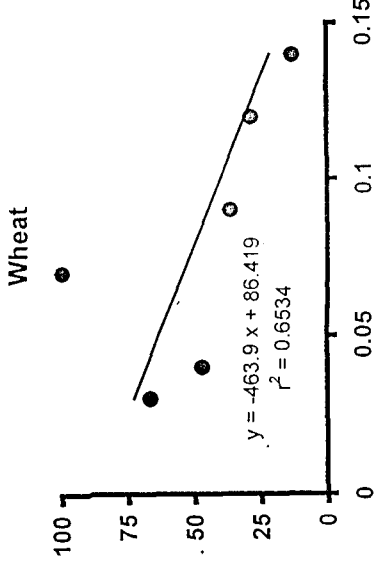
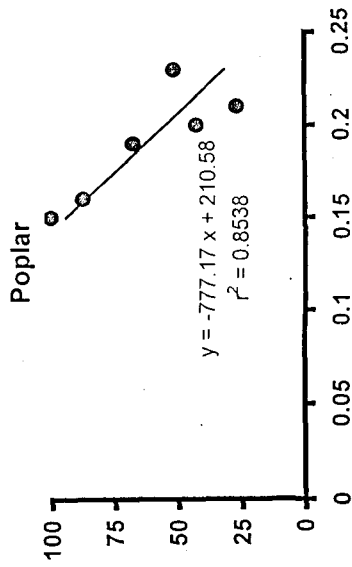
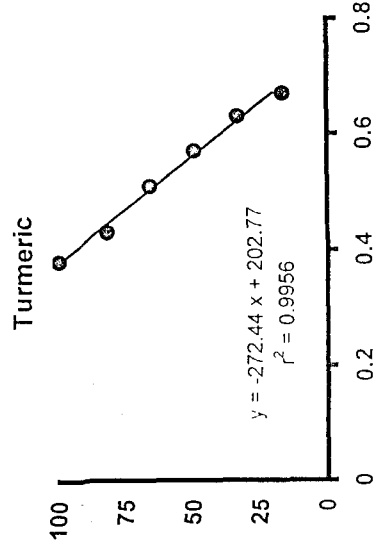
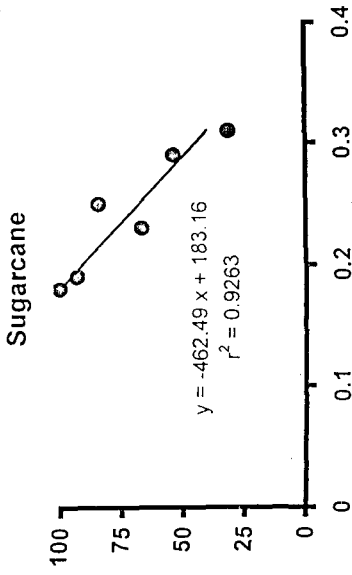
Values in parenthesis are means of replications

Factor	C.D. at 5%	S.E.(d)	S.E.(m)
Time elapsed	0.054	0.027	0.019
Decomposing material	0.063	0.031	0.022
Time elapsed x Decomposing material	0.153	0.077	0.055



P concentration

Fig.3. Relationship between % weight loss and % P concentration of leaf litter during five months of decomposition period.



P concentration

% weight loss

Fig.4. Relationship between % weight loss and % P concentration of fine roots during five months of decomposition period.

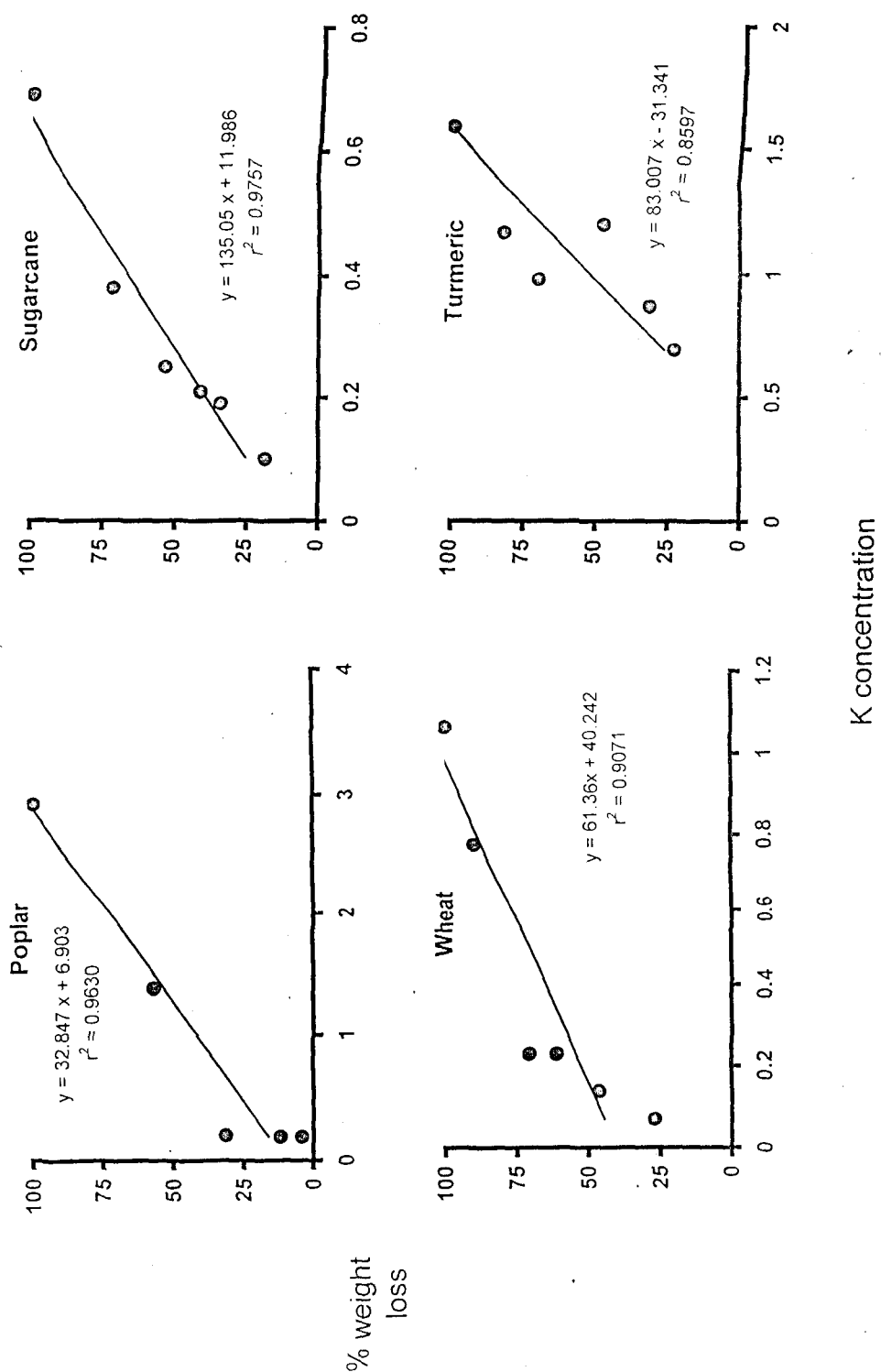


Fig.5. Relationship between % weight loss and % K Concentration of leaf litter during five months of decomposition period.

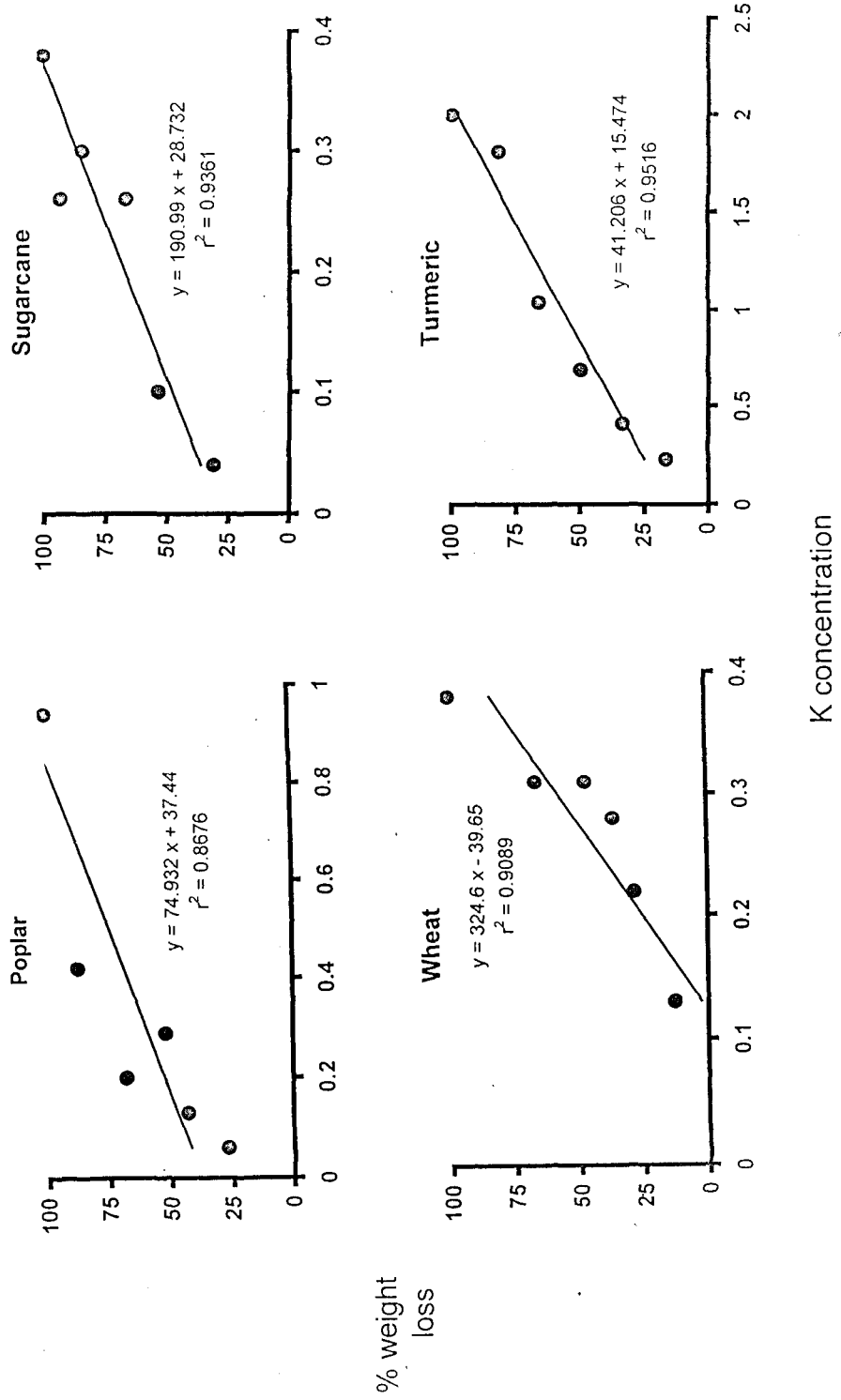


Fig.6. Relationship between % weight loss and % K concentration of fine roots during five months of decomposition period.

subsequently, the rate slowed down. The rate of mineralization of N in all the other leaf material was more or less constant (Fig. 7). In general, poplar leaves and sugarcane roots showed comparatively faster rate of N mineralization.

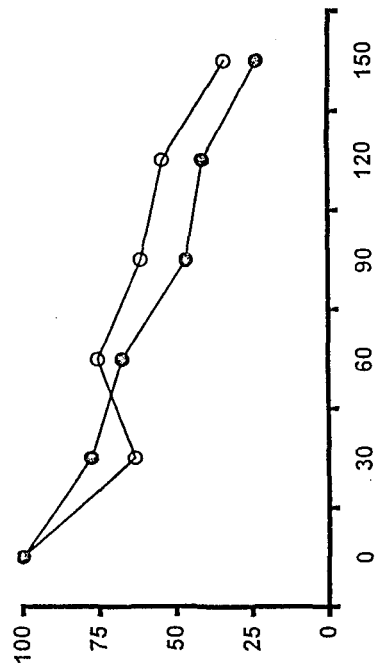
A net immobilization was observed only in case of wheat leaves and sugarcane roots at the end of 60 and 30 days, respectively. After 5 months, 100% release of N from leaf litter was observed only in case of poplar and least was in wheat (40%). The release of N followed the order of : sugarcane (90%) > turmeric (85%) > wheat (82%) > poplar (76%) (Fig. 7).

ii) Phosphorus : In general, rate of mineralization of P was faster in roots than leaf in all the species except poplar in which the leaves showed much faster rate than roots. The wheat roots showed exceptionally faster rate of mineralization during initial 30 days releasing 75% of initial P content (Fig 8).

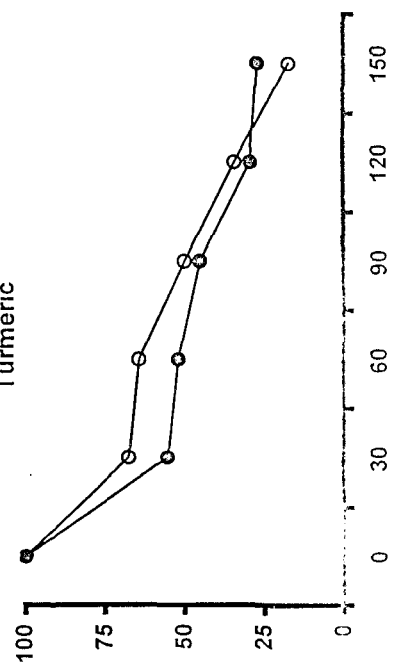
A net immobilization of P was observed in leaves and roots of sugarcane and leaves of wheat after 30 – 60 days; roots of wheat and leaf of turmeric showed immobilization from 60 - 120 days and 0 – 60 days, respectively (Fig. 8). At the end of 5 months, total P release was maximum in poplar leaves (100%) and minimum in turmeric leaves 28.4% (Fig. 8).

(iii) Potassium (K) : Among all species, the rate of K was observed to be 2-fold higher than that of N and P, releasing more than 75% of initial content during the first two months except turmeric which showed a slow release of K (Fig. 9). At end of 5 months, the maximum release of K was observed in poplar leaves (100%) and more or less same in turmeric leaves (90%) (Fig. 9). None of the species had shown immobilization of K during the course of decomposition.

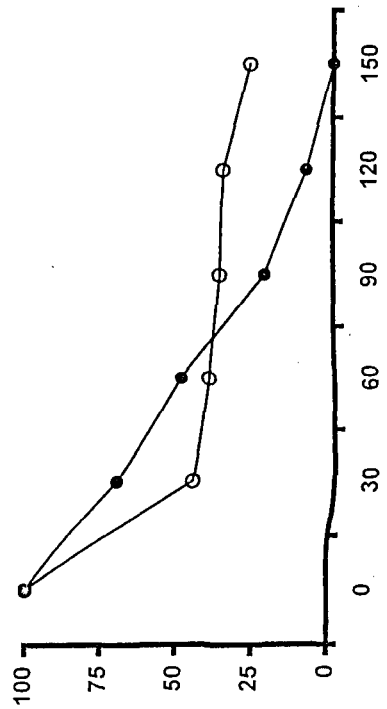
Sugarcane



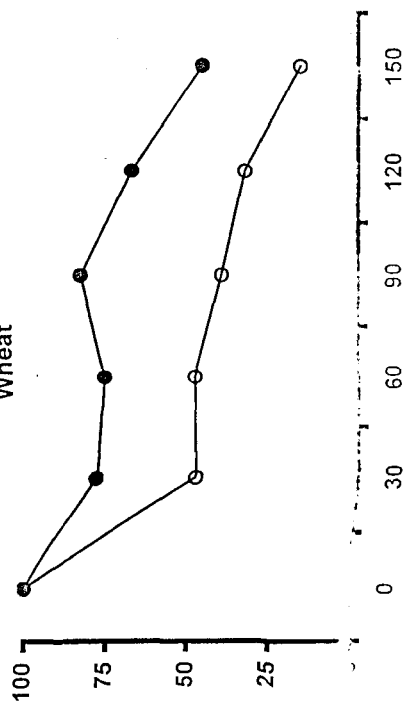
Turmeric



Poplar



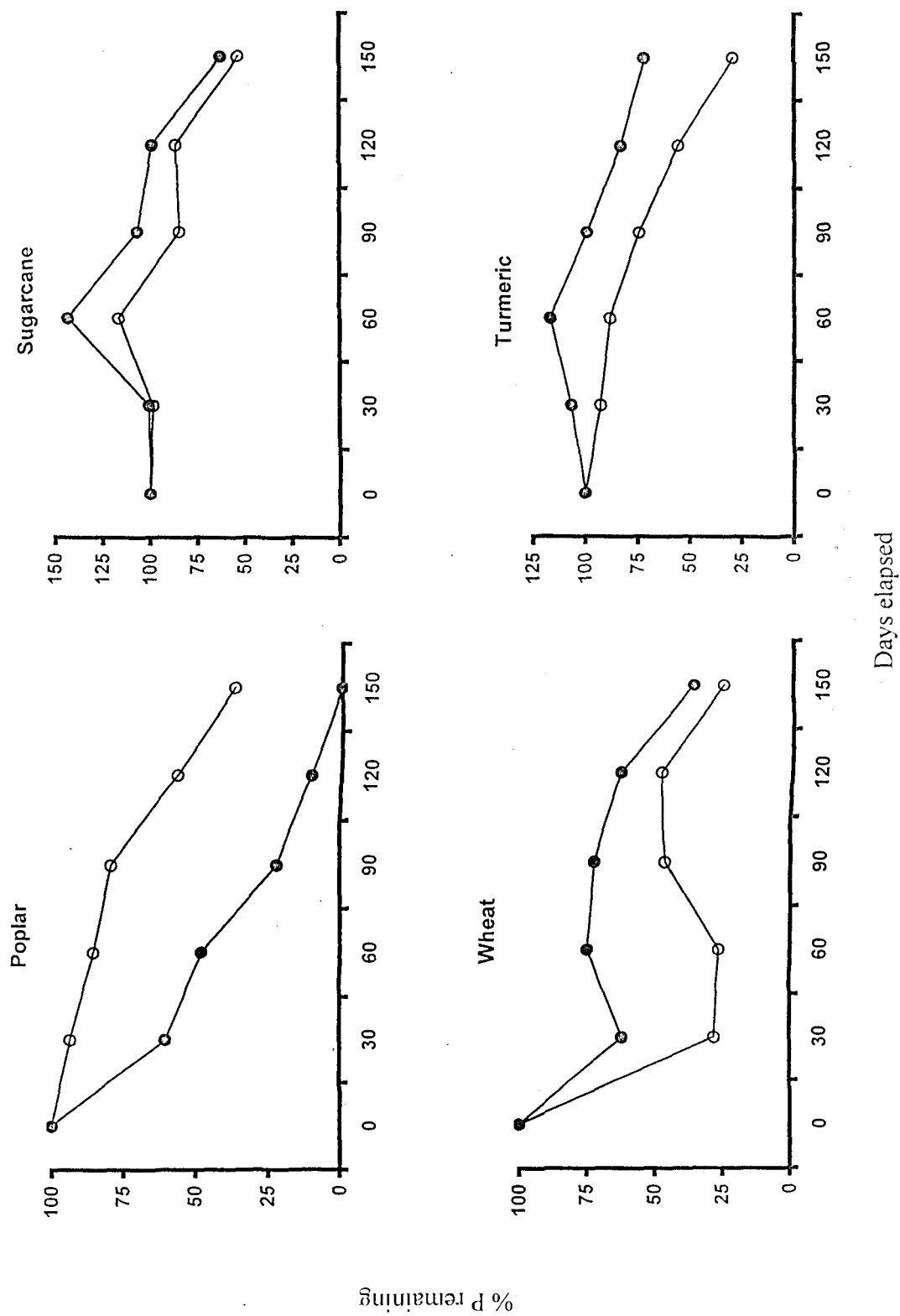
Wheat



Days elapsed

% N remaining

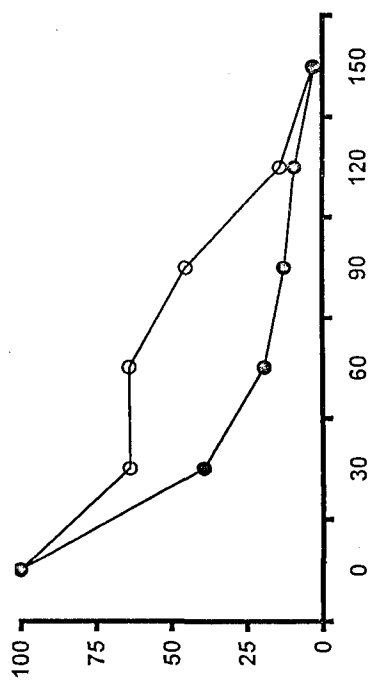
Fig. 7. Changes in nitrogen (% remaining of the initial weight) of leaf litter (●—●) and fine roots (○—○) of poplar and agricultural crops



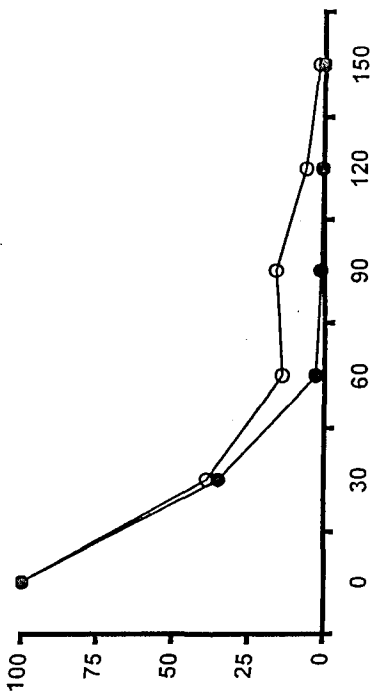
Days elapsed

Fig. 8. Changes in phosphorus (% remaining of the initial weight) of leaf litter (●—●) and fine roots (○—○) of poplar and agricultural crops

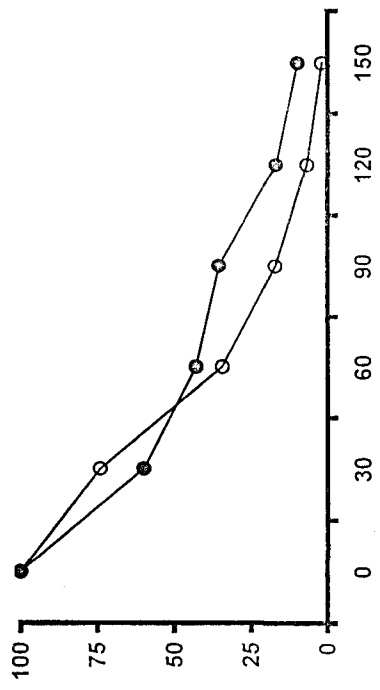
Sugarcane



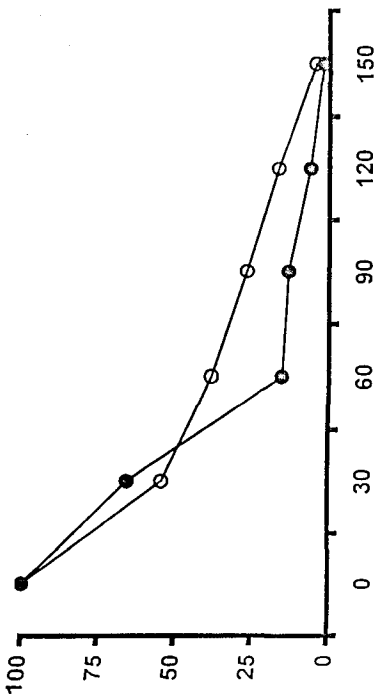
Poplar



Turmeric



Wheat



Days elapsed

Fig. 9. Changes in potassium (% remaining of the initial weight) of leaf litter (●—●) and fine roots (○—○) of poplar and agricultural crops.

DISCUSSION

In agroforestry systems, soil fertility is replenished by the input of biomass to the soil through litterfall and crop debris. With the help of trees and intercrops, a considerable amount of nutrients are added to soil, thus, partly replacing mineral fertilizer. Additionally, the synchronization of nutrients release from decomposition of litter with nutrients uptake by crops/trees, is considered a vital point for improving the efficiency of nutrients (Swift, 1981).

Keeping in mind the above hypothesis, the present study was carried out to estimate weight loss of leaf litter and fine roots and subsequently, release of nutrient in poplar agroforestry systems located in north-western India. Under short rotation of 7 to 8 years, with the increasing age of poplar trees, the farmer changes crops, *e.g.* during the initial 1 to 3 years, sugarcane is grown in the interspaces of trees; at 3-5 years age, wheat is intercropped when poplar sheds leaves during winter, and in older plantations of more than 5 years, turmeric (a shade-tolerant crop) is grown. The yield of these crops in association of poplar trees is excellent and provides high income to the farmers.

Sugarcane and turmeric are perennial crops which are harvested during winter (December – January) and very high amount of crop residue *i.e.* leaf litter and roots, are available during this period. Poplar also sheds all the leaves during same period. Hence, in 1-year old plantation, maximum litter is available in December-January. Wheat crop is harvested in the beginning of April, and high amount of leaf and fine root litter is available only after April. Thus, in 3-year old plantations, litter is available twice *i.e.* in January with the leaf fall of poplar and again in April with the harvest of wheat.

Poplar leaves showed the fastest rate of decomposition and the highest release rate of nutrients within 5 months of decomposition from January to April, which can be attributed to higher initial N and P contents. Higher the nutrient concentration of P and N and faster the decomposition rate, has also been observed by other workers (Meentemeyer and Berg, 1986; Satchell and Lowe, 1973; Pande, 1986).

Although, some workers have speculated that interspecific or intraspecific differences in decomposition rate may be due to initial nutrient concentration (especially N), this has not been found to be strictly the case with studies conducted by Daubenmire and Prusso (1963) and Anderson (1973b). A number of factors may dominate the substrate chemical properties in controlling decomposition rate, including temperature and moisture conditions, trace elements, tissue physical structure or toxic compound in the litter (Anderson

1973a). A similar trend has been observed with decomposition of roots in the present study. Despite having high initial concentration of N and P, the turmeric roots showed a slow decomposition rate as compared to that of wheat.

The value of decomposition constant (k) was the highest in poplar leaf (4.23). Singh *et al.* (1993) estimated a much lower value of k (1.05) for poplar leaf in plantations raised in 'tarai' belt of Uttar Pradesh (India). In the present study, rate of decomposition of poplar leaf was much faster due to management practices in agroforestry systems, *e.g.* pruning of trees which allows more penetration of light resulting in favorable temperature on the soil even during winter, the soil is ploughed and irrigated regularly which increase the aeration and moisture in the soil resulting in high microbial activity, and addition of N and P fertilizers to boost the yield of crops. This is in contrast to raising of pure plantations of poplar in 'tarai' belt without growing agricultural crops.

Nitrogen and phosphorus content of decomposing litter increased with time elapsed in the present study. A number of studies have also found an increase in N concentration (Coldwell and DeLong, 1950; Anderson, 1973b; Gosz *et al.*, 1973; Howard and Howard, 1974) during decomposition, which concentration increase in litter may be the result of losing N and P more slowly than losing dry weight. Potassium on the other hand, showed contrasting trend due to fast leaching. Similar results were also observed by Toky and Singh (1995) while studying the nutrient dynamics in *leucaena*, *Acacia* and *Eucalyptus*, in short rotation and high density ('energy') plantations in arid climate of north-western India.

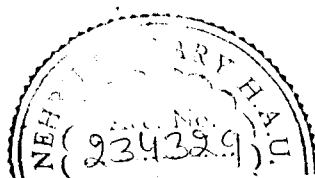
The current consensus is that N immobilization does not occur when litter N content is above 2 % (Palm and Sanchez, 1991; Wood, 1995). In the present study, this was true for initial contents of leaves and roots of all species except poplar, which showed no immobilization of N despite having concentration lesser than 2 %. A similar observation was made by Lehmann *et al.* (1995) where twigs of *Gliricidia callindra* and *Senna siamea* did not show immobilization during decomposition despite having N content lesser than 2 %. Absence of N immobilization may be due to lack of available carbon for microbes.

In 3-year old plantation, where wheat is intercropped with poplar, the decomposition of leaves and fine roots of poplar have significant advantage to growth of wheat crop. The leaf fall of poplar starts during December and is completed by end of January, and a considerable amount of litter (3340 kg/ha) is produced during this short period (Dhakla, S. and Toky, O.P., unpublished), which contains 41 kg N, 8 kg P and 73 kg K per ha. Poplar leaves showed 100 % release of nutrients after 5 months as shown by the present study, and therefore a sizeable quantity of nutrients released by poplar leaves during 5 months was made available to the wheat crop. Thus, release of nutrients from poplar leaves, is synchronizing with the peak demand of the wheat crop. Exceptionally, K release did not show synchrony with growth of wheat. Importance of K is relatively much lesser as compared to N and P that are present in low quantity in the soil; these two elements are supplemented regularly through inorganic fertilizers to meet out

the high demands of crops and trees. Potassium, on the other hand, is abundantly present in the soil.

In 3-year old plantation, significant amount of crop residue (6200 kg/ha) is also available to the soil in April with the harvest of wheat crop, which contains 24 kg N, 10 kg P and 66 kg K (Dhakla, S. and Toky, O.P., unpublished). The rate of decomposition has been found slow in wheat straw, which is beneficial process to the system. During summer (April to September) trees of poplar make the maximum growth which is benefited with the slow release of nutrients from wheat residues and it was estimated that 19 kg N 7 kg P and 63 kg K per ha was released to the soil during this period, which was available only to the poplar trees as no intercrop was grown in 3-year plantation during summer. This is another excellent example of synchronization of release of nutrient from agricultural crop (wheat) and uptake of nutrient by trees (poplar) simultaneously. Mafongoya *et al.* (1997) have also suggested that it would be more advantageous to have additions of slowly decomposing litter, which minimizes leaching losses.

In 1-year old plantation, 7120 kg of leaf litter per ha is produced by poplar and sugarcane (Dhakla, S. and Toky, O.P., unpublished) during a short period of December - January containing 69 kg N, 9 kg P and 75 kg K. This sizable amount of litter rich with N and K benefitted the poplar trees, which resume their growth in March after a dormant period during winter. This is another unique example of nutrient sharing between crop and trees.



In 7-year old plantation, having turmeric with poplar, synchronization between nutrients demand by turmeric crop and nutrients release by poplar trees could not be observed due to the fact that turmeric makes maximum vegetative growth from June onwards whereas the maximum nutrients from the decomposing poplar leaves are released in January and February. Hence, farmer supplements N and P through inorganic fertilizers to attain optimum yield of turmeric. Dhakla, S. and Toky, O.P. (Unpublished) estimated that 9230 kg/ ha of leaf litter of both poplar and turmeric is available in December to January containing 87 kg N, 19 kg P and 179 kg K per ha. De Costa and Attapattu (2000) suggested that in perennial crops in which vegetative phase continue up to more than 1 year, a close synchrony during specific period need not be sought.

External inputs of N and P through inorganic fertilizers is significantly reduced in older plantations of poplar as compared to younger ones, since older trees contribute a significant amount of nutrients through litterfall. Leaf fall of poplar increased from 1720 kg/ha in 1-year, 3340 kg/ha in 3- year and to 5430 kg/ha in 7-year old plantation and hence, making the nutrients available to crops grown underneath, showing unique example of integrated nutrient management in agroforestry systems. Such agroforestry are efficient from ecological and economical viewpoints, and hence are being adopted by the farmers on large scale.

SUMMARY AND CONCLUSION

1. The present work deals with the decomposition and nutrient release pattern of leaves and fine roots in different age (1-, 3-, and 7-year) plantations of poplar (*Populus deltoides*, clone G₄₈) in Yamunanagar district of Haryana state in north-western India. The trees were planted at a spacing of 5m x 5m and sugarcane, wheat and turmeric were intercropped in 1-, 3- and 7-year old plantations, respectively.
2. From each plantation, leaf litter and fine root samples of both tree and intercrop were collected from December to April depending upon their peak period of production of litter.
3. To estimate the rate of decomposition litterbag technique was used. Twenty gram of each material type was filled in nylon net bags having size of 20 cm x 20 cm and placed in the respective fields in the months coinciding with production of leaf litter and fine roots. Three litterbags of each material type were picked up at monthly interval and brought to the laboratory for weight loss and nutrient analysis.
4. Poplar leaves were completely decomposed within 5 months releasing nutrients, which were made available to the crops growing underneath

- trees. Fast decomposition rate was due to favorable microclimatic conditions in the soils of agroforestry systems.
5. In 3-year old poplar plantations, nutrients releasing from the decomposing poplar leaves synchronized with the peak demand by wheat crop.
 6. In 7-year old plantations, turmeric was a perennial crop having comparatively longer vegetative period. The nutrients releasing from the decomposing litter were utilized during this longer vegetative period and close synchrony during specific period is not sought.
 7. Decomposition rate depends upon concentration of N and P in the litter and it was observed that as the concentration of N and P increases in the litter the decomposition rate also increases.
 8. Nutrient release resembled the mass loss patterns of the decomposing materials except for K, which was leached independently from mass loss.
 9. Immobilization of N and P helped in the slow release of nutrients, which was helpful to the system as nutrients losses through leaching were minimum.
 10. The release of the different nutrients was in the order : $K > N > P$
 11. The present study is important for management of nutrients for management of nutrients in agroforestry systems having association of crops such as wheat, turmeric and sugarcane with poplar trees.

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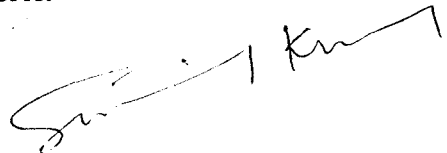
Abstract

- a) Title of Thesis : Leaf litter and fine root decomposition in poplar based agroforestry systems
- b) Full name of degree holder : Sushil Kumar
- c) Title of degree : Master of Science in Agroforestry
- d) Name and address of Major Advisor : Dr. O.P. Toky
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- e) Degree of awarding university : CCSHAU, HISAR
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The decomposition and nutrient release pattern of leaves and fine roots (< 2mm diameter) were examined in poplar agroforestry systems at village Amadulpur in Yamunanagar district of north-western India. Sugarcane, wheat and turmeric were intercropped with 1-, 3- and 7-year old plantations. The study was carried out through litterbag technique. Poplar showed 100% decomposition of leaf litter in 5 months, whereas the wheat has the slowest rate. However, in case of roots wheat showed fastest rate of decomposition. Nutrient release resembled the mass loss patterns of the decomposing materials except for K, which was leached independently from mass loss. The release of the different nutrients was in the order : $K > N > P$. No substantial N immobilization was observed in poplar leaf and roots material despite their low N contents. The different decomposition rates of leaves and roots among species as determined from residual mass were related to initial N, P and K concentration. Wheat is found to be most benefited as compared to other two crops because of synchronized release of nutrient from decomposing poplar leaves. The study has an important consideration in nutrient management in agroforestry systems particularly for crops like sugarcane, wheat and turmeric.



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