NUTRIENT RETURN TO THE SOIL THROUGH LITTERFALL UNDER CERTAIN TREE PLANTATIONS ON SODIC WASTELANDS IN NORTHERN INDIA

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RANA, B. S., SAXENA, A. K., RAO, O. P. & SINGH, B. P. 2007. Nutrient return to the soil through litterfall under certain tree plantations on sodic wastelands in northern India. We studied the patterns of litterfall and nutrient return to the soil under seven-year-old plantations of *Casuarina equisetifolia*, *Leucaena leucocephala*, *Eucalyptus* hybrid and *Dalbergia sissoo* established on sodic wastelands in northern India and compared them among themselves and with other plantations raised on normal soil. In the present plantations, the leaf litter ranged from 64 (*D. sissoo*) to 91% (*C. equisetifolia*) of the total aboveground tree litter production. Winter season reflected maximum leaf and total aboveground litterfall. The annual return of major nutrients (NPK) through litterfall amounted to 1.86–4.82 g m^{-2} $year^{-1}$ N (*D. sissoo* and *C. equisetifolia* respectively), 0.39–0.97 g m^{-2} $year^{-1}$ P (*D. sissoo* and *C. equisetifolia* respectively), and 1.48–1.80 g m^{-2} $year^{-1}$ K (*Eucalyptus* hybrid and *D. sissoo* respectively). Foliage accounted for most of the nutrients (67–92%) returned through litterfall. All the plantations studied were generally more efficient in N and K nutrient use than certain other plantations.

Keywords: Functioning of plantation, multipurpose trees, nutrient use efficiency, soil improvement

RANA, B. S., SAXENA, A. K., RAO, O. P. & SINGH, B. P. 2007. Pulangan nutrien ke tanih melalui jatuhan sarap di sesetengah ladang pokok yang terletak di tanah tandus sodik di utara India. Kami mengkaji corak jatuhan sarap dan pulangan nutrien ke tanih di ladang *Casuarina equisetifolia*, *Leucaena leucocephala*, hibrid *Eucalyptus* dan *Dalbergia sissoo* yang berusia tujuh tahun. Ladang-ladang ini terletak di atas tanah tandus sodik di utara India. Data yang didapati dibanding antara satu sama lain dan juga dengan ladang lain di tanah normal. Sarap daun di ladang-ladang yang dikaji berjulat antara 64% (*D. sissoo*) hingga 91% (*C. equisetifolia*) daripada jumlah hasil sarap pokok atas tanah. Musim sejuk menunjukkan nilai maksimum bagi jatuhan sarap daun dan jumlah jatuhan sarap atas tanah. Pulangan tahunan bagi nutrien utama (NPK) melalui jatuhan sarap adalah antara 1.86 g m^{-2} $tahun^{-1}$ hingga 4.82 g m^{-2} $tahun^{-1}$ N iaitu masing-masing bagi *D. sissoo* dan *C. equisetifolia*. Bagi P, jumlahnya adalah antara 0.39 g m^{-2} $tahun^{-1}$ (*D. sissoo*) hingga 0.97 g m^{-2} $tahun^{-1}$ (*C. equisetifolia*) sementara bagi K, 1.48 g m^{-2} $tahun^{-1}$ (hibrid *Eucalyptus*) hingga 1.80 g m^{-2} $tahun^{-1}$ (*D. sissoo*). Dedaun membentuk kebanyakan nutrien yang dipulangkan melalui jatuhan sarap iaitu sebanyak 67% hingga 92%. Umumnya, semua ladang yang dikaji lebih efisien dalam penggunaan N dan K berbanding beberapa ladang lain.

INTRODUCTION

Globally salt-affected soils are estimated to occupy 831.4 million ha in area; of this 434.3 million ha (52.2%) are sodic (Tyagi 2004). Asia and the Pacific and Australia have the largest area (248.6 million ha) under sodicity followed by Europe (72.7 million ha) and Latin America (50.9 million ha). India has about 2.4 million ha of sodic land. These soils are characterized by high pH, dominance of exchangeable sodium, poor physical conditions, low contents of organic C, N, Ca and Zn and presence of calcareousness. However, planting of trees on these soils may improve the soil conditions (Hairiah *et al.* 2006) and studies have proved that salt-tolerant tree species have been successfully established on sodic soils (Garg & Jain 1992). Most of the studies on sodic land plantations are limited to aspects of screening of species for salt tolerance, planting methods, manipulation of filling mixture and root zone, and post planting soil dynamics. However, in order to understand the functioning of plantations of sodic lands, detailed studies on nutrient cycling are of paramount importance.

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Litterfall governs the regulatory mechanism of nutrient cycling and organic matter content (Singh & Singh 1987). Substantial amounts of nutrients and organic matter produced by plants are returned to the soil through litterfall. Thus, litterfall exerts a great influence on physical, chemical and biological characteristics of soil (Pande *et al.* 2002) as well as further growth of trees.

The present study was carried out to quantify the total litter production, nutrient concentration and nutrient return through litterfall under seven-year-old plantations of *Casuarina equisetifolia*, *Leucaena leucocephala*, *Eucalyptus* hybrid and *Dalbergia sissoo* established on sodic wastelands. All four species are multipurpose tree species recommended for various afforestation programmes in the tropical region (Shah 1988). These species also have relatively better growth than other tree species on sodic land (Saxena *et al.* 1997). The main objective of this study was to examine how these sodic land plantations differ with each other and from plantations raised on normal soil at other locations in relation to dynamics of litterfall and nutrient return.

MATERIALS AND METHODS

The study sites are located at Kumarganj (26° 47' N, 82° 12' E, 113 m asl) in northern India. Geographically, the area is part of the Indo-Gangetic alluvial plains. The climate is monsoonal with an annual rainfall of 1012 mm. The year is broadly divisible into three seasons, namely, summer (March to June), rainy (July to October) and winter (November to February). Mean monthly maximum and minimum temperatures range between 23–39 °C and 7.5–25.8 °C respectively.

Three plantation sites for each of the four species were selected for the present study. These plantations were established in 1989 on sodic land with spacings of 2 × 2 m for *C. equisetifolia*, *L. leucocephala* and *Eucalyptus* hybrid and 3 × 3 m for *D. sissoo*.

Soil samples up to 30 cm deep were collected for analyzing soil characters. The pH and Ec were measured in a 1:2.5 soil-water solution; pH by using a pH meter with glass electrode and Ec by conductivity meter. Soil organic C was analyzed by rapid titration method (Walkley & Black 1934) and N, by micro-Kjeldahl method (Jackson 1958). NH_4-N was extracted using a 2 M KCl and analyzed by the phenate method (APHA 1995) while NO_3-N, by phenol disulphonic acid method using $CaSO_4$ as the extractant (Jackson 1958). The sum of NH_4-N and NO_3-N was considered as available N. Available P was determined in a dilute acid-fluoride extracted soil with the chlorostannous-reduced phosphomolybdic blue colour method (Jackson 1958). Available potassium (K) was analyzed with flame photometer after leaching soil with 1 N ammonium acetate solution (Jackson 1958).

Site characteristics of the plantation studied are shown in Table 1. The soil is sodic (usar) with silt clay loam texture characterized by high pH (8.8–8.9) indicating poor permeability. The soil is very poor in organic C and nutrient status. In fact, a hard kankar pan of 20–30 cm thickness is commonly found within 1-m depth of the soil. Presence of a $CaCO_3$ concretions is the dominant characteristic of older alluvium.

For the measurement of litterfall nine litter traps were randomly placed on the floor of each plantation site. Each trap was 50 × 50 cm and had 12-cm high wooden sides and a nylon net fitted at the bottom to facilitate drainage. Litter was collected for one year at monthly intervals from June till May. The litter from each trap was collected separately and fractionated into different litter components, namely, leaf, woody, and miscellaneous. The samples were oven dried at 80 °C to constant weight. Monthly samples for each litter component from the different sites of each species were pooled together to form

Table 1 Site characteristics of selected plantations

Plantation	Tree density (tree ha^{-1})	Total tree basal area (m^2 ha^{-1})	Soil pH	Ec (dS m^{-1})	Soil organic carbon (%)	Available nutrient (kg ha^{-1})		
						N	P	K
Casuarina equisetifolia	2500	38.56	8.82	1.535	0.26	301.89	16.45	325.80
Leucaena leucocephala	2500	27.15	8.76	1.228	0.28	333.10	18.68	336.54
Eucalyptus hybrid	2500	24.26	8.93	1.875	0.24	198.25	10.42	215.98
Dalbergia sissoo	1111	12.87	8.86	1.486	0.26	285.58	13.86	285.62

Soil samples for analysis were collected from 0–30 cm depth annual samples. The composite samples were ground separately and analyzed for different nutrients. Nitrogen was determined by micro-Kjeldahl procedure (Piper 1950). Phosphorus was analyzed by phosphomolybdic blue colour colorimeteric method (Jackson 1958). K, Ca, Mg, Cu, Zn, Mn and Fe were extracted by wet digestion of 0.5 g plant material in a strong acid mixture consisting of 10 ml concentrated HNO_3 + 3 ml concentrated H_2SO_4 + 1 ml $HClO_4$ by the same method outlined in the soil analysis by Jackson (1958). K was determined by flame photometer while Ca, Mg, Cu, Zn, Mn and Fe were determined by atomic absorption spectrophotometer.

Data for various litter components collected in different months from all the plantation sites were subjected to analysis of variance following Snedecor and Cochran (1969). Additionally, seasonal means were calculated from monthly collections to detect seasonal differences in litterfall. Finally annual totals were calculated as the sum of all collections. Standard error (± 1 SE) was also calculated for the concentration of each nutrient in all litter components of the different species (Snedecor & Cochran 1969). Nutrient concentration was multiplied by the weight of annual litterfall to compute the amounts of nutrients returned to the soil. The nutrient use efficiency (NUE) was calculated as the ratio of mass fall to nutrient in mass fall (including leaf, wood and miscellaneous litter) of a plantation (Vitousek 1982, Lugo 1992).

RESULTS

Litterfall

The monthly pattern of aboveground tree litterfall in plantations of different species is shown in Figure 1. The bulk of leaf fall (88% of the total leaf fall) in *D. sissoo* was restricted to the period December–February while rest of the species continued to shed leaves throughout

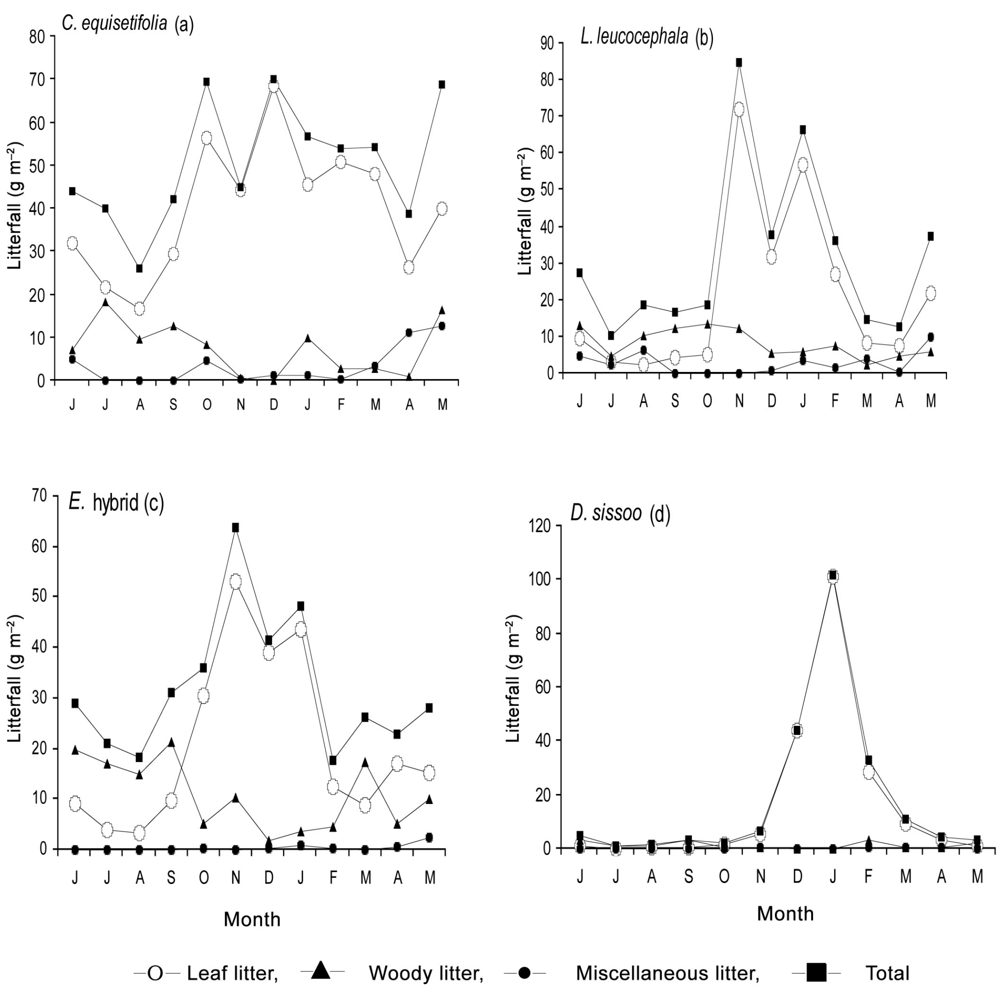

Figure 1 Monthly variation in litterfall in (a) *Casuarina equisetifolia*, (b) *Leucaena leucocephala*, (c) *Eucalyptus* hybrid and (d) *Dalbergia sissoo* plantations during the study period

the year at varying rates. However, the peak leaf fall in *L. leucocephala* (75%) occurred in November–February and in *Eucalyptus* hybrid (67%), in October–January. In *C. equisetifolia* there appeared to be two peaks, i.e. first in October (12%) and second in December (14%). Monthly wood litterfall in *D. sissoo* plantation ranged from 0 to 3.31 g m^{-2}, in *L. leucocephala* from 2.40 to 13.66 g m^{-2}, in *C. equisetifolia* from 0 to 18.28 g m^{-2} and in *Eucalyptus* hybrid plantation from 1.82 to 21.48 g m^{-2}. The wood fall patterns in all plantations were irregular though *D. sissoo* showed a peak in June, *C. equisetifolia* in July, *Eucalyptus* hybrid in September and *L. leucocephala* in October. The miscellaneous litterfall also did not show a regular pattern of distribution among different months. The high values were observed in May for *L. leucocephala* and *Eucalyptus* hybrid plantations as well as from April till May and February till April in *C. equisetifolia* and *D. sissoo* plantations respectively.

Total annual litterfall ranged from 217.1–609.0 g m^{-2} among all plantations (Table 2) in the order of *C. equisetifolia* > *Eucalyptus* hybrid > *L. leucocephala* > *D. sissoo*. Leaf litterfall values for *L. leucocephala* and *Eucalyptus* hybrid were almost similar. In the present plantations, most of the litterfall was leafy material accounting for 64–91% of the total litterfall. The highest annual wood litterfall was recorded for *Eucalyptus* hybrid

Table 2 Seasonal and annual estimates of different categories of litterfall in seven-year-old plantations of four species on sodic land

Litter components		Seasonal litter (g m^{-2} $season^{-1}$)			Annual litter (g m^{-2} $year^{-1}$)
		Summer	Rainy	Winter	
			Casuarina equisetifolia		
Leaf		146.4 (1.20)	124.1 (1.01)	209.5 (1.75)	480.0 (1.31)
Woody		27.2 (0.22)	48.9 (0.39)	13.1 (0.11)	89.2 (0.24)
Miscellaneous		32.1(0.26)	4.7 (0.04)	3.0 (0.02)	39.8 (0.11)
Total		205.7 (1.68)	177.7 (1.44)	225.6 (1.88)	609.0 (1.66)
CD (5%)					
Season (A)	7.650**				
Component (B)	5.580**				
A × B	5.942**				
			Leucaena leucocephala		
Leaf		47.3 (0.39)	14.7 (0.12)	188.0 (1.57)	250.0 (0.68)
Woody		26.2 (0.21)	41.3 (0.33)	31.5 (0.26)	99.0 (0.27)
Miscellaneous		19.3 (0.16)	8.6 (0.07)	5.9 (0.05)	33.8 (0.09)
Total		92.8 (0.76)	64.6 (0.52)	225.4 (1.88)	382.8 (1.04)
CD (5%)					
Season (A)	6.545**				
Component (B)	4.352**				
A × B	4.225**				
			Eucalyptus hybrid		
Leaf		50.7 (0.41)	47.6 (0.39)	148.9 (1.24)	247.2 (0.68)
Woody		52.5(0.43)	58.7 (0.48)	20.6 (0.17)	131.8 (0.36)
Miscellaneous		3.2 (0.03)	0.4 (0.003)	1.5 (0.01)	5.1 (0.01)
Total		106.4 (0.87)	106.7 (0.87)	171.0 (1.42)	384.1(1.05)
CD (5%)					
Season (A)	5.205**				
Component (B)	4.294**				
A × B	4.060**				
			Dalbergia sissoo		
Leaf		14.6(0.12)	2.6 (0.02)	179.8 (1.50)	197.0 (0.54)
Woody		6.7(0.05)	5.9 (0.05)	4.0 (0.03)	16.6(0.04)
Miscellaneous		1.7 (0.01)	0.2 (0.002)	1.6 (0.01)	3.5 (0.01)
Total		23.0 (0.18)	8.7 (0.07)	185.4 (1.54)	217.1 (0.59)
CD (5%)					
Season (A)	4.582**				
Component (B)	3.245**				
A × B	2.562**				

** significant at $p < 0.01$
Values in parentheses are daily estimates

followed by *L. leucocephala* and *C. equisetifolia* plantations. Wood litterfall accounted for 7.6–34.3% of total litterfall while miscellaneous litter, 1.3–8.8%. Winter season had maximum leaf and total litterfall.

Analysis of variance indicated that in all the plantations the differences in litterfall due to months and components were significant at $p < 0.01$. The interaction of months and components was also significant ($p < 0.01$), showing a differential temporal pattern of fall for leaf, wood, miscellaneous and total litter.

Nutrient return

In general nutrient concentration in litter was in the order N > Ca > K > Mg > P > Fe > Mn > Zn > Cu (Table 3). In all the four species, nutrient concentration was greater in leaf litter than the other litter components. The share of macronutrients (N, P, K and Ca) in leaf litter was: 0.87–0.90% N, 0.16–0.18% P, 0.23–0.87% K and 0.68–0.92% Ca. Woody litter showed 0.38–0.44% N, 0.15–0.19% P, 0.28–0.51% K and 0.72–0.93% Ca. Miscellaneous litter comprised 0.37–0.46% N, 0.15–0.19% P, 0.23–0.57% K and 0.77–0.88% Ca. Amongst micronutrients (Cu, Zn, Mn and Fe) in leaf litter, minimum level was in Cu and maximum in Fe. Thus, the range of distribution of different micronutrients in leaf litter was: 10.5–13.1 mg kg^{-1} Cu (*D. sissoo* vs. *C. equisetifolia*); 91.3–136.7 mg kg^{-1} Zn (*C. equisetifolia* vs. *Eucalyptus* hybrid), 254.7–312.0 mg kg^{-1} Mn (*D. sissoo* vs. *L. leucocephala*) and 368.7–471.7 mg kg^{-1} Fe (*Eucalyptus* hybrid vs. *D. sissoo*).

Weights of nutrients returned through annual litterfall are given in Table 4. *Casuarina equisetifolia* returned the highest amount of N (4.27 g m^{-2} $year^{-1}$) through leaf litter followed by *Eucalyptus* hybrid (2.20 g m^{-2} $year^{-1}$), *L. leucocephala* (2.17 g m^{-2} $year^{-1}$) and finally *D. sissoo* (1.77 g m^{-2} $year^{-1}$). *Casuarina equisetifolia* also showed the highest amount of P return (0.77 g m^{-2} $year^{-1}$) through leaf litter. However, annual return of P through leaf fall in all the species was far less than those of other major nutrients (N, K, Ca and Mg). The amount of K return through leaf fall was highest (1.71 g m^{-2} $year^{-1}$) in *D. sissoo*. Ca and Mg return through leaf fall were highest for *C. equisetifolia* and lowest for *D. sissoo*. Among the micronutrients in leaf litter Fe (0.20 g m^{-2} $year^{-1}$) and Cu (0.006 g m^{-2} $year^{-1}$) were highest in *C. equisetifolia*.

The fall of woody and miscellaneous litters had N annual returns of 0.07–0.5 g m^{-2} $year^{-1}$ and 0.015–0.18 g m^{-2} $year^{-1}$ respectively. Similar to leaf litterfall, the woody and miscellaneous litterfall

Table 3 Concentration (% ± 1 SE) of nutrients in different components of litterfall of four species

Nutrient	*Casuarina equisetifolia*			*Leucaena leucocephala*			*Eucalyptus* hybrid			*Dalbergia sissoo*		
	L	W	M	L	W	M	L	W	M	L	W	M
N	0.89 ± 0.14	0.42 ± 0.02	0.45 ± 0.01	0.87 ± 0.13	0.41 ± 0.05	0.46 ± 0.01	0.89 ± 0.10	0.38 ± 0.02	0.37 ± 0.03	0.90 ± 0.15	0.44 ± 0.50	0.43 ± 0.06
P	0.16 ± 0.02	0.15 ± 0.005	0.18 ± 0.03	0.16 ± 0.01	0.19 ± 0.02	0.19 ± 0.01	0.17 ± 0.02	0.19 ± 0.03	0.15 ± 0.02	0.18 ± 0.02	0.18 ± 0.02	0.18 ± 0.03
K	0.23 ± 0.003	0.28 ± 0.01	0.57 ± 0.09	0.38 ± 0.02	0.51 ± 0.08	0.44 ± 0.02	0.44 ± 0.05	0.28 ± 0.01	0.39 ± 0.01	0.87 ± 0.14	0.50 ± 0.04	0.23 ± 0.01
Ca	0.81 ± 0.12	0.72 ± 0.12	0.83 ± 0.05	0.73 ± 0.05	0.82 ± 0.06	0.85 ± 0.40	0.92 ± 0.08	0.93 ± 0.02	0.88 ± 0.14	0.68 ± 0.09	0.83 ± 0.08	0.77 ± 0.05
Mg	0.48 ± 0.08	0.50 ± 0.03	0.53 ± 0.02	0.54 ± 0.03	0.57 ± 0.02	0.49 ± 0.03	0.57± 0.10	0.55 ± 0.03	0.54 ± 0.08	0.56 ± 0.10	± 0.07	0.50 ± 0.01
Cu*	13.1 ± 2.14	10.7 ± 1.56	11.4 ± 1.23	10.9± 0.85	11.7 ± 0.80	12.8 ± 1.56	12.2 ± 2.50	12.8 ± 2.50	11.5 ± 0.86	10.5 ± 0.84	11.00 ± 1.68	11.2 ± 2.30
Zn*	91.30 ± 14.70	91.3 ± 12.76	85.3 ± 9.87	104 ± 7.52	106.0 ± 5.90	96.7 ± 6.58	136.7 ± 15.65	109.7 ± 15.35	124.0 ± 8.52	101.3 ± 7.82	89.3 ± 8.76	97.7 ± 6.75
Mn*	291.70 ± 25.80	281.7 ± 38.92	296.7 ± 29.65	312.0 ± 20.50	287.0 ± 30.55	290.3 ± 15.54	268.0 ± 20.65	281.0 ± 18.96	262.7 ± 12.64	254.7 ± 17.25	222.3 ± 16.45	200.3 ± 13.80
Fe*	418.30 ± 36.70	377.3 ± 41.26	439.3 ± 26.54	418.5 ± 52.68	403.0 ± 36.85	373.0 ± 29.86	368.7 ± 28.61	438.7 ± 23.56	427.0 ± 34.35	471.7 ± 23.90	373 ± 18.37	385.7 ± 15.75

L = leaf, W = woody, M = miscellaneous litter
* Values are in % (± 1 SE) except for those marked * which are in mg kg^{-1}

Table 4 Amount of nutrient return through litterfall in plantations of different tree species

Species and litter component	Nutrient (g m^{-2} year^{-1})								
	N	P	K	Ca	Mg	Cu	Zn	Mn	Fe
Casuarina equisetifolia									
Leaf	4.27	0.77	1.10	3.89	2.30	0.006	0.04	0.14	0.20
Woody	0.37	0.13	0.25	0.64	0.45	0.001	0.008	0.025	0.034
Miscellaneous	0.18	0.07	0.23	0.33	0.21	0.0005	0.003	0.01	0.02
Total	4.82	0.97	1.58	4.86	2.96	0.01	0.04	0.18	0.25
Leucaena leucocephala									
Leaf	2.17	0.40	0.95	1.83	1.35	0.003	0.026	0.078	0.105
Woody	0.41	0.19	0.51	0.81	0.56	0.001	0.01	0.03	0.040
Miscellaneous	0.16	0.06	0.15	0.29	0.17	0.0004	0.003	0.01	0.01
Total	2.74	0.65	1.56	2.93	2.08	0.004	0.04	0.12	0.16
Eucalyptus hybrid									
Leaf	2.20	0.42	1.09	2.27	1.41	0.003	0.03	0.07	0.09
Woody	0.50	0.25	0.37	1.22	0.72	0.002	0.014	0.04	0.06
Miscellaneous	0.02	0.01	0.02	0.04	0.03	0.0001	0.0006	0.001	0.002
Total	2.72	0.68	1.48	3.53	2.16	0.01	0.05	0.11	0.15
Dalbergia sissoo									
Leaf	1.77	0.35	1.71	1.34	1.10	0.002	0.02	0.05	0.09
Woody	0.07	0.03	0.08	0.14	0.09	0.0002	0.0015	0.004	0.006
Miscellaneous	0.015	0.006	0.008	0.03	0.02	0.0004	0.0003	0.001	0.001
Total	1.86	0.39	1.80	1.51	1.21	0.003	0.02	0.06	0.10

also reflected same patterns of nutrient return, although their amounts were considerably lower than those in leaf litter.

The nutrient use efficiency (NUE) for N in this study were 126, 140, 141 and 117 in *C. equisetifolia, L. leucocephala, Eucalyptus* hybrid and *D. sissoo* plantations respectively (Table 5). The NUE for P and K was higher in *C. equisetifolia* plantation than those of other plantations of the present study.

DISCUSSION

The leaf fall of the four tree species studied did not show seasonal equanimity. However, for all the four species, the rate of leaf fall on per day basis was greatest in winter followed by summer and rainy seasons. A similar pattern was also observed for total aboveground tree litterfall under all the plantations. *Dalbergia sissoo* is a deciduous species and the leaf fall was concentrated only for a few months, while the rest of the species were evergreen. Although the latter showed round the year leaf fall, higher values were recorded during winter and summer than in rainy season. Thus, it is evident that the seasonal climate prevailing in this region has profound influence on the pattern of leaf fall irrespective of the species. This seasonality may be attributed mainly to the effect of relatively dry period during winter months. This pattern of leaf fall is comparable with other plantations of this region (Rajvanshi & Gupta 1985, Bargali *et al.* 1992a, Joshi *et al.* 1997). The leaf fall accounted for 64.3% (*Eucalyptus* hybrid) to 90.8% (*D. sissoo*) of the total annual litterfall which is within the range of 37.7–96.3% reported for different other plantations (Meentemeyer *et al.*1982, Baker 1983, Rajvanshi & Gupta 1985, Pande & Sharma 1986, Bargali *et al.* 1992a, Bernhard-Reversat 1993, Lodhiyal *et al.*1995a, Joshi *et al.* 1997, Misra & Nisanka 1997, Panda & Mohanty 1998). Meentemeyer *et al.* (1982) calculated 70% leaf litter in the total litterfall in forests around the world.

Table 5 Nutrient use efficiency (NUE) in different plantations

Plantation	NUE		
	N	P	K
Casuarina equisetifolia	126	628	385
Leucaena leucocephala	140	589	245
Eucalyptus hybrid	141	565	260
Dalbergia sissoo	117	557	121
CD (5%)	5.146**	13.813**	7.651**

** significant at $p < 0.01$

The lack of pronounced seasonality in the fall of woody litter in our case is in conformity with other studies (e.g. Pandey & Singh 1981).

This is mainly due to non-periodic occurrence of storms or periods of high wind force during which dead wood material is dislodged (Christensen 1978). The annual woody litterfall estimated in this study ranging between 16.6 and 131.8 g m^{-2} $year^{-1}$ is comparable with other plantations of similar age (Lodhiyal *et al.* 1995a, Joshi *et al.* 1997, Misra & Nisanka 1997, Panda & Mohanty 1998).The total litterfall for *Eucalyptus* hybrid in this study (384.1 g m^{-2} $year^{-1}$) is similar to that produced by a *Eucalyptus* hybrid (330 g m^{-2} $year^{-1}$) plantation in the Uttaranchal Tarai region (Joshi *et al.* 1997) and by a *E. obliqua* (388–537 g m^{-2} $year^{-1}$) plantation in New Zealand (Baker 1983). However, the present value in this study was lower than the values reported for the coastal hills of Africa (Bernhard-Reversat 1993) and for *Eucalyptus* hybrid in Uttaranchal Tarai (Bargali *et al.* 1992a), *Eucalyptus* spp. in Dehra Dun, India (Pande & Sharma 1986) and also for *E. regnans* and *E. sieberi* in New Zealand (Baker 1983) but higher than *E. tereticornis* in Haryana, India (Gill *et al.* 1987). Total litter production by *C. equisetifolia*, *L. leucocephala* and *D. sissoo* in the present study was lower than the plantations of the same species raised in coastal Orissa, Uttaranchal Tarai and Kurukshetra regions respectively (Rajvanshi & Gupta 1985, Joshi *et al.* 1997, Misra & Nisanka 1997, Panda & Mohanty 1998). Overall comparison, in general, indicated that the litter production on the present sites was lower than the stands at other sites. The relatively lower values of litter production in the present study may be due to the slow growth of trees on sodic land and subsequent slow turnover of biomass.

It is evident from the study that considerable variation exists between nutrient contents of different species (Table 3). Generally, concentrations of Ca and N were higher than other macronutrients in all fractions of litter, irrespective of species. Leaf litter showed higher concentration of N than woody or miscellaneous litters. Higher concentration of N in the leaf litter of tropical trees has also been reported by Sharma and Pande (1989) and Vitousek (1984). The amounts of nutrients returned were usually in proportion to the quantity of litterfall in various species. Among all the species *C. equisetifolia* produced maximum litter annually and the nutrient return through this species was also maximum. Thus, chemical composition and litterfall of the species largely determine the amount of various nutrients in the litterfall.

The amounts of N, P, Ca and Mg returned through litterfall in *C. equisetifolia* plantation were greater than in plantations of other species. The K return was, however, maximum in *D. sissoo* plantation. The order of relative abundance of major nutrients (NPK) in the litterfall in the present study was N > K > P which agrees with the findings of Joshi *et al.* (1997) for certain plantations. In the present plantations, of the total annual nutrient input (pool size) through litterfall, leaf fall accounted for 67 (*L. leucocephala*) to 92% (*D. sissoo*) and woody and miscellaneous litterfall jointly for 8–33%. Foliage accounted for most of the N returned through litterfall (79–95%). Similar observations were also made for other plantations (Lodhiyal *et al.* 1995b, Joshi *et al.* 1997).

Comparing with certain plantations in northern India, N return through litterfall obtained in the present study for *C. equisetifolia* was higher than the values reported for *Eucalyptus* hybrid and *Shorea robusta* plantations (Bargali *et al.* 1992b, Mohsin *et al.* 1996, Joshi *et al.* 1997). Similarly, N return in *L. leucocephala* and *Eucalyptus* hybrid plantations approximates the value reported for *Eucalyptus* hybrid plantation by Joshi *et al.* (1997), but both plantations showed lower N return compared with the rest of the plantations. N return through *D. sissoo* litterfall in our study was also lower than the values reported for the north Indian plantations. The present value for P return in *C. equisetifolia* was lower than the values reported for *Tectona grandis* and *Populus deltoides* stands at Pantnagar. The amount of P return through litterfall in the rest of the species studied was greater than *Eucalyptus* hybrid (Bargali *et al.* 1992b, Mohsin *et al.* 1996, Joshi *et al.* 1997) but lower than other north Indian plantations. Similarly, the value for K return in the species in this study was also higher than *Eucalyptus* hybrid stands as reported by Bargali *et al.* (1992b) and Joshi *et al.* (1997). A comparison of species of the present study indicated that *C. equisetifolia* had greater nutrient return in nutrient poor sodic wasteland condition; this may be due to its better growth on poor soils (Panda & Mohanty 1998). The highest nutrient return through litterfall by this species contributed a sizeable improvement in soil condition and this conforms with results from our earlier study (Rana *et al.* 2003).

The values of NUE for N in this study were towards the higher end of the range of values (60–200) reported for a large number of forests (Vitousek 1982). It seems that the present species adapted themselves under N poor condition of the sodic soil by increasing N-use efficiency. Bridgham *et al.* (1995) have also used the ratio of litter production to litterfall nutrient as an index of NUE under infertile peatlands. *Casuarina equisetifolia* produced more litter per unit P and K compared with other plantations of the present study. This proves further that *C. equisetifolia* is more adapted to sodic soil conditions as it is more efficient in P and K nutrient use and retranslocates N to tissues of long durability (woody tissues) during senescence. Also *C. equisetifolia* favours enrichment of soil nitrogen pool under nutrient poor soil as it returns greater amount of nitrogen than other species through litterfall. On the other hand, *Eucalyptus* hybrid and *L. leucocephala* were more efficient with N and indicated high nutrient use efficiency than the rest of the plantations studied presently. Among the plantations examined *D. sissoo* was least efficient in all the nutrient use. However, all the plantations of the present study were generally more efficient in N and K nutrient use than certain other plantations (Joshi *et al.* 1997). It may be due to lower N and K concentrations in tissues and withdrawal of these nutrients from them during senescence. Thus, it appears that under nutrient poor condition of sodic wasteland the plants adopt greater nutrient conserving strategies and allow less nutrient return through litterfall than plants under favourable environments. Earlier studies based on foliar nutrients for a large number of tree species on sodic wasteland also support our present findings (Rana *et al.* 1994).

In conclusion, the amount of aboveground tree litter production was lower under the present plantations on sodic soil than other plantations located on normal sites may be because of slower growth rate of the former. Among all species examined, litterfall was maximum in *C. equisetifolia* and this species also indicated maximum nutrient return. The present plantations also showed greater nutrient use efficiencies with respect to litter production. It was further observed that *C. equisetifolia* produced more litter per unit P and K in comparison with the rest of the species. It is, therefore, suggested that this species should be chosen for large-scale plantation on sodic lands.

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