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PINUS PATULA PLANTATIONS IN KUMAUN HIMALAYA. II. NUTRIENT DYNAMICS

S.S. Bargali* & R.P. Singh

Department of Forestry, Kumaun University, Nainital - 263 002, (Uttar Pradesh) India

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BARGALI, S. S. & SINGH, R. P. 1997. *Pinus patula* plantations in Kumaun Himalaya. II. Nutrient dynamics. This paper deals with the nutrient dynamics in different age plantations of *Pinus patula* previously investigated for dry matter dynamics. The concentrations of nutrients in different vegetation layers were in the order, herb > shrub > tree, whereas the standing state of nutrients were in the order tree > shrub > herb. Considerable reductions (50.5 - 69%) in concentrations of nutrient in needles occurred during senescence. The uptake of nutrients by vegetation and also by different components with and without adjustment for internal recycling was calculated separately. The amounts of nutrients returned annually to the soil through litterfall were in the ranges 33.1- 41.9 kg ha^{-1} y^{1} for N, 2.6 - 3.3 kg ha^{-1} y^{1} for P and 10.6 - 14.1 kg ha^{-1} y^{1} for K.

Key words: *Pinus patula* - nutrient concentration - standing state - retranslocation - uptake - nutrient return - turnover

BARGALI, S. S. & SINGH, R. P. 1997. Ladang *Pinus patula* di Kumaun Himalaya. II. Dinamik nutrien. Kertas kerja ini membincangkan mengenai dinamik nutrien di ladang *Pinus patula* dengan umur yang berbeza terdahulu dikaji untuk dinamik bahan kering. Kepekatan nutrien lapisan pertumbuhan yang berbeza dengan susunan: herba> pokok renik> pokok, manakala kedudukan nutrien dalam susunan, pokok > pokok renik> herba. Pengurangan (50.5 - 69%) kepekatan nutrien dalam jejarum terjadi semasa penuaan. Kadar penyerapan nutrien oleh tumbuh-tumbuhan dan juga oleh komponen yang berbeza dengan atau tanpa penyesuaian untuk kitaran dalaman dikira secara berasingan. Jumlah nutrien yang dikembalikan ke dalam tanah melalui jatuhan sarap setiap tahun berjulat antara 33.1- 41.9 kg ha^{-1} y^{1} bagi N, 2.6 - 3.3 kg ha^{-1} y^{1} bagi P dan 10.6 - 14.1 kg ha^{-1} y^{1} bagi K.

Introduction

Allocation and cycling of nutrients by vegetation constitute a major characteristic of the ecosystem. Primary production, one of the major functions of forest ecosystem, is influenced by the availability of nutrients and this in turn depends on their

*Present address: *Indira Gandhi Agricultural University, Krishi Vigyan Kendra, Post Box No.6, Anjora, Durg - 491 001 (M.P.), India.*

distribution and cycling. The concentration of nutrients within any part of the ecosystem usually depends upon a functional balance within the system. Pomeroy (1970) argued that the flux of material is essential for the continuity and stability of living systems. Nutrient cycling in forests and plantations has received more attention over the past two three decades with major emphasis on the biological cycle between plant and soil (Attiwill 1980, Bargali & Singh 1991, Bargali *et al.* 1992 a,b, Bisht 1993, Bargali 1995).

A greater proportion of the total plant nutrient stock is immobilised in the growing tree biomass and standing litter mass on the forest floor, and in the soil a greater proportion of nutrients generally occurs in surface soil. Thus nutrients are a major limiting factor on production. According to Olson (1968), the flow of energy and the very existence and role of the living species in the ecosystem depend on the flow of nutrients. The present paper comprises information on the concentration, standing state, uptake, return and turnover of nutrients in *Pinus patula* plantations of Kumaun Himalaya. The site has been described in detail in the first part of this paper (Bargali & Singh 1997).

Methods

Samples of bole, branch, twig, foliage and cone from the upper, middle and lower strata of trees were collected from 12 trees (i.e. from three individuals of each DBH class as four DBH classes were present in each plantation between 10 and 30 cm diameter) of each plantation. The ages of the plantations were 15, 18 and 21 years. The samples for root components (stump, lateral and fine roots) were collected by digging out roots to 1 m depth. Similarly, samples for shrubs (stems, foliage and root) and herbs (above ground and below ground) were collected. Three composite samples of each component of trees (from all age classes), shrubs and herbs were oven dried at 60 °C and the samples analysed for nutrients. For each replicate of composite sample, 0.5 g plant material was analysed for total nitrogen after digestion in 10 ml concentrated sulphuric acid using 5 g catalyst mixture (potassium sulphate and cupric sulphate in the ratio of 9:1) with a quick digestion unit. The total nitrogen was determined by micro Kjeldahl's method (Peach & Tracey 1956, Misra 1968). Phosphorus and potassium were extracted by wet ashing of 0.5 g plant material in acid mixture consisting of 10 ml H_2SO_4 + 3 ml HNO_3 + 1 ml $HClO_4$; phosphorus was determined by spectrophotometer and potassium by flame photometer (Jackson 1958).

The total amount of nutrients in the vegetation was obtained by summing the amounts in the different components. The amount of nutrients in each stratum (0 - 10, 10 - 20, 20 - 30 cm) of soil was obtained from bulk density, soil volume and nutrient concentration values. The amounts of nutrients estimated in all three strata were summed to obtained total nutrient content up to 30 cm depth.

Nutrient uptake was computed by multiplying the value of net primary productivity of different components with their respective nutrient concentration, following Chaturvedi and Singh (1987), Rawat and Singh (1988), and Bargali and

Singh (1991, 1995). Similarly, the amount of nutrient transferred to the forest floor via litterfall was calculated.

The percentage retranslocation of nutrients from senescing leaves to the perennial tissues was calculated following Ralhan and Singh (1987) and Bargali *et al.* (1992 a), viz. 100 x (nutrient mass in mature leaf - nutrient mass in senesced leaf) ÷ (nutrient mass in mature leaf).

Results and discussion

Concentration of nutrients

Table 1 gives the concentrations of N, P and K in different components of trees, shrubs and herbs. The concentrations of all nutrients decreased with increase in plantation age. The pattern of nutrient concentration in different life forms was in the order: herbs > shrubs > trees. The leaf component of the plant is metabolically the most active and accumulates the maximum amount of nutrients. Since the proportional contribution of this component decreases from herbs to trees, the overall nutrient concentration also decreases (Golley *et al.* 1975). Bargali *et al.* (1992 a) also reported a similar decrease in nutrient concentration with age.

Concentration of nutrients in different above-ground components in the present study was in the order: foliage > cone > twig > branch > bole, and in root components: fine root > lateral root > stump root. This pattern conforms with the earlier results of Rodin and Bazilerich (1967), Morrison (1973), Singh (1979), Chaturvedi and Singh (1987), Rawat and Singh (1988) and Bargali *et al.* (1992 a). In the present study the predominance of N and K is similar to the reports of Rodin and Bazilevich (1967) for pine forests of USSR and Chaturvedi and Singh (1987) for chir pine (*Pinus roxburghii*) forests of India.

The concentrations of selected nutrients in the soils of certain Himalayan coniferous forests reported by Chaudhari *et al.* (1977), Sharma (1977), Singh (1979) and Chaturvedi and Singh (1987) show that the values of N and P in the present plantations lie within the reported ranges and a greater proportion occurred in the upper strata of the soil (Table 2).

Standing state of nutrients

The distribution of nutrients in different components differs considerably on account of variations in biomass and nutrient concentration. The differences in biomass, however, dominate the differences in standing state of nutrients in different components and the role of concentration is minimised. Thus the quantity of all nutrients in the vegetation was highest in the 21-y-old and lowest in the 15-y-old plantations (Tables 3a, b and c). This is expected as the total vegetation biomass was highest in the 21-y-old plantation and lowest in the 15-y-old plantation (Bargali & Singh 1997). The greatest amount of all nutrients

Table 1. Concentrations of nutrients (% ± s.e.) in different components of trees, shrub and herb layers

Component	Nutrient	Plantation age (years)		
		15	18	21
Tree				
Bole	N	0.54 ± 0.051	0.53 ± 0.056	0.53 ± 0.039
	P	0.08 ± 0.005	0.07 ± 0.006	0.07 ± 0.007
	K	0.14 ± 0.012	0.14 ± 0.010	0.13 ± 0.010
Branch	N	0.76 ± 0.041	0.76 ± 0.059	0.75 ± 0.066
	P	0.09 ± 0.007	0.09 ± 0.009	0.09 ± 0.009
	K	0.43 ± 0.019	0.42 ± 0.036	0.41 ± 0.038
Twig	N	0.98 ± 0.048	0.97 ± 0.082	0.97 ± 0.074
	P	0.11 ± 0.009	0.11 ± 0.008	0.11 ± 0.009
	K	0.46 ± 0.019	0.45 ± 0.026	0.44 ± 0.027
Foliage	N	1.98 ± 0.108	1.96 ± 0.152	1.96 ± 0.129
	P	0.16 ± 0.012	0.16 ± 0.014	0.15 ± 0.015
	N	0.71 ± 0.025	0.70 ± 0.033	0.70 ± 0.042
Cone	N	1.36 ± 0.112	1.36 ± 0.112	1.35 ± 0.131
	P	0.13 ± 0.016	0.13 ± 0.012	0.12 ± 0.010
	K	0.15 ± 0.012	0.14 ± 0.010	0.14 ± 0.013
Stump root	N	0.14 ± 0.012	0.13 ± 0.012	0.13 ± 0.009
	P	0.03 ± 0.006	0.03 ± 0.003	0.03 ± 0.002
	K	0.06 ± 0.007	0.06 ± 0.007	0.05 ± 0.004
Lateral root	N	0.21 ± 0.041	0.21 ± 0.029	0.20 ± 0.019
	P	0.04 ± 0.007	0.04 ± 0.004	0.04 ± 0.003
	K	0.09 ± 0.007	0.09 ± 0.008	0.08 ± 0.006
Fine root	N	0.26 ± 0.043	0.25 ± 0.046	0.25 ± 0.048
	P	0.05 ± 0.003	0.05 ± 0.005	0.05 ± 0.003
	K	0.13 ± 0.007	0.13 ± 0.007	0.11 ± 0.009
Shrub	N	0.76 ± 0.026	0.75 ± 0.023	0.74 ± 0.052
Stem	P	0.07 ± 0.008	0.07 ± 0.007	0.07 ± 0.006
	K	0.42 ± 0.032	0.41 ± 0.036	0.40 ± 0.036
Foliage	N	1.41 ± 0.072	1.40 ± 0.092	1.38 ± 0.108
	P	0.15 ± 0.010	0.15 ± 0.015	0.15 ± 0.009
	K	0.96 ± 0.121	0.95 ± 0.112	0.95 ± 0.082
Root	N	0.67 ± 0.039	0.65 ± 0.062	0.63 ± 0.059
	P	0.07 ± 0.010	0.07 ± 0.007	0.07 ± 0.008
	K	0.40 ± 0.024	0.40 ± 0.030	0.38 ± 0.021
Herb				
Above-ground	N	1.71 ± 0.102	1.71 ± 0.102	1.71 ± 0.102
	P	0.16 ± 0.006	0.16 ± 0.006	0.16 ± 0.006
	K	1.23 ± 0.081	1.23 ± 0.081	1.23 ± 0.081
Below-ground	N	1.13 ± 0.021	1.31 ± 0.021	1.13 ± 0.021
	P	0.08 ± 0.007	0.08 ± 0.007	0.08 ± 0.007
	K	0.92 ± 0.021	0.92 ± 0.021	0.92 ± 0.021

generally resided in the boles, due to their high proportion of biomass, although boles had the lowest nutrient concentration and foliage had the highest among the above-ground tree components. A similar pattern in above-ground components was reported by Negi *et al.* (1983) for an evergreen oak forest in India. A temperate deciduous oak forest had relatively lower nutrient storage in the foliage (2.1- 4.6%) and values for bole ranged between 25.3 and 65.9% for different nutrients (Johnson & Risser 1974). All the forest types have distinct nutrient storage patterns. According to Foster and Morrison (1976) the storage in roots, in general accounts for 7-16% of the total elemental storage. In the present study storage of nutrients in roots accounts for 3.0 - 5.7%.

Table 2. Concentrations and contents of nutrients in the soil

Nutrient	Soil depth (cm)	Plantation age (y)		
		15	18	21
			Concentration (% ± s.e.)	
Organic carbon	0-10	3.51 ± 0.22	3.54 ± 0.27	3.50 ± 0.34
	10-20	1.23 ± 0.04	1.32 ± 0.08	1.28 ± 0.04
	20-30	1.03 ± 0.06	1.03 ± 0.08	1.06 ± 0.03
Nitrogen	0-10	0.32 ± 0.012	0.33 ± 0.013	0.32 ± 0.012
	10-20	0.16 ± 0.010	0.15 ± 0.010	0.17 ± 0.031
	20-30	0.12 ± 0.012	0.12 ± 0.012	0.13 ± 0.022
Phosphorus	0-10	0.11 ± 0.004	0.012 ± 0.0001	0.011 ± 0.0005
	10-20	0.007 ± 0.0004	0.007 ± 0.0003	0.008 ± 0.0001
	20-30	0.005 ± 0.0003	0.004 ± 0.0003	0.004 ± 0.0001
Potassium	0-10	0.22 ± 0.012	0.23 ± 0.016	0.22 ± 0.016
	10-20	0.18 ± 0.011	0.18 ± 0.016	0.19 ± 0.012
	20-30	0.12 ± 0.009	0.14 ± 0.007	0.12 ± 0.006
			Content (kg ha^{-1})	
Nitrogen	0-10	2560	2706	2592
	10-20	1536	1410	1615
	20-30	1236	1272	1339
	Total	5332	5388	5546
Phosphorus	0-10	88.0	98.4	89.1
	10-20	67.2	65.8	76.0
	20-30	51.5	42.4	41.0
	Total	206.7	206.6	206.3
Potassium	0-10	1760	1886	1782
	10-20	1728	1692	1805
	20-30	1236	1484	1236
	Total	4724	5062	4823

Retranslocation of nutrients

Evidently, a significant amount of nutrients is recycled internally (Table 4). Several workers, Duvigneaud and Denaeyer De Smet (1970), and Whittaker *et al.* (1979) have suggested that the elements normally in short supply for plants are efficiently redistributed before senescence. According to Staaf and Berg (1981) and Staaf (1982), an efficient retranslocation is a typical feature of climax forest tree species, particularly for conservation of essential elements which are in short supply. This type of conservative behaviour leads to a certain independence from soil as a nutrient medium but it also means a reduced transfer with litter, a factor which favours an even nutrient availability and a less circulation in the ecosystem (Staaf & Berg 1981, Singh *et al.* 1984, Chaturvedi & Singh 1987, Bargali & Singh 1991, 1995, Bargali *et al.* 1992a). This behaviour, however, explains the capability of *P. patula* to grow on poor soils.

Table 3a. Standing state of nitrogen (kg ha^{-1} ± s.e.) in different age plantations of *P. patula*

Component	Plantation age (y)		
	15	18	21
Tree			
Bole	241.9 ± 37.1	320.9 ± 39.6	378.1 ± 42.8
Branch	103.6 ± 11.2	107.9 ± 12.6	125.2 ± 19.6
Twig	108.9 ± 11.3	113.6 ± 11.8	132.4 ± 12.9
Foliage	221.8 ± 16.3	226.6 ± 19.6	249.1 ± 26.9
Cone	88.0 ± 6.9	98.9 ± 10.0	118.6 ± 11.2
Stump root	14.9 ± 1.2	14.5 ± 1.2	17.1 ± 1.6
Lateral root	11.0 ± 0.6	11.7 ± 0.8	13.2 ± 1.0
Fine root	10.4 ± 0.2	10.2 ± 0.6	16.2 ± 1.7
Total	800.5	904.3	1049.9
Shrub			
Stem	0.8 ± 0.03	0.9 ± 0.03	1.2 ± 0.09
Foliage	0.4 ± 0.02	0.4 ± 0.03	0.8 ± 0.06
Root	0.1 ± 0.01	0.1 ± 0.01	0.2 ± 0.01
Total	1.3	1.4	2.2
Herb			
Above-ground	23.2 ± 2.2	22.6 ± 2.3	23.4 ± 2.6
Below-ground	3.4 ± 0.2	3.2 ± 0.2	3.2 ± 0.3
Total	26.6	25.8	26.6
Total vegetation	828.4	931.5	1078.7

Table 3b. Standing state of phosphorus (kg ha^{-1} ± s.e.) in different age plantations of *P. patula*

Component	Plantation age (y)		
	15	18	21
Tree			
Bole	34.5 ± 6.2	42.4 ± 7.1	49.9 ± 7.4
Branch	12.5 ± 1.2	13.1 ± 1.4	15.4 ± 1.4
Twig	12.5 ± 1.1	13.2 ± 1.3	15.4 ± 1.0
Foliage	17.5 ± 3.2	18.0 ± 3.6	19.1 ± 3.7
Cone	8.3 ± 1.2	9.3 ± 1.4	10.5 ± 1.6
Stump root	3.0 ± 0.2	3.1 ± 0.4	3.7 ± 0.5
Lateral root	2.1 ± 0.2	2.3 ± 0.2	2.7 ± 0.3
Fine root	1.9 ± 0.3	2.0 ± 0.2	3.2 ± 0.3
Total	92.3	103.4	119.9
Shrub			
Stem	0.07 ± 0.005	0.09 ± 0.008	0.11 ± 0.009
Foliage	0.05 ± 0.005	0.05 ± 0.003	0.10 ± 0.009
Root	0.01 ± 0.001	0.01 ± 0.001	0.02 ± 0.001
Total	0.13	0.15	0.23
Herb			
Above-ground	2.2 ± 0.2	2.1 ± 0.2	2.2 ± 0.2
Below-ground	0.2 ± 0.02	0.2 ± 0.02	0.2 ± 0.02
Total	2.4	2.3	2.4
Total vegetation	94.8	105.8	122.5

Table 3c. Standing state of potassium (kg ha^{-1} ± s.e.) in different age plantations of *P. patula*

Component	Plantation age (y)		
	15	18	21
Tree			
Bole	62.7 ± 6.2	84.8 ± 7.3	92.7 ± 9.4
Branch	58.6 ± 6.1	59.6 ± 5.8	68.5 ± 8.7
Twig	51.1 ± 8.1	52.7 ± 5.6	60.1 ± 6.3
Foliage	79.5 ± 8.6	80.9 ± 9.2	88.9 ± 9.3
Cone	9.7 ± 1.5	10.2 ± 1.5	12.3 ± 2.1
Stump root	6.4 ± 0.9	6.7 ± 0.9	6.7 ± 1.1
Lateral root	4.7 ± 0.6	5.0 ± 0.7	5.3 ± 0.7
Fine root	5.2 ± 0.8	5.3 ± 0.6	7.1 ± 0.9
Total	277.9	305.2	341.6
Shrub			
Stem	0.4 ± 0.02	0.5 ± 0.03	0.6 ± 0.06
Foliage	0.3 ± 0.01	0.3 ± 0.01	0.6 ± 0.03
Root	0.1 ± 0.01	0.1 ± 0.01	0.1 ± 0.01
Total	0.8	0.9	1.3
Herb			
Above-ground	16.7 ± 2.1	16.2 ± 2.6	16.8 ± 2.3
Below-ground	2.8 ± 0.2	2.6 ± 0.3	2.6 ± 0.4
Total	19.5	18.8	19.4
Total vegetation	298.2	324.9	362.3

Table 4. Retranslocation of nutrients (%) during senescence of foliage in *P. patula*

Nutrient	Plantation age (y)		
	15	18	21
Nitrogen	50.5	50.0	49.5
Phosphorus	56.2	56.2	53.3
Potassium	69.0	67.1	67.1

Nutrient uptake

The uptakes of nutrients by the tree layer (after adjustment for retranslocation of nutrients from senescing tissues) ranged from 75.83 to 79.53 kg ha^{-1} y^{1} for N, 8.38 to 8.66 kg ha^{-1} y^{1} for P and 22.60 to 23.08 kg ha^{-1} y^{1} for K (Tables 5a, b and c). Estimates of nutrient uptake for temperate deciduous forests (Duvigneand & Denayer De Smet 1970, Nihlgard 1972, Johnson & Risser 1974) are 92 - 204 kg ha^{-1} y^{1} for N, 7- 15 kg ha^{-1} y^{1} for P and 43 - 99 kg ha^{-1} y^{1} for K. The amount of nutrient uptake is usually directly proportional to the size of net primary production, but the relationship varies for different forest communities (Rodin & Bazilevich 1967). The N extraction from the soil is maximum followed by K and P in the present study. Remezov and Pogrebnyak (1969) have stated that conifers extract N from the soil in the highest amount than K and P.

Table 5a. Nitrogen uptake (kg ha^{-1} y^{1}) by different layers of vegetation and their components

Component	Plantation age (y)		
	15	18	21
Tree			
Bole	19.30	22.31	24.01
Branch	6.52	5.09	3.00
Twig	14.47	14.36	16.20
Foliage	37.62(18.62)	39.98(19.99)	48.80(24.64)
Cone	13.81	12.38	7.69
Stump root	0.95	1.01	1.25
Lateral root	0.78	0.80	0.84
Fine root	1.38	1.45	1.90
Total	94.83(75.83)	97.38(77.37)	103.69(79.53)
Shrub			
Stem	0.30	0.38	0.30
Foliage	0.14	0.14	0.28
Root	0.07	0.06	0.13
Total	0.51	0.58	0.71
Herb			
Above-ground	23.25	22.57	23.43
Below-ground	3.39	3.16	3.16
Total	26.64	25.73	26.59
Total vegetation	121.98(102.98)	123.69(103.68)	130.99(106.83)

Values in parentheses are the uptakes after adjustment for retranslocation.

Table 5b. Phosphorus uptake (kg ha^{-1} y^{-1}) by different layers of vegetation and their components

Component	Plantation age (y)		
	15	18	21
Tree			
Bole	2.27	2.95	3.17
Branch	0.79	0.60	0.36
Twig	1.67	1.67	1.88
Foliage	2.96 (1.30)	3.18(1.39)	3.73(1.74)
Cone	1.30	1.16	0.68
Stump root	0.19	0.23	0.29
Lateral root	0.15	0.16	0.17
Fine root	0.26	0.28	0.37
Total	10.04(8.38)	10.23(8.44)	10.65(8.66)
Shrub			
Stem	0.03	0.04	0.03
Foliage	0.01	0.01	0.03
Root	0.01	0.01	0.01
Total	0.05	0.06	0.07
Herb			
Above-ground	2.20	2.14	2.22
Below-ground	0.23	0.21	0.21
Total	2.43	2.35	2.43
Total vegetation	12.52(10.86)	12.64(10.85)	13.15(11.16)

Values in parentheses are the uptakes after adjustment for retranslocation.

Table 5c. Potassium uptake (kg ha^{-1} y^{-1}) by different layers of vegetation and their components

Component	Plantation age (y)		
	15	18	21
Tree			
Bole	5.00	5.89	5.89
Branch	3.69	2.81	1.64
Twig	6.79	6.66	7.35
Foliage	13.45(4.17)	14.28(4.70)	17.43(5.74)
Cone	1.52	1.27	0.80
Stump root	0.41	0.47	0.48
Lateral root	0.33	0.34	0.34
Fine root	0.69	0.75	0.84
Total	31.88(22.60)	32.47(22.89)	34.77(23.08)
Shrub			
Stem	0.17	0.20	0.16
Foliage	0.10	0.09	0.19
Root	0.04	0.04	0.08
Total	0.31	0.33	0.43
Herb			
Above-ground	16.73	16.24	16.85
Below-ground	2.76	2.58	2.58
Total	19.49	18.82	19.43
Total vegetation	51.68(42.4)	52.62(42.04)	54.63(43.14)

Values in parentheses are the uptakes after adjustment for retranslocation.

Table 6. Concentration (% ± 1 s.e.) of nutrients in litterfall of different components of the vegetation

Component	Nutrient	Plantation age (y)		
		15	18	21
Needle	N	0.98 ± 0.061	0.98 ± 0.082	0.99 ± 0.068
	P	0.07 ± 0.010	0.07 ± 0.011	0.07 ± 0.013
	K	0.22 ± 0.056	0.23 ± 0.036	0.23 ± 0.041
Woody	N	0.52 ± 0.052	0.53 ± 0.042	0.53 ± 0.052
	P	0.06 ± 0.005	0.06 ± 0.006	0.06 ± 0.003
	K	0.16 ± 0.013	0.16 ± 0.009	0.16 ± 0.015
Shrub	N	0.86 ± 0.072	0.86 ± 0.062	0.86 ± 0.083
	P	0.07 ± 0.002	0.07 ± 0.007	0.07 ± 0.006
	K	0.36 ± 0.024	0.36 ± 0.030	0.36 ± 0.034
Herb	N	1.31 ± 0.064	1.31 ± 0.082	1.31 ± 0.083
	P	0.10 ± 0.021	0.10 ± 0.011	0.09 ± 0.008
	K	0.49 ± 0.062	0.47 ± 0.059	0.49 ± 0.051

Nutrient return through litterfall

The concentrations of nutrients are given in Table 6 and the amounts of nutrient return through litterfall in Table 7. The nutrient concentration values in litterfall in the present study are towards the lower limit of reported ranges; 0.54 - 3.49% for N, 0.06 - 0.32% for P and 0.09 - 1.05% for K (Foster & Gessel 1972, Turner & Singer 1976, Cole & Rapp 1980, Pandey 1980, Lang, *et al.* 1981). The values of total annual input of N, P and K via litterfall in the present study were low compared to those for plantations of *Pinus kesiya* (Das 1980) and *P. roxburghii* (Chaturvedi & Singh 1987).

The reasons for the differences in annual return of nutrients in various forests are numerous. As pointed out by Ovington (1956) and Henery (1977), the nutrient content in the leaf varies considerably among species and even within the same species in different localities. The density and age of forest which determine the quantity of litterfall also affect the nutrient return. Further differences in soil nutrient levels affect the nutrient concentration of leaves, hence the nutrient return (Ovington 1956). The edaphic factors have been shown to have a considerable influence on nutrient return (Duvigneaud & Denaeyer De Smet 1970). Edwards (1982) recognised two kinds of mineral turnover in forests: a rather rapid cycle in leaf and twig litter and in throughfall, and a slower cycle of minerals incorporated into larger woody axes. In the present study, the percentages of the nutrients in the above-ground standing crop that were returned through leaf litterfall were: N, 65 to 71%; P, 56 to 62%; and K, 57 to 59%, Edwards (1982) further argued that short term cycling of minerals is relatively rapid compared to the capital of minerals stored in vegetation, and that probably only a small proportion of the annual uptake of minerals is incorporated into new wood.

Table 7. Amounts (kg ha^{-1} y^{-1}) of N, P and K in different components of litterfall of the vegetation

Nutrient	Component	Plantation age (y)		
		15	18	21
N	Tree			
	Needle	9.78 ± 0.78	12.61 ± 0.96	16.83 ± 1.12
	Woody	5.28 ± 0.43	6.31 ± 0.58	6.89 ± 0.71
	Total	15.06	18.92	23.72
	Shrub	0.26 ± 0.03	0.26 ± 0.03	0.53 ± 0.05
	Herb	17.82 ± 1.09	17.29 ± 1.62	17.95 ± 1.34
	Total	33.14	36.47	42.20
P	Tree			
	Needle	0.72 ± 0.07	0.93 ± 0.10	1.22 ± 0.13
	Woody	0.57 ± 0.06	0.66 ± 0.06	0.73 ± 0.08
	Total	1.29	1.59	1.95
	Shrub	0.02 ± 0.001	0.02 ± 0.001	0.04 ± 0.003
	Herb	1.33 ± 0.14	1.29 ± 0.12	1.23 ± 0.16
	Total	2.64	2.90	3.22
K	Tree			
	Needle	2.19 ± 0.26	2.74 ± 0.24	2.99 ± 0.29
	Woody	1.62 ± 0.14	1.89 ± 0.21	2.08 ± 0.21
	Total	3.81	4.63	5.07
	Shrub	0.11 ± 0.01	0.11 ± 0.01	0.22 ± 0.02
	Herb	6.66 ± 0.60	6.20 ± 0.58	6.71 ± 0.74
	Total	10.58	10.94	12.09

Turnover of nutrients on the forest floor

In the present study the turnover rates of nutrients on the forest floor were estimated at 0.49 - 0.50 for N, 0.43 - 0.46 for P and 0.56 - 0.58 for K. The values of turnover time of nutrients on the forest floor reported by Pandey and Singh (1981) for mixed oak conifer forest, Chaturvedi and Singh (1987) for chir pine forest, and Rawat and Singh (1988) for oak forests are lower than those of the present study. In the present study the turnover times of N (2.0 - 2.04 y) and P (2.17-2.33 y) are longer than for K (1.72-1.89 y). These results are consistent with the observations of Reiners and Reiners (1970) and Lang and Formann (1978). K is soluble and readily leached from the organic matter and recycled faster than the other nutrients. Slower turnover of N and P in the litter layer is also caused by retranslocation before senescence (Gosz *et al.* 1973). Further, the conservative nature of microbial biomass controls the amount of these nutrients in forest floor and their turnover times are thus markedly longer (Maclean & Wein 1978).

Conclusion

The net nutrient uptake of *P. patula* plantations is low (N, 103-107 kg ha^{-1} y^{1}; P, 10.9 - 11.2 kg ha^{-1} y^{1}; K, 41.4 - 43.1 kg ha^{-1} y^{1}) as compared to natural *P. roxburghii* forest (N, 135.7 kg ha^{-1} y^{1}; P, 13.6 kg ha^{-1} y^{1}; K, 55.5 kg ha^{-1} y^{1}; Chaturvedi & Singh 1987) as well as natural forests of the surroundings (Singh & Singh 1987). The proportional retranslocation of nutrients from needles (leaves) during senescence in *P. patula* is on the higher side of the ranges reported for the Central Himalayan forest trees (21.5 - 53.5%, Singh & Singh 1987) and plantations of *Eucalyptus* and *Populus* species (25.2 - 62.3%, Bargali & Singh 1991) indicating that *P. patula* has relatively high efficient internal cycling of nutrients.

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