EFFICIENCY OF NUTRIENT UTILIZATION IN AN AGE SERIES OF *EUCALYPTUS TERETICORNIS* PLANTATIONS IN THE TARAI BELT OF CENTRAL HIMALAYA

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BARGALI, S. S. 1995. Efficiency of nutrient utilization in an age series of *Eucalyptus tereticornis* plantations in the Tarai belt of Central Himalaya. An attempt was made to examine the use of N, P and K in an age series of 1 to 8-y-old *Eucalyptus tereticornis* plantations in the Tarai belt of Central Himalaya. Various parameters were calculated, viz. nutrient uptake, nutrient reabsoprtion before leaf abscission, nutrient use efficiency, and above-ground productivity per unit leaf nutrient. The foliage nutrient concentration and fractional nutrient reabsorption before leaf abscission decreased with the increase in plantation age. The above-ground productivity per unit leaf nutrient (g g^{-1} leaf nutrient y^{-1}) decreased with the increase in plantation age as a result of which the nutrient use efficiency (g g^{-1}) increased with increasing plantation age.

Key words: *Eucalyptus tereticornis* - nutrient uptake - productivity - nutrient use efficiency

BARGALI, S.S. 1995. Kecekapan penggunaan nutrien dalam siri tahun ladang *Eucalyptus tereticornis* di kawasan Tarai di Himalaya Tengah. Satu percubaan dibuat untuk mengkaji penggunaan N, P dan K dalam siri tahun 1 hingga 8 tahun ladang *Eucalyptus tereticornis* di kawasan Tarai di Himalaya Tengah. Pelbagai parameter dikira, iaitu, pengambilan nutrien, penyerapan semula nutrien sebelum pengabsisan daun, keberkesanan penggunaan nutrien dan produktiviti atas tanah nutrien dari se unit daun. Kepekatan nutrien daun dan penyerapan semula nutrien berperingkat sebelum pengabsisan daun berkurangan dengan bertambahnya umur ladang. Produktiviti atas tanah nutrien dari se unit daun (g g^{-1} nutrien daun t^{-1}) berkurangan dengan bertambahnya umur ladang dan mengakibatkan kecekapan penggunaan nutrien (g g^{-1}) meningkat dengan pertambahan umur ladang.

Introduction

The circulation of nutrients in forests and plantations has received increasing attention over the past two to three decades with the major emphasis on the biological cycle between plant and soil of nutrient uptake, nutrient reabsorption before leaf senescence, nutrient use efficiency, etc. (Ovington 1965, Attiwill 1980, Bargali & Singh 1991, Bisht 1993). All these processes are ecologically important because plant nutrient uptake and nutrient recovey from senescing leaves are major components of ecosystem nutrient cycles.

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A large area in the Tarai (a level area with abundant surface water) region of Indian Central Himalaya has been planted with *Eucalyptus tereticornis* to cope with increasing demand for paper and pulp wood. Earlier researches on an age series of *E. tereticornis* plantations had suggested that the nutrient availability in the soil decreased with increasing plantation age (Bargali *et al.* 1992a, 1993). The objective of this study was to examine the relationship between nutrient availability and the various parameters (i.e. total nutrient uptake, nutrient recovery from senescing leaves and biomass produced per unit of nutrient uptake), in an age series (1 to 8 y) of *E. tereticornis* plantation.

Materials and methods

Study area

The study was carried out in the Tarai belt of Central Himalaya where uniform crops of *E. tereticornis* are being raised after clear-cutting of the uneven-aged natural mixed broad-leafed forests. All the eight sites were located between 29°3'-29°12' N and 79° 20' - 79° 23' E at an altitude of 280 m. The climate of this area is subtropical monsoon, with an annual rainfall of 1593 mm (Bargali & Singh 1991). About 86% of the rainfall occurs from mid-June to September, while there is a long dry season from October to mid-June. The mean monthly temperature ranges from 14 °C in January to 30 °C in June.

Geologically, Tarai is characterized by sedimentary deposits (sandstone) from the Tertiary. The soils in the area are deep, moist and fertile alluvial loams, conspicuously free from gravel. The forest vegetation, which is being replaced by eucalypt plantations, consists of deciduous and evergreen broad-leaved species such as *Acacia catechu, Adina cordifolia, Albizia* sp., *Bauhinia* sp., *Butea monosperma, Bombex ceiba, Mallotus phillippinensis, Shorea robusta, Syzygium cumini, Terminalia bellirica* and *Toona ciliata.*

Data collection

Soil samples were collected in triplicates from eight (1 to 8-y-old) *Eucalyptus* plantations by inserting a soil corer to 30 cm depth. Total nitrogen was determined by micro-Kjeldhal technique (Peach & Tracey 1956). For each replicate a 0.5 g sample of soil was digested in 10 ml concentrated sulphuric acid using 5 g catalyst mixture (potassium sulphate and cupric sulphate in ratio of 9:1), with quick digestion unit. Total nitrogen was determined by Kjel Auto VS-KTP nitrogen analyzer based on micro Kjeldhal technique. Phosphorus and potassium were extracted by wet ashing of 0.5 g soil sample, in acid mixture consisting of 10 ml H_2SO_4 + 3 ml HNO_3+ 1 ml $HClO_4$ following the methods of Jackson (1958). Phosphorus were determined by spectrophotomer and potassium by flame photometer. The amounts of nutrients in soil were obtained from bulk density (i.e. soil per unit volume) and nutrient concentration values.

Nutrient uptake was obtained by multiplying the values of net primary productivity (Bargali *et al.* 1992a) of different components by their respective nutrient concentrations (Bargali *et al.* 1992b) (Table 1). Foliage collection was made in the field from all-aged plantations. In every case 20 g of fully mature leaves were collected from all points around the basal perimeter of five individuals of each age plantation. Similar collections of attached senescent leaves that were ready to abscise were also made (leaves ready to abscise were considered if they fell off the branch when touched or when the branch was shaken lightly). The foliage collected from the five individuals was composited, resulting in one sample of mature and one sample of senescent foliage at each plantation site.

All foliage samples were dried at 60 °C, ground into fine powder, and analysed for nutrients following the method as used for soil. The leaching of nutrients was not considered separately.

Tablel. Biomass net primary productivity and nutrient content in 1 to 8-y-old *E. tereticornis* plantations (data from Bargali *et al.* 1992 a, b)

Age (years)	Total biomass ($t\ ha^{-1}$)	Foliar biomass ($t\ ha^{-1}$)	Root biomass ($t\ ha^{-1}$)	Net Primary productivity ($t\ ha^{-1}\ y^{-1}$)	Nutrient content in plant ($kg\ ha^{-1}$)		
					N	P	K
1	0.6 ± 0.01	0.2 ± 0.1	0.1	2.6	6.2	0.24	2.8
2	4.0 ± 0.7	0.6 ± 0.1	0.9	4.9	12.8	0.93	12.9
3	25.9 ± 1.6	2.7 ± 0.3	7.3	12.2	65.1	4.82	70.9
4	47.1 ± 6.1	4.0 ± 0.5	12.4	15.9	99.5	7.80	113.3
5	67.5 ± 9.2	5.5 ± 0.3	13.3	17.4	143.3	11.50	152.5
6	90.9 ± 17.2	7.4 ± 0.7	16.0	18.8	193.9	15.40	201.3
7	107.9 ± 16.4	8.7 ± 0.9	17.6	20.0	229.7	18.30	244.0
8	121.0 ± 23.4	9.4 ± 2.7	19.3	20.4	246.2	21.20	275.9

Data analysis

Data obtained were subjected to linear regression analysis to relate various parameters (i.e. nutrient in soil vs. nutrient uptake, foliage nutrient concentration vs. age of plantation, foliage nutrient concentration vs. reabsorption of nutrients, etc.). The linear equation used was of the type $Y = a + bX$, where a is the Y-intercept, and b is the slope of the regression coefficent (r).

Differences between nutrient concentrations of mature and abscising leaves were used to calculate an index of nutrient recovered or an index of nutrients recovery efficiency, which indicates the reabsorption of nutrients before leaf abscission (NUER), following Schlesinger *et al.* (1989).

$$\text{NUER} = \frac{\text{Concentration in mature foliage-concentration in senescent foliage}}{\text{Concentration in mature foliage}}$$

Above-ground productivity per g leaf nutrient (g g^{-1} leaf nutrient y^{-1}), which is the leaf nutrient demand per unit dry matter production was determined following Bisht (1992):

$$\text{Above-ground productivity per g leaf nutrient} = \frac{\text{Above-ground net production}}{\text{Foliar nutrient content}}$$

Nutrient use efficiency in growth (NUEG) or efficiency of nutrient use, which indicates the amount of biomass produced per unit of nutrient mass was calculated following Chapin (1980), Vitousek (1982), and Shaver and Melillo (1984):

$$\text{NEUG} = \frac{\text{Plant biomass}}{\text{Plant N or P or K mass}}$$

Results and discussion

In general, the nutrient content in the soil decreased with increase in plantation age, while the net uptake of nutrients increased with plantation age (Table 2). There existed negative correlations between nutrient availability and nutrient uptake by plants according to the equations given in Table 3. Harrison and Helliwell (1979) and Chapin *et al.* (1982) have suggested that, as nutrient availability decreased in the soil, the proportion of available nutrients taken up by the plants would increase. Low nutrient uptake by *Eucalyptus* in young plantations may have been due to saturation of their uptake capacity particularly at one and two-year-old plantations when root biomass was low (Table 1). The nutrient concentration as well as nutrient content in the soil decreased with age as a consequence of nutrient uptake by vegetation and leaching of nutrients following plantation.

Table 2. Nutrient content in soil and net nutrient uptake by plants in 1 to 8-y-old plantations

Age of plantation (years)	Nutrient in soil (kg ha^{-1})			Net nutrient uptake (kg ha^{-1} y^{-1})		
	N	P	K	N	P	K
1	7126.4	314.4	5259.0	9.32	0.89	7.95
2	7165.7	301.4	5330.9	15.22	1.10	12.80
3	7240.7	286.1	5048.5	32.91	2.16	24.34
4	7119.5	280.1	5131.3	42.90	2.88	29.74
5	7111.8	264.3	4503.2	48.38	3.06	30.36
6	7123.0	250.0	4429.6	56.85	3.40	31.63
7	7105.7	263.8	4418.3	64.63	3.86	37.54
8	7091.8	223.5	4401.1	67.60	4.06	37.15

The foliar nutrient concentration decreased with increasing plantation age (Table 4), possibly for the initial nutrient concentrations to be diluted with increasing age.There existed significant negative ($p < 0.01$) correlation between foliar nutrient concentration and plantation age (Table 3). In conformity to the trend of generally reported tendency for tissue nutrient to decrease with decrease in nutrient availability (Chapin 1980, Bisht 1993) the foliar nutrient concentration decreased with decrease in soil nutrient availability for all the nutrients examined (Table 4). Attiwill (1979, 1980) also reported similar results for *E. obliqua.*

Table 3. Summary of relationship between nutrient uptake, soil nutrient, foliar nutrient, age of plantation and fractional reabsorption of nutrients. Correlation coefficient r, intercept a and slope b are given. All regressions are of the type Y = a + bX and statistically significant ($p < 0.01$)

Y	a	b	X	r
N uptake	5625.2	- 0.784	Soil N	- 0.837
P uptake	13.0	- 0.038	Soil P	- 0.926
K uptake	132.3	- 0.022	Soil K	- 0.863
Foliar N	1.57	- 0.050	Plantation age	- 0.968
Foliar P	0.90	- 0.003	Plantation age	- 0.976
Foliar K	0.98	- 0.015	Plantation age	- 0.969
N reabsorption	43.82	- 2.49	Plantation age	- 0.975
P reabsorption	45.24	- 3.45	Plantation age	- 0.990
K reabsorption	68.58	- 0.77	Plantation age	- 0.984
N reabsorption	- 33.94	49.35	Foliar N	0.997
P reabsorption	- 58.43	1144.74	Foliar P	0.991
K reabsorption	- 20.72	48.89	Foliar K	0.997

As nutrient availability decreased with increasing plantation age, the proportion of nutrient in mature leaves that was recovered before leaf abscission decreased (Table 4). Ostman and Weaver (1982), and Chapin and Kedrowski (1983) also reported a similar relationship between availability of nutrients and nutrient reabsorption. There existed significant negative correlation between percentage nutrient reabsorption and age of plantation and significant positive correlation between nutrient concentration in mature leaves and reabsorption of nutrients (Table 3). Chapin and Kedrowski (1983) also reported a similar relationship between NUER and foliar nutrient concentration. The low NUER for *Eucalyptus* suggests that *E. tereticornis* plants with lower nutrient status are less effective at nutrient reabsorption than are plants with higher nutrient status. The decreased NUER with increasing age indicates that the nutrient supply to new primary production must depend more upon uptake and less upon internal recycling within plants (Turner & Olsen 1976, Gray & Schlesinger 1983, Shaver & Melillo 1984). However, the amount of foliar nutrient reabsorbed before leaf abscission increased with increasing plantation age (Table 4), possibly because of increasing amount of foliage with increasing age (Table 1).

The biomass and net primary productivity increased significantly ($p < 0.01$) with age (Table 1), Similar observations were also reported by Attiwill (1980) for *E. obliqua* and Bradstock (1981) for *E. grandis*. The foliar nutrient demand per unit of net primary production (Table 5) indicates that with increasing age, *Eucalyptus* requires larger foliar crop per unit of net primary production and indicates its early successional trait.

Table 4. Comparisons of foliar nutrient concentration and nutrient reabsorption in 1 to 8-y-old plantations of *E. tereticornis*. Concentration data are means ± 1 SE with n = 3

Age of plantation	Nutrient	Concentration (%) in mature foliage (A)	Concentaration (%) in senescent foliage (B)	A-B	A-B x 100 / A	Amount of nutrient reabsorption kg $ha^{-1}y^{-1}$
1	N	1.557 ± 0.073	0.899 ± 0.065	0.658	42.26	9.3
	P	0.089 ± 0.004	0.051 ± 0.005	0.038	42.69	0.3
	K	0.956 ± 0.020	0.309 ± 0.021	0.647	67.68	6.4
2	N	1.494 ± 0.080	0.897 ± 0.060	0.597	39.96	6.0
	P	0.086 ± 0.005	0.053 ± 0.004	0.033	38.37	0.3
	K	0.953 ± 0.076	0.312 ± 0.023	0.641	67.26	6.6
3	N	1.412 ± 0.099	0.898 ± 0.058	0.514	36.40	11.3
	P	0.081 ± 0.005	0.052 ± 0.004	0.029	35.80	0.6
	K	0.947 ± 0.024	0.315 ± 0.023	0.632	66.74	14.1
4	N	1.324 ± 0.108	0.905 ± 0.069	0.419	31.65	12.0
	P	0.076 ± 0.006	0.053 ± 0.002	0.023	30.26	0.6
	K	0.907 ± 0.031	0.316 ± 0.023	0.591	65.16	17.5
5	N	1.285 ± 0.117	0.909 ± 0.067	0.376	29.26	12.0
	P	0.074 ± 0.006	0.055 ± 0.004	0.019	25.67	0.6
	K	0.890 ± 0.031	0.319 ± 0.022	0.571	64.16	18.5
6	N	1.273 ± 0.121	0.900 ± 0.067	0.373	29.30	14.5
	P	0.073 ± 0.007	0.055 ± 0.004	0.018	24.66	0.7
	K	0.890 ± 0.036	0.319 ± 0.023	0.571	64.16	22.2
7	N	1.227 ± 0.112	0.901 ± 0.063	0.326	26.57	14.4
	P	0.070 ± 0.006	0.055 ± 0.004	0.015	21.43	0.7
	K	0.866 ± 0.029	0.320 ± 0.023	0.546	63.05	24.3
8	N	1.212 ± 0.117	0.906 ± 0.065	0.306	25.24	14.3
	P	0.069 ± 0.007	0.056 ± 0.003	0.013	18.84	0.6
	K	0.857 ± 0.026	0.320 ± 0.023	0.537	62.66	25.2

The nutrient use efficiency of *Eucalyptus* increased with increasing age of plantation and decreasing nutrient avilability (Table 5). It has been suggested by Vitousek (1984) for forest ecosystems, and Gray and Schlesinger (1983) for shrubs, that as N or P availability decreased, the amount of biomass produced per unit of N or P uptake should increase. The high nutrient use efficiency observed in higher age plantation may be related to decreased availability of nutrients (Blair & Cordero 1978); as nutrient in soil decreased with increasing plantation age, the *Eucalyptus* tended to compensate through more efficient use of the nutrients.

Table 5. Above-ground productivity per unit leaf nutrient and nutrient use efficiency for 1 to 8-y-old *E. tereticornis* plantations

Age of plantation (years)	Above-ground productivity per unit leaf nutrient ($g\ g^{-1}$ leaf nutrient y^{-1})			Nutrient use efficiency ($g\ g^{-1}$)		
	N	P	K	N	P	K
1	782.88	13987.47	1311.32	171.67	2503.50	214.58
2	477.49	8432.27	747.77	316.93	4362.00	314.47
3	237.94	4064.56	352.05	397.46	5368.17	364.94
4	228.00	3920.18	332.95	473.63	6041.83	415.94
5	199.58	3470.82	299.58	470.81	5866.67	442.40
6	169.56	2961.12	242.64	469.03	5905.48	451.78
7	152.36	2667.60	215.82	470.06	5900.13	442.51
8	151.86	2632.30	217.16	491.58	5708.81	438.66

This study showed that as the nutrient uptake by the plant increased with increasing age of plantation, the nutrient content of the soil decreased. This decrease in soil nutrient content caused a decrease in nutrient recovery before leaf senescence. As a result, nutrient use efficiency of the plant increased with increasing age of plantation. The effect may be mediated by adjustment of uptake kinetics and allocation pattern.

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