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Research Article

Litterfall and carbon, nutrient returns in stands of *Ceiba pentandra* (L.) Gaertn. sub-humid tropics of Eastern India

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ABSTRACT : The study was conducted in a nine-year old *Ceiba pentandra* stands planted in a three tree spacing 4 x 4 m, 4 x 6 m and 4 x 8 m and pruning regimes. A litterfall sample was collected from the field of *C. pentandra* for the experimental research for 12 months. Data collected was analyzed in laboratory and the result was subjected to descriptive and inferential statistical analyses using the MSTATC 1.41 Version. The results shows that the litterfall occurred throughout the year showing significant differences between tree spacing, pruning regimes and months. Total litterfall includes tree components (leaf litter + wood litter + flower litter + pod litter) ranged from 0.451 to 1.153 mg ha^{-1} in through out of the year. Total litterfall followed unimodal pattern with highest peak in April and lowest in August. In different tree spacings, for total monthly litterfall, leaf litter contributed from 59 to 60 per cent, wood litter from 30 to 31.6 per cent, flower litter from 2.4 to 3.0 per cent and pod litter from 6.2 to 6.8 per cent. Litterfall was significantly higher in 4 x 4 m and lower in 4 x 8 m tree spacing. Pruning of trees had reduced by 7.8 per cent in total litter production. Annual litterfall production in 4 x 4 m tree spacing 9.09 Mg ha^{-1}yr and in 4 x 6 m and 4 x 8 m tree spacings was statistically at par. The order of annual litter production of tree components leaf litter> wood litter> flower litter> pod litter. The study showed that climatic variable and litterfall was strongly and positively correlated with temperature and negatively correlated with relative humidity. The *Ceiba pentandra* stands with high density, where the canopy closure produce highest amount litterfall in 4 x 4 m tree spacing, which return highest amount of C and nutrients to soil quantity of carbon and nutrients returned to soil via annual litterfall ranged from 345.49 to 385.16 kg C ha^{-1} yr^{-1}, 228.55 to 239.10 kg N ha^{-1} yr^{-1}, 21.79 to 23.74 kg P ha^{-1} yr^{-1} and 119.45 to 142.81 kg K ha^{-1} yr^{-1}. Choice cultivation of *C pentandra* is a one of multipurpose tree species for agro forestry planted with 4 x 4 m which produce highly litter to implications in returning carbon and N, P, K nutrients elements to the soil through litter which increase the fertility and productivity of soil as compare to the other tree species in India.

KEY WORDS : Litterfall, Pruning, Carbon, Nutrient returns, *Ceiba pentantra*

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INTRODUCTION

India is one among the important tropical countries, of late renewed its interest as part of global and national policies to rehabilitate the degraded lands, which are almost covered in 175 m ha of the country (Singh, 1994). Over exploitation, shifting cultivation, uncontrolled wind and water erosion, soil salinity, alkalinity and poor land management in the last few decades virtually transformed 100 m ha into wasteland Ravindranath and Hall (1994). This large tract of degraded land mass of India has vast potential and could become crucial in national and global efforts to enhance carbon sequestration. National agriculture policy (2000) also envisaged restoring degraded lands by tree farming or through agroforestry practices. Both agroforestry and tree plantations have strong potential for sequestering carbon as they could sequester 0.8 to 2.2 pg of carbon per year globally over a period of 50 years

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time frame Dixon *et al.* (1994). Carbon management has tremendous potential to increase productivity of degraded lands since it improves fertility and nutrient use efficiency. Carbon can contribute positively to soil quality by improving porosity, available water holding capacity and cation exchange capacity (CEC), improve pH, help in increasing yields and economical returns per unit of land Delgado and Follett (2002). Land management practices *viz.*, agroforestry and monoculture tree plantations have different impacts on development of soil organic matter and nutrient pools. Plants get their nutrients from the soil in which they grow. As the plants develop, they shed their leaves and branches as litter which decays to enhance the nutrients of the soil that are again used up by plants a process known as nutrient cycling Wood *et al.* (2006). Nutrients returns to the soil through litterfall help to maintain soil fertility by increasing the organic matter in the soil (Perez *et al.*, 2003; Hermansah *et al.*, 2002). Thus, there is a link between soil and plants cover regarding cycling of nutrients elements. The most important concern of litterfall studies is the quantification of this process as a principal way in nutrient cycling, and the analysis of the efficiency of this cycle (Proctor, 1983). Litter plays a major role in the transfer of energy and nutrient. The data on litterfall is useful for predicting the productivity of an ecosystem. Litter production depends on tree species, environmental conditions and management practices followed in plantations. Different species have distinct growth and phonological stages and thus, show variation in their litterfall pattern, which is correlated to weather conditions. The amount of litterfall could be modified through pruning management quantity as wall as quality of litter could be affected by land management practices. If litter production, decomposition and nutrient release synchronize with the nutrient demands of trees and crop will improve the productivity Cuevas and Medina (1986). Apart from this broad observation, there have been efforts to find the relationship between climatic variables and litter production at regional levels Vogt *et al.* (1986). Williams and Tolome (1996) reported that some tropical tree species showed a positive correlation of litterfall with maximum temperature. Williams *et al.* (1997) observed that leaf fall coincide with the attainment of the seasonal minimal level in leaf water potential. There is a need for a narrower, location-specific investigation of the interaction of climatic variables and litter production if the processes involved are to be well understood. The returns of nutrient elements have been observed to vary with floristic composition of plant cover Pypker *et al.* (2005)

Litter production in agroforestry might be enhanced through increased production of leaf and twigs in trees due to supply of frequent irrigation and fertilizer to associated intercrops. The litter quality depends upon the nutrients status, amount of soluble and non-soluble organic compounds in litter. Therefore, both litter production and litter quality are carefully considered before introducing any species in agroforestry system. Besides there are potential extra benefits from trees planted in tangible (Fuelwood, food, fodder, floss and and non-tangible (Nutrient cycling, hydrological cycle, carbon sequestration) benefits in humid tropics. Choice of tree species plays a key role and influences both trajectories of growth rate, biomass production, carbon sequestration and nutrient cycling in agroforestry systems. *Ceiba pentandra* (L), commonly known as silk cotton tree is a fast growing multipurpose tree and proved as one among the promising species for agroforestry practices Rajendran *et al.* (2002). Because of the straight bole, acute branching and deciduous nature and potential to produce high quality floss and seeds at early age made the species as an ideal choice of farmers to practice in agroforestry. Gawali (2003) evaluated that the total biomass production in nine year old *Ceiba pentandra* stands contributed highest in stem 45.3 to 47.7 per cent fallowed by root 22.8 to 22.9 per cent, branch 16.75 to 17.84 per cent, pod 6.36 to 9.11 per cent and leaf 5.82 to 5.92 per cent tree component.

This study evaluate 1) litterfall production in nine-year old *Ceiba pentandra* stands planted in a three tree spacing 4 x 4 m, 4 x 6 m and 4 x 8 m and pruning treatment 2) Quantify anuual litter production with respect to different tree spacing, pruning regimes and climatic variable 3) Find out correlation between climatic variable and monthly variable 4) Quantify the carbon and NPK nutrient elements returns to soil in stands C *pentandra* (L.) Gaertn. multipurpose tree species.

EXPERIMENTAL METHODS

Study site:

The study site agriculture field of Department of forestry, IGAU, Raipur, Chattisgarh state is situated in eastern India. It lies at 21.76^0 N latitude and 81.36^0 E longitude having an altitude of 295 m above mean sea level. The climate is sub humid tropical with an average rainfall of 1250 mm. Most of the rainfall (90%) is received during monsoon season from second week of June to third week of September. Average number of rainy days from 60 to 79. Mean monthly maximum temperature in study site ranges from 30.9^0 C in December to 43.3^0 C in May, while the minimum temperature varies from 11.9^0 C in December to 28.3^0 C in May. Maximum temperature occasionally goes beyond 45^0 C for few days in May and minimum even falls below 10^0 C in December. Relative humidity is generally highest in July and August, while it is lowest during April and May. The mean relative humidity varies from 82 per cent in August to 32 per cent in May. The weather conditions prevailing during the study. The measurement of different climatic variables were carried out in the open at the central weather station of Agro-meteorology Department, I.G.A.U. Raipur, India.

Experimental design and samples collection:

The litterfall study was conducted in a split-split-plot design with four replicates (Gomez and Gomez, 1984). Litter was collected at monthly intervals from September 2002 to August 2003 by randomly placing litter traps of size 0.5 x 0.5 m (four in each experimental plot) beneath tree in different treatments. Twenty-four (3 tree spacing x 2 pruning x 4 replicates=24) traps were placed for collection of litter production. The litter collected from the traps in various treatments were sorted and separated into different components *viz.*, leaf, wood, flower and pods. These samples placed in a paper bag and dried in an electric oven at 70^0 C temperature until they reach constant weight. The different components of litter were summed to obtain total litterfall. The litterfall recorded in traps was extrapolated to hectare basis and later converted in to Mg ha^{-1}. The oven dry litter collected for twelve months was summed to derive annual litter production.

Laboratory analyses of samples:

The different components (12 months) of litter were bulked and composite sample was prepared. Four sub samples of litter were randomly drawn from composite sample and oven dried at 70^0 C temperature for 72 hrs. The oven dried samples were ground in a Wiley mill and pass through 2 mm sieve before chemical analysis. The litter was analysed for total carbon on solid sample module using automatic carbon analyzer (SSM-5000A). Total nitrogen was analysed in concentrated H_2SO_4 using a catalyst mixture (Potassium sulphate and Copper Sulphate in ratio 9:1) with KEL PLUS digestion unit. The total nitrogen was estimated following micro-kjeldhal method. Phosphorus and Potassium were estimated after digesting sample in diacid mixture (HNO_3 and $HClO_4$ in 9:4 ratio). Phosphorus was determined by Vanado-molybdo phosphoric yellow colour procedure and potassium by Flame Photometer method (Jackson, 1967). Carbon and nutrient status kg ha^{-1} were obtained from the product of litter biomass and average C and nutrient concentration.

Stastical analyses of data:

Data collected was analyzed in laboratory and the result was subjected to descriptive and inferential statistical analyses using the MSTATC 1.41 Version.

EXPERIMENTAL RESULTS AND ANALYSIS

The results obtained from the present study have been discussed in detail under following heads :

Litterfall pattern in *Cieba*:

Tree spacing, pruning and monthly litter collection had significantly influenced leaf litter production in different tree spacings, monthly leaf litter production ranged from 0.436 to 0.449 Mg ha^{-1}. Leaf litter was significantly higher in 4 x 4 m and lower in 4 x 8 m tree spacing. Significantly higher leaf litter was produced in unpruned compared to pruned trees Table 1. Wide variation was observed in leaf litter production in different months. Peak leaf litter was observed in January and lowest in August. Litterfall showed distinct monthly variations. Through out the year leaf litter ranged from 0.267 Mg ha^{-1} to 0.614 Mg ha^{-1}. The cumulative leaf fall indicated unimodal pattern with a hump in January Fig. 1.

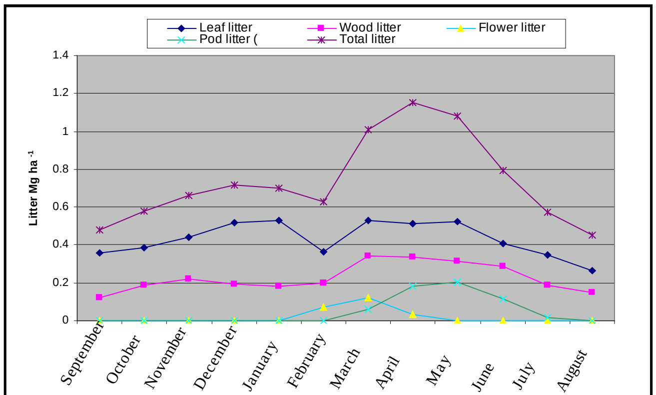

Fig. 1 : Montly litterfall pattern in *Ceiba pentandra*

It followed unimodal pattern with peak in April. Jamaludheen and Kumar (1999) also observed unimodal distribution of litterfall in *Acacia*, *Ailanthus*, *Pterocarpus* and *Casuarina* plantations. Higher litter fall values were observed in dry compared to wet season. The peak of litterfall in the tropics coincides with the dry season (John, 1973). Wood litter varied significantly due to differences in tree spacing, pruning regimes and months. A maximum wood litter amounting 0.241 Mg ha^{-1} $month^{-1}$ was produced in 4 x 4 m followed by 0.221 Mg ha^{-1} $month^{-1}$ in 4 x 6 m and 0.217 Mg ha^{-1} $month^{-1}$ in 4 x 8 m tree spacing. The maximum wood litter of 0.227 Mg ha^{-1} $month^{-1}$ was produced under unpruned compared to pruned treatment 0.225 Mg ha^{-1}. The maximum wood litter was produced in March and lowest in September. In ceiba wood litter ranged from the 0.124 to 0.335 Mg ha^{-1}. Interactions between tree spacing x prunings, pruning x month, spacing x month and spacing x pruning x month were statistically significant for wood litter Table 1. This may be related to the phenology of the *Ceiba* tree associated with the edaphic factors, where due to high water stress conditions in summer (High temperature and low humidity), trees will rapidly defoliate. Leaf fall of the most dominant speices was asynchronous. Besides, the higher pod and twig litter added to other litter components, thus, cumulatively more litterfall was observed during this period. The rapid loss of foliage is mechanism of combating drought during summer by the species. This phenomenon was also observed by Nwoboshi (1981) where rapid shedding of litter by teak in south western Nigeria in dry season was occurred to withstand drought. Litterfall is not only affected by water scaracity. More likely it is the result of the interaction of different factors: resource availability, heavy winds, soil characteristics, mineral dediciency and the rain mechanical effects (John, 1973).

Litter from floral component also significantly affected by both tree spacing and pruning treatments. Monthly variation was also significant for this component. It ranged from 0.023 Mg ha^{-1} to 0.018 Mg ha^{-1} in different tree spacings. It was significantly higher in 4 x 4 m tree spacing, which gradually reduced with an increase in tree spacing. The maximum litter from floral components was found in unpruned than pruned stands. It produced from January to April. It was highest in March 0.122 Mg ha^{-1}. Interactions among spacing x month, pruning x month and spacing x pruning x month were found significant, whereas spacing x pruning did not show any effect on flower litter Table 1. Tree spacing, pruning and month showed significant effect on pod litter production. It ranged from 0.052 to 0.045 Mg ha^{-1} in different tree spacings, which was highest in 4 x 4 m and lowest in 4 x 8 m tree spacing. The unpruned stands produced significantly higher pod litter compared to pruned trees. Pod litter was produced from March to July. The highest amount of pod litter was produced in May. Interactions between spacing x month, pruning x months, spacing x pruning and spacing x pruning x month were statistically significant for this parameter Table 1. Total litterfall (leaf litter + wood litter + flower litter + pod litter) significantly ranged between 0.721 to 0.761 Mg ha^{-1} month^{-1}. It was highest in 4 x 4 m, while lowest in 4 x 8 m 0.721 Mg ha^{-1} tree spacing. The total litter was statistically at par in 4 x 6 m and 4 x 8 m tree spacings. Significantly highest litter of 0.766 Mg ha^{-1} was produced in unpruned than pruned condition. Total litterfall ranged from 0.451 to 1.153 Mg ha^{-1} in different months. Total litterfall followed unimodal pattern with highest peak in April and lowest trough in August. Interactions between tree spacing x pruning, pruning x month, tree spacing x month and tree spacing x month x pruning were found significant for total litterfall. In different tree spacings, for total monthly litterfall, leaf litter contributed from 59 to 60 per cent, wood litter from 30 to 31.6 per cent, flower litter from 2.4 to 3.0 per cent and pod litter from 6.2 to 6.8 per cent Table 1.

Correlation between climatic variable and monthly litterfall:

The present studies are shown that the litterfall is strongly correlated to the climatic variables. It was established that the climatic variable which influenced litterfall were maximum temperature and minimum humidity. This study showed that the change in litterfall on seasonal basis was not gradual but an erratic process with the dominating climatic variables asserting their role more in the dry season than in the rainy season. It was not the shift from one season to the other that made the difference in quantity of litter produced, but the interactions of relevant climatic variables within seasons, which also had differing effects depending on the phenological characteristics of species. The study also showed that component and total litter was strongly and positively correlated with temperature and negatively correlated with relative humidity Table 2. These findings are in agreement with earlier reports of Lugo *et al.* (1978); Salako and Tian (2002) and Agbim (1987).

Lugo *et al.* (1978) reported positive correlation between litterfall and temperature and rainfall. Agbim (1987) found a significant negative correlation between *Chromolaena odorata* litterfall and atmospheric relative humidity in a study

Table 1 : Monthly litterfall pattern in different components of *Ceiba pentandra*, Mg ha^{-1}

Treatments	Leaf litter	Wood litter	Flower litter	Pod litter	Total litter
Tree spacing					
4 x 4 m	0.449	0.241	0.023	0.052	0.761
4 x 6 m	0.438	0.221	0.017	0.048	0.725
4 x 8 m	0.436	0.217	0.018	0.045	0.721
C.D. at 5%	0.4145	0.013	0.0067	0.011	0.2416
Pruning					
Unpruned	0.456	0.227	0.021	0.056	0.766
Pruned	0.425	0.225	0.017	0.041	0.705
C.D. at 5%	0.0147	0.0128	0.0064	0.0109	0.0359
S x P	0.0202	0.0182	NS	0.015	0.0504
P x M	0.0813	0.0514	0.0110	0.0302	0.0853
S x M	0.0516	0.0642	NS	0.0713	0.0943
S x Px M	0.0417	0.0723	NS	0.0412	0.0746

Note: S - Tree spacing, P - Pruning regimes and M- Month NS= Non- significant, C.D. - Significant at 5% level conducted in the dry season in Southern-Eastern Nigeria. Regression analysis showed that only 58.88 per cent variation in litterfall was explained temperature, whereas relative humidity explained 74.48 per cent variation in total litterfall. Earlier studies also showed that only a fraction of total litterfall will be well explained during particular season. Vogt *et al.* (1986) reported that climatic variables (latitude, temperature and precipitation) could explain 50 per cent of the variation in above ground litterfall for broadleaved forest of the world, but they were poorly related to data analyzed for needle leaved forests. Vitousek (1984) also reported that the interaction of temperature and precipitation was significant for litter production in the tropics.

Annual litter production:

Perusal of data on results indicates that tree spacing had significantly influenced component wise and total annual litterfall Table 3. In different tree spacings, total annual litter varied from 8.65 to 9.09 Mg ha^{-1} yr under different tree spacing.

The production of litter depends primarily on the site productivity but environment and other factor such as temperature, water and nutrient availalblity limit production Jorgensen *et al.* (1975). Litterfall data for the *Ceiba* species in similar age groups in their natural forest environment and plantation are not available for comparison with present study. Therefore, a comparison is made with available litterfall data nearby multipurpose tree species in India Table 4. Litterfall

Table 2: Correlation between climatic variable and monthly litterfall

	Max. temp. (^{0}C)	Rainfall (mm)	RH % (Max.)	Wind velocity (kms/hr)	Sunhour	Litter
Max temp. (^{0}C)	1					
Rainfall (mm)	-0.1479	1				
RH % (Max.)	-0.9384 NS	0.2772	1			
Wind velocity (kms/hr)	0.5186	0.6677	-0.3996 NS	1		
Sunhour	0.0567 NS	-0.8285	-0.1538 NS	0.6636	1	
Litter	0.7520 *	-0.527 NS	-0.8332 NS	0.02982 NS	0.5144 *	1

* indicate significance of value at P=0.05, NS=Non-significant

Table 3: Annual litter production, Mg ha^{-1}

Treatment	Leaf litter	Wood litter	Flower litter	Pod litter	Total litter
Spacing					
4 x 4 m	5.42	2.98	0.76	0.62	9.09
4 x 6 m	5.25	2.65	0.18	0.57	8.69
4 x 8 m	5.23	2.59	0.25	0.54	8.65
C.D. at 5%	NS	NS	0.04	0.003	NS
Pruning					
Unpruned	5.47	2.72	0.20	0.66	9.18
Pruned	5.10	2.61	0.19	0.46	8.46
C.D. at 5%	NS	NS	NS	NS	NS

Note : C.D. at 5 % level, NS = Non- significant

Table 4: Comparative account of total annual litterfall of certain multipurpose tree species in plantation and agroforestry system in India, Mg ha^{-1}

System	Tree species	Age (yr)	Litterfall	Source
Woodlots	*Acacia auriculiformis*	9	12.69	Jamaludheen and Kumar (1999)
Plantation	*Albizia lebbeck*	7	7.99	Varshney and Garg (1996)
Plantation	*Azadirachata indica*	8	6.06	Pandey *et al.* (2001)
Plantation	*Dalbergia sissoo*		2.72-5.14	Lodhiyal *et al.* (1995)
Plantation	*Populus deltiodes*	23	1.43	Mohisin *et al.* (1996)
Agrisilviculture	*Populus deltiodes*	23	7.46	
Agrisilviculture	*Populus deltiodes*	5	1.42-6.7	Mohsim and Ram 2002
Plantation	*Ceiba pentandra*	9	8.65-9.09	Present study

production is within the range and comparable with litterfall reported by Rajgopal *et al.* (2001). Jamaludheen and Kumar (1999) reported that annual litter production in 8-9 year old stands was highest (12.69 Mg ha^{-1} yr^{-1}) *Acacia* followed by *Paraserinthes* (9.17 Mg ha^{-1} yr^{-1}) and lowest in *Peterocarpus* (3.42 Mg ha^{-1} yr^{-1}). The present study also showed both tree density and pruning showed significant effect on annual litter production. It was higher under 4 x 4 m tree spacing and gradually decreased with increase tree spacing. Number of trees ha^{-1} (625 trees) was almost two times higher in 4 x 4 m spacing compared to 4 x 8 m spacing.

The greater number of trees and prolonged shade conditions contributed for higher litter production in 4 x 4 m spacing. Pruning of trees had reduced by 7.8 per cent in total litter production. It is proven fact that pruned trees contains lower foliage biomass and thus they contribute lower litterfall. George and Kumar (1998) and Jamaludheen and Kumar (1999) showed lower production annual litter under pruned stands of *Acacia auriculiformis*, *Paraserianthes falcataria*, *Pterocarpus marsupium*, *Artocarpus herterophyllus* in silivipastoral and wood lots system. Age, stand density and/ or stage of stand development are also major determinants of litterfall. Litterfall increase with stand age and/or unite canopy closer George and Kumar (1998). Similar trend in litter contribution by different component in other species was observed by Rajgopal *et al.* (2001), Jamaludheen and Kumar (1999). Tree spacing had significantly influenced annual litterfall of pods, while leaf litter, wood litter and flower did not show any significant differences Table 3. In different tree spacings, annual leaf litter production ranged from 5.23 to 5.42 Mg ha^{-1} yr^{-1}. It was significantly higher in 4 x 4 m and lower in 4 x 8 m tree spacing. Annual litterfall was statistically at par in 4 x 6 m and 4 x 8 m tree spacings. Wood litter ranged from 2.60 to 2.98 Mg ha^{-1} yr^{-1}, flower litter from 0.19 to 0.76 Mg ha^{-1} yr^{-1} and pod litter from 0.54 to 0.62 Mg ha^{-1} yr^{-1} under different tree spacings Table 3. Pruning of trees did not exhibit any significant influence on annual litter production in any of the components. However, unpruned stands produced numerically higher amount annual litter by all tree components. In pruning treatments, annual leaf litterfall ranged from 5.10 to 5.47 Mg ha^{-1} yr^{-1}, wood litter from 2.72 to 2.61 Mg ha^{-1} yr^{-1}, flower litter from 0.19 to 0.20 Mg ha^{-1} yr^{-1} and pod litter from 0.46 to 0.66 Mg ha^{-1} yr^{-1} Table 3. Total annual litterfall was neither significantly influenced by tree spacings nor by pruning. Numerically higher annual total litter production was observed under trees planted in narrow tree spacing (4 x 4 m) and also in unpruned stands.

Concentration of carbon and nutrients in litter mass:

The study showed that nutrient concentrations varied as 1.98% N, 0.23% P, 1.18% K and 37.08% C. Concentration of nutrients in litter in *Ceiba* is comparable to litter nutrient concentrations in other species (Rajagopal *et al.*, 2001; Jamaludheen and Kumar 1999, Salako and Tian, 2002).

Carbon and nutrient returned to soil through litterfall:

Carbon addition in soil through annual litterfall in *C. pentandra* stands ranged from 345.4 to 385.16 kg ha^{-1} yr^{-1}. Annual C addition to soil through litter was highest in 4 x 4 m and lowest in 4 x 8 m tree spacings Table 5. The higher C return

Table 5 : Annual carbon and nutrient addition to soil through litterfall , kg $ha^{-1}yr^{-1}$

Treatment	Carbon	Nitrogen	Phosphorus	Potassium
Spacing				
4 x 4 m	385.1	239.1	23.7	142.81
4 x 6 m	372.0	233.9	22.3	128.8
4 x 8 m	345.4	228.5	21.7	119.45
C.D. at 5%	0.032	NS	NS	0.145
Pruning				
P_0	367.4	242.0	23.7	134.25
P_1	359.0	282.0	20.8	127.29
C.D. at 5%	0.04	NS	NS	0.04

Note : CD at 5 % level , NS = Non- significant

Table 6 : Comparative account of nutrient via litterfall in plantation and agroforestry system in India

System	Tree species	Age (yr)	Nutrient (kg ha^{-1} yr^{-1}) N	P	K	Source
Woodlots	*Acacia auriculiformis*	9	203.0	15.7	12.6	Jamaludheen and kumar (1997)
Plantation	*Populus deltoides*	4	91-148	8-15	70-99	Lodhiyal and Lodhiyal (1997)
Plantation	*Azadirchata indica*	8	98.02	2.24	32.02	Pandey *et al.* (2001)
Plantation	*Dalbergia sisoo*	7	74.8-108.4	5.6-8.4	8.7-46.9	Lodhiyal *et al.* (2002)
Plantation	*Ceiba pentandra*	9	228.5-239.1	21.7	119.4-142.8	Present study

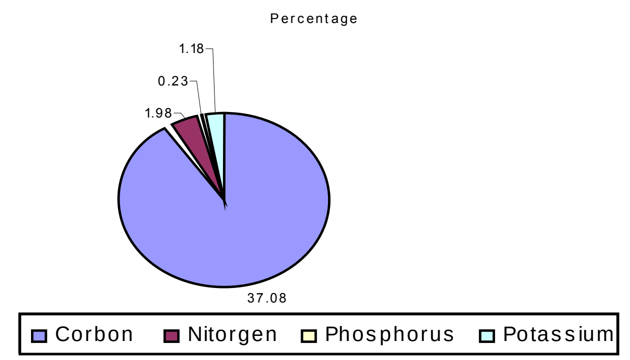

Fig. 2 : Corbon and nutrient returned to soil through litterfall

to soil in 4 x 4 m was due to comparatively higher amount of litterfall in these stands. Similarly, the unpruned stands had produced greater amount of litter compared to pruned trees resulted in higher C content in former and lower C in later stands. George and Kumar (1998) also emphasised the higher age and high density, where the canopy closure became full will produce highest amount litterfall, which return highest amount of C and nutrients to soil. In Table 5 quantity of nutrients returned to soil via annual litterfall ranged from 228.55 to 239.10 kg N ha^{-1} yr^{-1}, 21.79 to 23.74 kg P ha^{-1} yr^{-1} and 119.45 to 142.81 kg K ha^{-1} yr^{-1}. Significantly higher amount of all these nutrients returned in soils under 4 x 4 m tree spacing compared to other tree spacings. A similar trend in nutrient return from poplar plantations was observed by Lodhiyal *et al*. (1995) and multipurpose trees by George and Kumar (1998).

Jamaludheen and Kumar (1998) reported that highest amount of nutrients 203 kg N ha^{-1} and 15.7 kg K ha^{-1} *Acacia auriculiformis*, while *Artocarpus hirsuta* returned the lowest amount of nutrients (38 kg N ha^{-1} yr^{-1}, 0.8 kg P ha^{-1} yr^{-1} and 3. 4 kg K ha^{-1} yr^{-1}). The comparative accounts of nutrient via litterfall in plantations and agroforestry system of multipurpose tree in India is shown in Table 6. As compare to the tree species *Ceiba* shows the higher N, P and K nutrient release to soil through litter fall.

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