Oecologia Montana 1997,
6, 28 - 34

Aspects of productivity and nutrient cycling of poplar (*Populus deltoides* Marsh) plantation in the moist plain area of the Central Himalaya

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Abstract. We studied the productivity and nutrient cycling in a 9-year-old poplar plantation raised in Tarai belt (low lying lands with high water table) of the Central Himalaya. The total vegetation biomass and net primary productivity was 195.4 t ha^{-1} and 23.4 t ha^{-1} yr^{-1}, respectively. Of the total biomass and NPP, tree layer accounted for 96.6% and 88.5%, respectively. The concentration of nutrients (NPK) in *P. deltoides* was highest (0.18-2.24%) in foliage and lowest (0.02-0.18%) in bole wood component. The standing state of nutrients (NPK) ranged from 82 to 845 kg ha^{-1}. The forest floor was maximum 9.7 t ha^{-1} in winter and minimum 2.8 t ha^{-1} in the rainy season. The annual litter fall was 8.3 t ha^{-1} yr^{-1}. The mean nutrients returned annually to soil in litter fall was 148.2 kg N, 15.6 kg P and 86.3 kg K $year^{-1}$. Of these nutrients, tree litter fall accounted for about 71 to 88%. The turnover rate and turnover time of nutrients (NPK) in the forest floor of poplar plantation ranged from 0.71 to 0.77 and 1.30 to 1.41 years, respectively.

Key words: Biomass, net primary productivity, nutrient use efficiency, *Populus deltoides*, clone D121, Tarai, plantation.

Introduction

Forest area in Tarai has continuously been converted into agricultural land due to accelerating population growth. Land availability is now a main constraint to a successful reforestation effort (Lodhiyal 1994). The reforestation scheme includes monocultures of fast growing exotic tree species which are introduced after the clear felling of natural uneven-aged mixed broad-leaved forests occurring there.

Poplar (*Populus deltoides* Marsh), a commercial exotic tree species has been planted over a large scale since 1976 in the Central Himalayan moist plain area, India. It is fast growing, producing high quality wood for match and veneer factories with numerous marketing options and can be propagated vegetatively. Besides these characteristics, its deciduous nature with a short period of litter fall and high rate of litter decomposition improves the soil fertility. The moist plain areas known as Tarai have favourable conditions for such plantations (Singh 1989). To replace the present slow growing and otherwise not very useful native species in the region of Central Himalayas, poplar plantations were introduced on a large scale by foresters and farmers.

The main objective of this study was (i) to estimate biomass, net primary productivity and nutrient cycling of poplar plantation and (ii) to compare whether the poplar plantation is more productive than eucalypt plantation and natural forests, and about their nutrient use pattern.

Materials and methods

Study site

The climate of the Tarai region (low lying lands with a high water table adjacent to foothills) of the Indian Central Himalayan (between 29°3'-29°12' N lat. and 79°20'-79°23' E long. at an altitude of 260 m), where the study site is located, is subtropical monsoon type, with a long dry season from early October to mid-June to September. A detailed description of climate, geology and soils is given in Bargali *et al.* (1992).

Material and methods

The natural vegetation replaced by Poplar (*Populus deltoides*) is referred as moist Tarai sal (*Shorea robusta* of Dipterocarpaceae) forest, and Alluvial Savannah Woodland forest type (Champion and Seth 1968). Native trees were 30-40 m tall and predominantly deciduous.

Tree density of the 9-yr-old plantation of *P. deltoides* was 400 trees per ha on a spacing 5x5m, the plant to plant and row to row distance was 5 m, each way.

The total basal area of *P. deltoides* trees was 34.2 m^2 ha^{-1}. One hundred trees in a 50x50 m subplot within a one hectare sample plot were measured for dbh (at 1.37 m). Shrub vegetation was sampled by ten, 2x2 m quadrats, which were randomly distributed within the subplot. The analysis of herb layer was accomplished by using ten randomly placed 1x1 m quadrats in the same subplot.

Four diameter classes of *P. deltoides* trees were established: 25.0-27.5 cm, 27.5-30.0 cm, 30.0-32.5 cm and 32.5-35.0 cm for sampling purposes. Twelve trees (3 individuals of each diameter class) were sampled. The roots were dug out to a 1 m depth within an area extending 1 m radius around base of the each tree. The fine roots were estimated by digging out three 25x25x25 cm monoliths before exposing the stump and lateral roots. The tree was then felled after the roots were dug out into the space between adjoining individuals. After morphometric measurements, the stump was cut from the bole. The aboveground part was separated into bole, branch and foliage parts. The root system was categorised into stump, lateral and fine roots. Fresh weight of all components were determined in the field. Pre-weighed composite samples from upper, middle and lower strata (about 500 g fresh weight) of each component were brought to the laboratory and oven dried at 60°C to constant weight.

The harvest data was subjected to regression analysis to relate the dry weight of each component with the diameter at breast height. The regression model used was: $y = a + bx$; where, y = dry weight of the component (kg $tree^{-1}$), x = dbh (cm), a is the y intercept, and b is the slope (Lodhiyal *et al.* 1994). A significant relationship was developed between dbh (x) and weight (y) for all components. A good positive relationship (r^2= 0.62-0.99) was found between these two variables, so linear regression equations were used for biomass estimation.

Six individuals of average size for each shrub species were harvested and then the roots were dug out up to 50 cm depth for each individual shrub. Stand biomass was calculated by summing up the biomass values across diameter classes (see Lodhiyal *et al.* 1994).

Data for forest floor was collected by using ten, 50x50 cm quadrats, randomly placed on the forest floor in three seasons, viz., rainy, summer and winter. In each quadrat, all the herbaceous live and dead shoots were harvested at ground level and placed in labelled polyethylene bags.

The litter input was measured by placing 15 litter traps randomly on the forest floor of the poplar plantation. Each trap was 50x50 cm with 15 cm high wooden sides and fitted with a nylon net bottom. Litter for each trap was collected in polyethylene bags and brought to the laboratory at one month intervals during the study period. One hundred trees of different diameter class were marked with white paint at breast height (1.37 m) in order to assess annual diameter increment. The marked trees were measured in September 1987 and remeasured in September 1988. Mean diameter increment for each diameter class was then calculated.

Using the allometric equations, the 1987 (B_1) and 1988 (B_2), biomass for different components of trees in a mean diameter class was calculated separately. The net change in biomass ($\Delta B = B_2 - B_1$) yielded annual biomass accumulation. The sum of ΔB values for different components yielded net biomass accumulation in the trees. The annual leaf fall was added to foliage biomass accumulation. Wood litter fall values were added to the biomass accumulation in twigs. In fine root biomass accumulation, 1/5 of leaf litter was added to root mortality following the assumption made by Kalela (1954), Orlov (1955, 1968) and Ogino (1977). However, this may seriously underestimate root production (Harris *et al.* 1980).

The oven dried samples of different components of trees, shrubs and herbs were analysed for nutrients. The total nitrogen was determined by Kjeldahl technique (Peach and Tracy 1956, Misra 1968). Phosphorus was determined by spectrophotometer and potassium by flame-photometer (Jackson 1958).

Nutrient uptake was computed by multiplying the value of net primary productivity of different components with their respective nutrient concentration. The value of nutrient uptake by trees, shrubs and herds were summed to estimate by the total annual uptake by the vegetation.

The litter fall samples were also analysed for nutrients. The nutrients concentration was multiplied by the weight of annual litter fall to compute the amount of nutrients transferred to the forest floor.

The turnover rate (K) for each element to the forest floor was calculated as $K = A/(A+F)$ (Chaturvedi and Singh 1987). A is the amount of nutrients added to the forest floor by litter fall, and F is the nutrient contents of the lowest value of standing crop of litter in the annual cycle. Turnover time (t) is reciprocal of the turnover rate (K).

Some retranslocation of N, P and K occurred during the senescence of foliage. The percentage was assessed as follows:

$$\text{Percent retranslocation} = \frac{X - Y}{X} \times 100.$$

Where, Y = (nutrient in per unit weight litter fall) x (amount of litter fall), and X = (nutrient in per unit weight of green foliage) x (amount of litter fall).

Results

Stand structure and physico-chemical properties of soil in 30 cm soil depth are given in Table 1.

Biomass and net primary productivity. The regression coefficients determined in the present study are given in Table 2. The biomass of each component and of the total tree was significantly related to the dbh. The biomass and net primary productivity components are given in Table 3. The total vegetation production was 23.5t ha^{-1} yr^{-1}, of which, the tree layer, shrub layer, and herb layer accounted for 88.5%, 4.3%, and 7.2%, respectively (Table 3).

Seasonal variation in the amount of forest floor material is shown in Table 4. The total litter fall was

Parameters		Poplar Plantation (9-year-old)
Altitude (m)		260
Area (ha)		6
Density (ha)		400
Basal area (m^2 ha^{-1})		34.2
Soil bulk density (g cm^{-3})		1.24
Sand (%)		32.4
Silt (%)		45.4
Clay (%)		22.2
Soil moisture (%)		16
Porosity (%)		52
Water holding capacity (%)		73.6
Soil pH		6.5
Organic carbon (%)		2.4
Nutrient concentration (%)		
	N	0.139
	P	0.010
	K	0.061
Decomposition of litter (% yr^{-1})		90.6
Rate of decomposition (day^{-1})		0.247
Soil nutrient content (kg $ha^{-1}yr^{-1}$)		(in 30 cm depth)
	N	5136.48
	P	393.52
	K	2178.64

Table 1. Stand structure and physico-chemical properties of soil of poplar plantation.

Component	a	b	r^2	t
Tree layer				
Bole wood	-2.24	7.64	0.99	42.76
Bole bark	-5.86	1.29	0.99	42.20
Branch	-1.69	1.27	0.96	15.99
Twig	-1.32	0.44	0.82	6.77
Foliage	-1.98	0.92	0.93	11.36
Stump root	-1.99	1.93	0.93	21.17
Lateral root	-1.78	1.06	0.64*	11.55
Fine root	-0.22	0.13	0.64*	19.13
Shrub layer				
		Clerodendron		*infortunatum*
Stem	-0.27	0.97	0.81	4.17
Foliage	0.02	0.06	0.90	6.18
Roots	0.29	0.17	0.91	6.05
		Murraya	*koenighii*	
Stem	0.61	0.56	0.97	11.53
Foliage	-0.11	0.20	0.81	4.14
Roots	0.62	0.07	0.82	4.15
		Lantana	*camara*	
Stem	0.66	0.60	0.87	5.29
Foliage	-0.46	0.52	0.82	4.35
Roots	0.36	0.13	0.69*	2.97

Table 2. Allometric relationship between the biomass of tree components (Y=kg\tree) and diameter at breast height (X=cm) for tree, and biomass of shrub components and basal diameter for shrub species in 9-year-old poplar plantation; a = intercept, b = slope, r^2 = correlation coefficient, t = t-test, correlations without asterisks = significant at P<0.01, *= significant at P<0.05.

Component	Biomass ($t\ ha^{-1}$)	NPP ($t\ ha^{-1}\ yr^{-1}$)
Tree layer	188.8±5.54	20.8±8.25
% allocation		
Bole*	61.7	31.7
Branch**	11.3	8.2
Foliage	6.0	40.9
Coarse roots***	20.1	11.0
Fine roots	0.9	8.2
Shrub layer	4.9±1.26	1.0±2.68
% allocation		
Stem	61.2	60.0
Foliage	10.2	30.0
Roots	28.6	10.0
Herb layer	1.7±2.56	1.7±2.56
% allocation		
Aboveground	82.3	82.3
Belowground	17.7	17.7
Total vegetation	195.4	23.5

Table 3. Biomass and productivity in different components of 9-year-old poplar plantation. NPP = net primary productivity, * = bole wood + bole bark (which accounted for 7.8% of biomass and 4.3% of net primary productivity values),** = branch + twigs (current shoot bearing leaves, which accounted for 2.8% of biomass and 3.9% of net primary productivity),*** = stump root (main root) + lateral roots (lateral branches of main root which accounted for 7.0% of biomass and 3.8% of net primary productivity).

Component	Amount ($t\ ha^{-1}$) Winter	Summer	Rainy
Forest floor			
Fresh leaf litter	1.83 (19.0)	1.17 (17.3)	0.09 (3.3)
Partially and more decompos. litter	5.95 (61.6)	3.86 (57.1)	0.92 (33.4)
Other litter*	1.88 (19.4)	1.73 (25.6)	1.74 (63.3)
Total	***9.66 (100)***	***6.76 (100)***	***2.75(100)***
Litter fall			
Leaf litter	7.30 (94.9)	-	0.50 (84.7)
Wood litter	0.39 (5.1)	0.03 (100)	0.09 (15.3)
Total	***7.69 (100)***	***0.03 (100)***	***0.59 (100)***

Table 4. Forest floor and litter fall in an 9-year-old poplar plantation. Values in parentheses = relative contribution, * = consists the components of bark, twigs, branches of tree and dead parts of shrub and herb.

Component	N	P	K
Tree layer	844.7	82.0	430.9
% allocation in			
Bole	33.1	38.0	43.4
Branch	17.5	20.1	13.1
Foliage	30.1	24.9	22.3
Coarse roots	18.4	16.1	20.1
Fine roots	0.9	0.9	1.0
Shrub layer	42.3	3.5	22.9
%allocation in			
Stem	50.4	54.3	54.6
Foliage	25.5	22.8	17.0
Roots	24.1	22.9	28.4
Herb layer	23.9	1.30	22.7
% allocation			
inAboveground	87.4	84.6	85.0
Belowground	12.6	15.4	15.0
Total vegetation	***910.9***	***86.8***	***476.5***

Table 5. Standing state of nutrient ($kg\ ha^{-1}$) in 9-year-old poplar plantation.

Component	N	P	K
Tree layer	122.8	13.9	65.4
% allocation			
in Bole	13.6	13.7	17.0
Branch	11.8	11.5	8.4
Foliage	60.7	64.0	60.0
Coarse roots	7.6	5.8	7.9
Fine roots	6.3	5.0	6.7
Shrub layer	9.0	0.8	4.5
% allocation			
inStem	43.3	50.0	55.6
Foliage	47.8	37.5	33.3
Roots	8.9	12.5	11.1
Herb layer	19.5	1.1	19.8
% allocation			
inAboveground	84.1	81.8	82.8
Belowground	15.9	18.2	17.2
Total vegetation	***151.3***	***15.8***	***89.7***

Table 6. Net uptake of nutrient ($kg\ ha^{-1}\ yr^{-1}$) in 9-year-old poplar plantation.

8.3 t ha^{-1}, of which 94% was leaf litter.

Nutrients in plantation. The nutrient concentration (N, P and K) reported for tree components was in the following order: foliage > twig > bolebark branch > fine root > lateral root > stump root > bole wood (Lodhiyal 1990). The relative contributions of various tree components to the standing state of nutrients were in the following order: bole > foliage > coarse roots >branch >fine roots (Table 5).

The percent of nutrient retranslocation from leaves of *P. deltoides* during senescing was 60.8 for N, 41.5 for P and 45.4 for K.

From 60 % to 64 % of the total N, P, and K uptake by trees contributed to foliage (Table 6). Turnover time (t) of nutrient on forest floor ranged from 1.3 to 1.4 years.

The total nutrient (N, P and K) contents returned to the soil subsystem through litter was 148.2 kg N ha^{-1}yr^{-1}, 15.5 kg P ha^{-1}yr^{-1} and 86.3 kg K ha^{-1}yr^{-1}. Of these nutrients, tree litter accounted for 70.5-88.1%, shrub for 3.2-4.8% and herb for 8.5-26.3% (Table 7).

Component	N	P	K
Tree layer			
Leaf litter	103.7	12.5	54.6
wood litter	6.1	0.6	2.2
roots	7.3	0.6	4.1
Total	117.1	13.7	60.9
Shrub layer			
Leaf litter	6.4	0.5	2.2
Roots	0.8	0.1	0.5
Total	7.2	0.6	2.7
Herb layer			
Aboveground	16.4	0.9	16.4
Belowground	7.5	0.4	6.3
Total	23.9	1.3	22.7
Total vegetation	***148.2***	***15.6***	***86.3***

Table 7. Nutrient return through litter fall in 9-year-old poplar plantation.

Discussion

The biomass of poplar in the present study 195.4 t ha^{-1} was markedly greater than that reported for *Eucalyptus tereticornis* plantation of 8-year-old (126.7 t ha^{-1}, Bargali and Singh 1991) for Tarai region, but was far smaller than those (718 t ha^{-1}) reported for the natural sal (*Shorea robusta*) forest of the region (Singh and Singh 1992). The net primary productivity (NPP) of this poplar plantation (23.5 t ha^{-1} yr^{-1} was similar to the value of 23.4 t ha^{-1} yr^{-1} reported for *Eucalyptus tereticornis* plantation in the study area (Bargali and Singh 1991). It may be pointed out that the poplar plantation of the present study had much lower density (400 trees ha^{-1}) than the *Eucalyptus tereticornis* (2000 trees ha^{-1}) of the above study. A much higher NPP, 32.4 t ha^{-1} yr^{-1}, has been reported for a high density (666 trees ha^{-1} compared to 400 trees ha^{-1}) *P. deltoides* plantation in the study area (Lodhiyal *et al.* 1994). This value is higher than those reported for natural forests (about 19 t ha^{-1} yr^{-1}) for the region (Singh and Singh 1992). The poplar accumulated biomass at a higher rate than eucalypt, for its BAR (Biomass Accumulation Ratio) was 8.8 compared to 6.0 for eucalypt.

In the poplar plantation net uptake values for N, P and K were higher than for the eucalypt plantation (8-yr-old) studied by Bargali and Singh (1991). Consequently, NPP per unit of nutrient uptake (a measure of Nutrient Use Efficiency, NUE) was lower than that reported for eucalypt plantation. However, the present study poplar plantation had higher NUE than those reported for the natural forests of Central Himalaya (see Singh and Singh 1992). As for example, NUE for nitrogen was 169.3 kg dry matter N uptake^{-1}year^{-1} for the present *P. deltoides*, 302 kg for *Eucalyptus tereticornis*, 128.0 kg for *Shorea robusta*, and 164.0 kg for *Pinus roxburghii* occurring in adjacent mountain area (Table 8). Thus, for N, though P. deltoides is more nutrient demanding per unit of dry matter production than eucalypt, it is less nutrient demand-

Parameter	Plantation			NF	
	P9	P4	E8	S	Ch
Tree biomass (t ha^{-1})	188.8	108.9	121.0	710.0	283.0
Total veget.biomass(t ha^{-1})	195.4	112.8	126.7	718.0	286.4
Tree NPP of vegetation (t ha^{-1}yr^{-1})	20.8	29.5	20.4	15.5	18.7
Total NPP of vegetation (t ha^{-1}yr^{-1})	23.5	32.4	23.0	19.0	22.0
Biomass accumulation ratio (BAR)	8.8	3.7	5.9	45.8	15.1
Litter fall (t ha^{-1} yr^{-1})	8.3	6.7	6.5	6.5	6.5
Foliar nutrient Concentration (%)					
N	2.24	2.38	1.2	1.2	1.4
P	0.18	0.19	0.07	0.3	-
K	0.85	1.08	-	-	-
Retranslocation (%)					
N	60.8	64.6	25.2	38.6	21.5
P	41.5	50.2	18.1	40.8	23.1
K	45.4	50.9	-	-	-
Net uptake (kg ha^{-1} yr^{-1})					
N	122.8	176.1	67.6	121.0	114.0
P	13.9	18.8	4.1	10.0	13.0
K	65.4	94.1	-	-	-
Turnover rate of litter	0.89	0.93	-	-	-
Turnover time of litter	1.12	1.07	-	-	-
Turnover rate of nutrient on the forest floor					
N	0.76	0.86	0.74	0.57	0.34
P	0.71	0.83	0.80	0.67	0.36
K	0.77	0.88	-	-	-
Nutrient return though litter fall (kg ha^{-1})					
N	117.08	110.6	42.8	69.8	56.9
P	13.68	12.3	2.2	5.4	6.4
K	60.86	67.4	-	-	-
Rate of decomposition (% day^{-1})	0.247	0.27	0.23	0.25	0.13
NPP/Net uptake (kg dry matter nutrient uptake^{-1}year^{-1})					
N	69.3	156.8	302.0	128.0	164.0
P	1507	1556	4976	1550	1438
K	317.9	261.2	-	-	-
Nutrient content in soil (kg ha^{-1})					
N	5137	5138	7092	4007	3964
P	394	402	227	152	218
K	2179	2067	-	-	-

Table 8. Comparison of biomass, productivity and nutrient parameters of nine-year-old poplar (*P. deltoides*) trees (P9) of Clone D121, four-year-old poplar (P4) plantation (Lodhiyal *et al.* 1994), eucalypt eight-year-old (E8) forest in the same region (Bargali and Singh 1991), sal (S) and chir pine (Ch) forests (Singh and Singh 1992). NF = Central Himalayan Natural Forest.

ing species than the most efficient nutrient user among the Central Himalayan forest, viz., *Pinus roxburghii* (Singh and Singh 1992).

Interestingly, the *P. deltoides* retranslocates a greater fraction of nutrient from senescing leaves than does. *Eucalyptus tereticornis* (i.e. 60.8% N compared to 25.2% N for eucalypt, Bargali and Singh 1991). Evidently, the higher nutrient concentration in green leaves of *P. deltoides* (e.g. 2.24% N in *Populus* to 1.20% N in *Eucalyptus*, Bargali and Singh 1991) is the main factor for its lower NUE. The greater amount of nutrient return through litter fall (e.g. 148.2 kg N in *P. deltoides* vs. 76 kg N in *Eucalyptus* hybrid) should, however, lead to a rapid build up of soil nutrient pool in a poplar plantation.

To conclude, *P. deltoides* in short period (9-yr-old) attain higher NPP and NUE values than natural forests (100-yr-old) of Central Himalaya (Singh and Singh 1992). However, NUE value of poplar is lower than 8-yr-old eucalypt plantation of the Tarai belt (a low lying lands with high water table) (Bargali and Singh, 1991). Since in the future one of the major practical issue is going to be how to achieve high wood production in a system subject to frequent harvests (Grubb 1989). The nutrient use efficiency would be one of the major criteria for species selection in forestry. From NUE stand point of view, *P. deltoides* would be a better plantation species than natural forest species of central Himalaya and can be less preferable than eucalypt species. However, from the stand point of a long term effect on soil nutrient status *P. deltoides* may be much preferable for better nutrient quality of its litter.

Compartment models of dry matter flow and nutrient cycling in 9-yr-old plantation are given in Fig. 1 and Fig. 2, respectively.

Dry matter transfer

The mean annual incident solar isolation is 5,955 MJ ha^{-1} yr^{-1}. Out of this about 2,978 MJ $ha^{-1}yr^{-1}$ (50% of the total) is considered photosynthetically available.

The biomass of the vegetation is 195.4x10^3 kg ha^{-1}. Trees account for 96.6%, shrubs 2.5%, and herbs 0.9% of the total dry matter. In the tree layer the ratio of above-ground photosynthetic: non-photosynthetic tissue and root:shoot ratio were 0.08 and 0.29, respectively.

Net primary production is 23,593 kg ha^{-1} yr^{-1}. The share of tree, shrub, and herb layers in the total net production of the vegetation are 88.4, 7.5, and 4.1%, respectively. In the tree layer, the largest fraction of net production is allocated to foliage (40.9%) followed by bole (31.7%). The apportioning of net production in shrubs follows the order: stem (60%) > foliage (30%) > root (10%). Similar trends were also reported for poplar, (Lodhiyal *et al.* 1995), pine (Chaturvedi and Singh 1987), and oak forests (Rawat and Singh 1988). In herbs, the aboveground components command a majority of net production (82.3% in term of dry matter), and much higher than the Central Himalayan forest (62-64%, Chaturvedi and Singh 1987; Rawat and Singh 1988). The maximum proportion of net production in all three layers of plantations is allocated to the photosynthetically active parts (Lodhiyal *et al.* 1995). To maximize the proportion of photosynthates allocated to build new leaves is an effective strategy for obtaining maximum growth (Schulze 1982).

The restitution of biomass through litter formation is 10,059 kg ha^{-1} yr^{-1}. Of the total litter fall from the tree layer, leaf litter constitutes 94%. The present values are higher than natural forests (67-77%, Chaturvedi and Singh 1987; Rawat and Singh 1988) and eucalypt plantation (55%, Bargali and Singh 1991). The biomass restitution in term of dry matter equals 37.4% of the total annual production of tree and 33.1% of that of total vegetation. Our estimates are similar to that of 8-yr-old poplar and eucalypt plantations (Lodhiyal *et al.* 1995, Bargali *et al.* 1992) but lower than those of natural forests (Chaturvedi and Singh 1987; Rawat and Singh 1988). The mean standing crop of litter on the forest floor was 6,388 kg ha^{-1} which is 3.4% of tree and 3.3% of the total vegetation.

Decomposition of litter at the soil surface, as indicated by turnover rate is 8,952 kg ha^{-1} yr^{-1}. This amounts to 89% of the total litter fall. Compared to this, in the present 9-year-old poplar plantation, the annual weight loss in leaf litter as determined by litter bags was 91-94% (Lodhiyal 1990). At the end of annual cycle, 1,107 kg ha^{-1} yr^{-1} remains and is carried over the next year.

Mortality of main roots in trees and shrubs is little in actively growing plant, but considerable mortality occur in fine roots. Orlov (1968) and Ogino (1977) assumed that the fine root mortality is equivalent to one fifth of leave litter; we followed this assumption. Our present estimate of fine root production may be a gross underestimate (Fogel 1983; Vogt *et al.* 1986). Since all herbaceous vegetation at all sites are mostly annual, the root mortality of trees, shrubs and herbs, respectively, amounts to 1,560, 108 and 308 kg ha^{-1} yr^{-1} in present study poplar plantation.

Nutrient cycling

A compartment model of nutrient dynamics (pools and fluxes) is presented in Fig 2. The amount present in the soil to a depth of 30 cm is considered as a source and that associated with decomposition is released into the soil for reuse. The direction of nutrient flux from soil to foliage indicates a one way movement. Although, it is realized that the nutrients are utilized by the foliage in organic matter synthesis, and they are redistributed among different components at varying rates giving raise to internal recycling.

The total quantity of nutrients was 910.9 N, 86.8 P and 476.5 K kg ha^{-1} yr^{-1}. Of the total nutrients, the tree layer accounted for 90.4-94.4% in 9-yr-old poplar plantation. However, the total quantity of nutrients in soil is lower as compared with 5-8-yr-old poplar plantation (Lodhiyal *et al.* 1995). This indicates that the soil nutrient decreased with increase in age of stands.

The allocation of uptake of nutrients (N, P and K) to total vegetation uptake was as follows trees (73-81%) > herbs (6.9-22.1%) > shrubs (5.0-6.0%). The total amount of nutrient retranslocation from the aboveground senescing plant parts of the tree layer was 115.6 N ,6.3 P, and 32.6 K ha^{-1} yr^{-1}. In shrubs, the amount of nitrogen, phosphorus and potassium

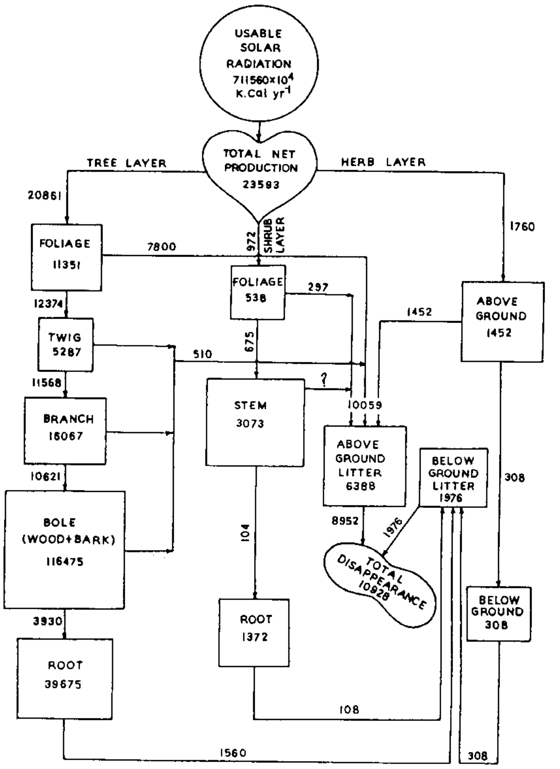

Fig. 1. Compartment model for dry matter distribution in 9-year-old poplar (*Populus deltoides* Marsh) plantation. Rectangles represent compartments for standing crop of dry matter, arrows represent net flux rate. Circular, leaf and kidney shaped enclosures represent the total annual fluxes values for usable solar radiation (MJ ha^{-1} yr^{-1}), total net production (kg ha^{-1}), and total disappearance (kg ha-1 yr-1). Compartment values are kg ha^{-1} and turnover rates kg ha^{-1} yr^{-1}, respectively.

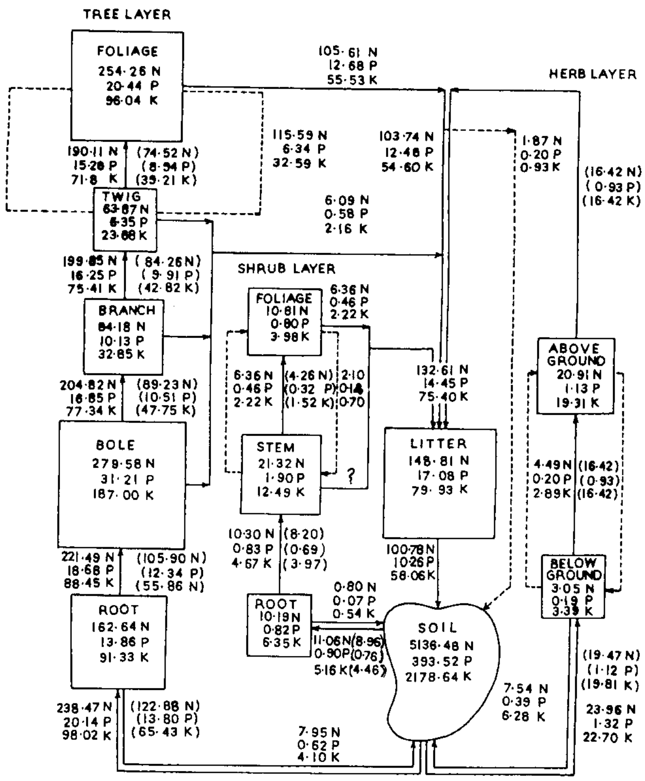

Fig. 2. Compartment model of 9-year-old Poplar (*Populus deltoides*) plantation. This show the distribution and cycling of nitrogen (N), phosphorus (P) and potassium (K) in tree, shrub and herb layers of 9-year-old stand. Rectangles represent a pool for standing state of nutrients from one compartment to next compartment. The values in the pools represent the average nutrient contents. Net annual fluxes of nutrients (NPK) between pools are given on the arrows. Units are kg ha^{-1} for pools and kg ha^{-1} yr^{-1} for fluxes between pools. Values in parentheses indicate adjustment for internal cycling. Recycling rates between foliage and twigs kg ha^{-1} yr^{-1} for fluxes between pools. Values in parentheses indicate adjustment for internal cycling. Recycling rates between foliage and twigs is shown by broken lines.

was 2.10, 0.14 and 0.70, respectively. However, in herbs, the amount of nutrients was 4.49 N, 0.02 P and 2.89 K kg ha^{-1} yr^{-1}.

Acknowledgement

Financial support from the Council of Scientific and Industrial Research, Government of India, New Delhi is gratefully acknowledged.

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Received 28 October 1995; revised 5 February 1996; accepted 11 March 1996