Tropical Ecology **47**(2): 259-269, 2006 ISSN 0564-3295

www.tropecol.com

Growth and leaf nutrient status of companion species as influenced by neighbouring species in mixed plantations raised on mine spoil

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Abstract: Effect of neighbouring species on growth and foliar nutrient status of companion species was studied in mixed plantation raised on coal mine spoil. The three combinations used were legume:legume,legume:non-legume and non-legume:non-legume. The neighbouring species had influenced the growth and foliar N and P status of companion species in mixed plantations. *Acacia catechu* had shown greater growth and foliar N and P status when grown with neighbouring legume *Pongamia pinnata* than when grown with another neighbouring legume *Albizia lebbeck*. The growth and foliar N and P status of non-legumes *Gmelina arborea* and *Terminalia bellerica* were greater when these species were grown with the legume *Pongamia pinnata* than when grown with non-legume. The legume *Pongamia pinnata* had exhibited better growth and increased N and P concentration when grown with non-legumes *Gmelina arborea* and *Terminalia bellerica* than when grown with legume *Acacia catechu*. *Tectona grandis,* on other hand side, had shown reduced growth and foliar N and P concentration, when grown with neighbouring legumes *Dalbergia sissoo* and *Leucaena leucocephala* than when grown with neighbouring non-legume *Dendrocalamus strictus*. The growth rates (height, diameter and volume increments) were positively related to foliar N and P concentration.

Resumen: Se estudió el efecto de especies vecinas sobre el crecimiento y el estatus de los nutrientes foliares de especies acompañantes en plantaciones mixtas establecidas sobre desechos de minas de carbón. Las tres combinaciones utilizadas fueron leguminosa:leguminosa, leguminosa:no leguminosa y no leguminosa:no leguminosa. Las especies vecinas influyeron sobre el crecimiento y el estatus del N y el P foliares de las especies acompañantes en las plantaciones mixtas. *Acacia catechu* mostró un mayor crecimiento y un mejor estatus de N y P cuando creció con la leguminosa vecina *Pongamia pinnata* que cuando creció con *Albizia lebbeck*, otra leguminosa vecina. El crecimiento fue mayor y el estatus foliar de N y P de las no leguminosas *Gmelina arborea* y *Terminalia bellerica* fue mayor cuando éstas crecieron con la leguminosa *Pongamia pinnata* que cuando crecieron con una no leguminosa. La leguminosa *Pongamia pinnata* tuvo un mejor crecimiento e incrementó sus concentraciones de N y P cuando creció con las no leguminosas *Gmelina arborea* y *Terminalia bellerica* que cuando creció con la leguminosa *Acacia catechu. Tectona grandis,* por otra parte, mostró un crecimiento y concentraciones de N y P foliares más bajos al crecer con las leguminosas vecinas *Dalbergia sissoo* y *Leucaena leucocephala*, que cuando creció con la vecina no leguminosa *Dendrocalamus strictus*. Las tasas de crecimiento (incrementos en altura, diámetro y volumen) estuvieron relacionadas positivamente con la concentración foliar de N y P.

Resumo : O efeito das espécies vizinhas no crescimento e no status dos nutrientes nas folhas das espécies companheiras foi estudado em plantações mistas crescendo em solos de

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despojos mineiros de carvão. As três combinações usadas foram: leguminosa, leguminosa : não leguminosa e não leguminosa : não leguminosa. As espécies vizinhas influenciaram o crescimento e o status do N e P foliares das espécies companheiras em plantações mistas. A *Acacia catechu* evidenciou uma maior crescimento e um status de N e P foliares maiores quando vegetando na vizinhança de uma leguminosa a *Pongamia pinnata* do que quando crescendo com outra leguminosa a *Albizia lebbeck.* O crescimento e o status do N e P foliar nas espécies não leguminosas *Gmelina arborea* e *Terminalia bellerica* eram maiores quando estas espécies cresciam com uma leguminosa, a *Pongamia pinnata,* quando em confronto com a ausência de uma leguminosa. A leguminosa *Pongamia pinnata* exibiu um melhor crescimento e apresentou uma maior concentração de N e P quando crescendo com não leguminosas como a *Gmelina arborea* and *Terminalia bellerica* do que crescia associada à *Acacia catechu*, uma leguminosa. A *Tectona grandis*, por seu lado, mostrou um crescimento reduzido e uma menor concentração de N e P foliar quando na vizinhança das leguminosas *Dalbergia sissoo* e *Leucaena leucocephala* do que quando crescendo na vizinhança de uma não leguminosa a *Dendrocalamus strictus.* As taxas de crescimento (altura, diâmetro e o acréscimo do volume) mostraram-se positivamente relacionados com a concentração do N e P foliares.

Key words: Diameter increment, foliar N, foliar P, height increment, neighbouring species, volume increment.

Introduction

During mining operations overburden materials overlying a coal seam are removed and dumped in haphazard manner without any consideration for the respective sequence of soil profile. This overburden dump is known as mine spoil. Mine spoil is nutritionally and microbiologically impoverished habitat (Singh & Jha 1993). This drastically disturbed system is highly prone to erosion and could cause contamination of rivers and adjoining agricultural lands with harmful substances leached out from it through rain water. Therefore, stabilisation of mine spoil becomes inevitable.

Natural restoration of mine spoil is a slow process (Iverson & Wali 1982) but it can be accelerated by planting woody species. The planted woody species in mixed plantations of various combinations increase the biological fertility and biodiversity of mine spoil. Several field studies report positive effect of neighbouring species on growth and production of companion species in mixed plantation (Binkley 1983; Binkley *et al.* 1992; de Wit *et al.* 1966; Funk *et al.* 1979; Heilman 1983; Schlesinger & Williams 1984; Trenbath 1976; Vandermeer 1989; Van Sambeck *et al.* 1985). However, contrary to this other studies suggests negative effect of neighbouring species on growth and production of companion species in mixed plantations (Dawson & Gordon 1979; De Bell & Radwan 1979; Hansen & Dawson 1982; Jobidon & Thibault 1982; Younger & Kapustaka 1983).

The objective of the present study was to evaluate the influence of neighbouring species on growth and leaf nutrient status of companion species in mixed plantation of various combinations raised for revegetation of coal mine spoil.

Materials and methods

Site description

The study was conducted at the Jayant coal mine in Singrauli coalfields, India. Singrauli coalfields extend over 2200 km^2 (23°47' - 24° 12' N; 81°48' - 82°52' E and elevation of 280 - 519 m above mean sea level), of which 80 km^2 lies in Uttar Pradesh and rest in Madhya Pradesh. The climate is tropical monsoonal and the year is divisible into a mild winter (November-February), a hot summer (April-June) and a warm rainy season (July-September). March and October are transitional months. Mean monthly minimum temperature within an annual cycle ranges from 6.4 to 28°C and mean monthly maximum from 20 to 48°C. The annual rainfall averages 1069 mm, 90% of which occurs during the period between June and September. The texture of the spoil material was 80% sand, 10% silt, and 10% clay, with a pH of 7.4, total N 0.013% and total P 0.0085% (Singh 1999). Soil cores to a depth of 10 cm consisted of 86% of particles greater than 2 mm in diameter. The potential natural vegetation is a tropical dry deciduous forest.

Experimental design and methods

A mixed culture plantation experiment was set on fresh mine spoil in July 1993. Nursery raised 1 year old individuals of different woody species were planted in three different types of combination i.e., legume : legume combination, legume : non-legume combination, and non-legume :non-legume combination. The legume : legume combinations were *Acacia catechu : Albizia lebbeck,* and *Acacia catechu : Pongamia pinnata,* Legume : non-legume combinations were *Dalbergia sissoo : Tectona grandis, Leucaena leucocephala : Tectona grandis, Pongamia pinnata : Gmelina arborea* and *Pongamia pinnata : Terminalia bellerica.* The non-legume : non-legume combinations were *Azadirachta indica: Phyllanthus emblica, Gmelina arborea : Terminalia bellerica* and *Dendrocalamus strictus : Tectona grandis.* Of the eleven species used, *A. catechu, A. lebbeck, D. sissoo, L. leucocephala* and *P. pinnata* were N_2 fixing leguminous species and the remaining were non-leguminous species. Species were planted in different rows within 20 m x 20 m plots at a spacing of 2 m x 2 m. Three replicate plots were maintained for each of the combinations except *G. arborea:T. bellerica,* where only one plot could be maintained.

For growth studies five individuals were selected for each species in each plot. Thus a total of fifteen individuals were selected for each species, except for the combination of *G. arborea* : *T. bellerica* where only five individuals were selected because only one plot could be maintained. In case of *D. strictus* five clumps were selected in each plot. First measurement of height and diameter of the marked individuals was done for the first year of study in April 1996 (i.e. 33 months after plantation). The marked trees were measured after 20 months in December 1997 (the second year of study, i.e. 53 months after plantation). Diameter measurement was done 20 cm above the ground surface. Height was measured using scaled bamboo stick. Volume was calculated as height x (stem diameter)^2, a commonly used predicator of tree biomass (De Bell *et al.* 1989; Zavitkovski & Stevens 1972).

Mature, healthy leaves were collected from exposed, mid canopy positions of the tagged trees in September 1997, dried at 80°C and powdered for chemical analysis. Foliage N was estimated with the microkjeldahl method of Jackson (1958). Phosphorus was analysed after digestion in a mixture of $HClO_4$, HNO_3 and H_2SO_4 (1:5:1) using the phosphomolybdic acid blue method of Jackson (1958).

Growth rate was assessed as annual increments in height, diameter and volume from the differences in values measured in April 1996 and December 1997. The influence of leaf nutrient status on growth was explored through regression analysis. Data were subjected to Analysis of variance (Snedecor & Cochran 1968) for each combination except those of *G. arborea : T. bellerica* combination. Differences between treatment means were tested for significance through a two-tailed Student's *t*- test.

Results

Height, diameter and volume

Legume *A. catechu* grown with the legume *P. pinnata* exhibited higher value for height, diameter and volume in both the years than *A. catechu* interplanted with legume *A. lebbeck* (Table 1). Analysis of variance revealed significant effect of species (d.f. 1;28) on height (F = 4.86; P = 0.031), diameter (F = 8.84; P = 0.004) and volume (F = 5.53; P = 0.022) whereas, year x species interaction was not significant.

The legume *P. pinnata* was grown with two non-legumes viz. *G. arborea* and *T. bellerica* (Table 2) and with the legume *A. catechu* (Table 1). *P. pinnata* grown with *G. arborea* attained greater height, diameter and volume than when interplanted with *T. bellerica* (Table 2). *P. pinnata* grown with the legume *A. catechu* exhibited lowest values for height, diameter and volume (Table 1) among the three combinations. Analysis of variance indicated significant effect of species (d.f. 2;84) on height F = 12.69; P = 0.001), diameter (F =24.83; P = 0.000) and volume (F = 21.69; P = 0.000), and the year x species interaction was significant only for volume (F=3.43; P = 0.045).

The non-legume *G. aborea* was grown with the legume *P. pinnata* (Table 2) and non-legume *T. bellerica* (Table 3). *G. arborea* grown with *P. pinnata* attained greater height, diameter and volume than *G. arborea* grown with *T. bellerica* (Tables 2 and 3).

The non-legume *T. grandis* was grown with legumes *D. sissoo* and *L. leucocephala* (Table 2) and non-legume *D. strictus* (Table 3). *T. grandis* grown with *D. sissoo* had greater height, diameter and volume than *T. grandis* grown with *L. leucocephala* (Table 2). The highest values for height, diameter and volume, however, were realized by *T. grandis* when the latter was grown with *D. strictus* (Table 3). Analysis of variance revealed significant effect of species (d.f. 2;84) on

Table 1. Height, diameter and volume in tree species of two different ages in mixed plantations of legume: legume combination; values are Mean ± 1 S. E.

Species	Age (month)	Height (m)	Diameter (cm)	Volume (cm^3)
		Acacia catechu : Albizia lebbeck		
Acacia catechu	33	1.6 ± 0.1	3.1 ± 0.2	1760 ± 341
	53	2.3 ± 0.1	4.3 ± 0.3	4605 ± 891
Albizia lebbeck	33	1.9 ± 0.2	3.6 ± 0.3	3437 ± 214
	53	2.4 ± 0.2	4.5 ± 0.4	6384 ± 1950
		Acacia catechu : Pongamia pinnata		
Acacia catechu	33	1.9 ± 0.1	3.6 ± 0.2	2672 ± 317
	53	2.4 ± 0.1	5.1 ± 0.2	6821 ± 869
Pongamia pinnata	33	2.0 ± 0.1	3.2 ± 0.2	2347 ± 420
	53	2.4 ± 0.2	4.0 ± 0.3	4595 ± 899

Table 2. Height, diameter and volume in tree species of two different ages in mixed plantations of legume : non-legume combination; values are Mean ± 1 S. E.

Species	Age (month)	Height (m)	Diameter (cm)	Volume (cm^3)
		Dalbergia sissoo : Tectona grandis		
Dalbergia sissoo	33	2.4 ± 0.1	4.0 ± 0.3	4497 ± 944
	53	3.1 ± 0.2	4.8 ± 0.4	8627 ± 1814
Tectona grandis	33	1.3 ± 0.1	2.8 ± 0.1	1061 ± 149
	53	1.6 ± 0.1	3.5 ± 0.2	2083 ± 291
		Leucaena leucocephala : Tectona grandis		
Leucaena leucocephala	33	2.9 ± 0.2	4.7 ± 0.4	8061 ± 2079
	53	4.0 ± 0.3	6.2 ± 0.6	19483 ± 5041
Tectona grandis	33	1.2 ± 0.1	2.4 ± 0.2	899 ± 218
	53	1.5 ± 0.1	2.9 ± 0.3	1520 ± 369
		Pongamia pinnata : Gmelina arborea		
Pongamia pinnata	33	2.7 ± 0.2	4.7 ± 0.3	6791 ± 1051
	53	3.3 ± 0.2	6.4 ± 0.4	15138 ± 2342
Gmelina arborea	33	2.6 ± 0.3	6.1 ± 0.8	15595 ± 510
	53	3.4 ± 0.3	7.3 ± 0.9	29395 ± 9639
		Pongamia pinnata : Terminalia bellerica		
Pongamia pinnata	33	2.1 ± 0.1	3.5 ± 0.2	2768 ± 440
	53	2.6 ± 0.2	4.8 ± 0.3	6710 ± 1062
Terminalia bellerica	33	1.1 ± 0.1	2.9 ± 0.2	1134 ± 280
	53	1.4 ± 0.1	3.6 ± 0.3	2213 ± 546

height (F=7.66; P = 0.000), diameter (F=18.98; P = 0.000) and volume (F= 12.97; P = 0.000) and the year x species interaction was not significant.

The non-legume *T. bellerica* was grown with the legume *P. pinnata* (Table 2) and the non-legume *G.arborea* (Table 3). *T. bellerica* grown

Table 3. Height, diameter and volume in woody species of two different ages in mixed plantations of non-legume : non-legume combination; values are Mean ± 1 S. E.

Species	Age (month)	Height (m)	Diameter (cm)	Volume (cm^3)
	Azadirachta indica : Phyllanthus emblica			
Azadirachta indica	33	2.0 ± 0.2	3.4 ± 0.2	2720 ± 621
	53	2.4 ± 0.2	4.2 ± 0.3	5147 ± 1174
Phyllanthus emblica	33	1.5 ± 0.1	2.2 ± 0.1	812 ± 130
	53	1.8 ± 0.1	2.7 ± 0.2	1557 ± 260
	Gmelina arborea : Terminalia bellerica			
Gmelina arborea	33	1.5 ± 0.1	3.8 ± 0.3	2291 ± 467
	53	2.1 ± 0.1	5.2 ± 0.5	6005 ± 1220
Terminalia bellerica	33	0.8 ± 0.2	2.3 ± 0.4	583 ± 219
	53	1.1 ± 0.2	3.0 ± 0.5	1311 ± 478
	Tectona grandis : Dendrocalamus strictus			
Tectona grandis	33	1.5 ± 0.1	3.7 ± 0.3	2572 ± 566
	53	1.9 ± 0.1	4.6 ± 0.4	5045 ± 1105
Dendrocalamus strictus	33	2.0 ± 0.1	1.9 ± 0.1	742 ± 96
	53	2.0 ± 0.1	2.0 ± 0.1	853 ± 107

Table 4. Foliar N and P concentration in woody species of various species combination in mixed plantations raised on mine spoil; Mean ± 1 S.E.

Species combination/ Species group	Species	N concentration (%)	P concentration (%)
Legume vs Legume			
A. catechu : A. lebbeck	*A. catechu*	2.02 ± 0.04[a]	0.147 ± 0.008[a]
	A. lebbeck	1.95 ± 0.03	0.152 ± 0.004
A. catechu : P. pinnata	*A. catechu*	2.11 ± 0.03[a]	0.152 ± 0.004[a]
	P. pinnata	2.0 ± 0.03[a]	0.134 ± 0.006[a]
Legume vs Non-legume			
D. sissoo : T. grandis	*D. sissoo*	1.88 ± 0.02	0.156 ± 0.005
	T. grandis	0.94 ± 0.02[a]	0.098 ± 0.004[a]
L. leucocephala : T. grandis	*L. leucocephala*	2.35 ± 0.03	0.129 ± 0.003
	T. grandis	0.92 ± 0.01[a]	0.094 ± 0.008[a]
P. pinnata : G. arborea	*P. pinnata*	2.12 ± 0.01[b]	0.156 ± 0.004[b]
	G. arborea	1.75 ± 0.02[a]	0.160 ± 0.009[a]
P. pinnata : T. bellerica	*P. pinnata*	2.04 ± 0.02[a]	0.147 ± 0.008[ab]
	T. bellerica	1.04 ± 0.03[a]	0.103 ± 0.006[a]
Non-legume vs Non-legume			
A. indica : P. emblica	*A. indica*	1.65 ± 0.02	0.156 ± 0.004
	P. emblica	1.08 ± 0.01	0.103 ± 0.009
G. arborea : T. bellerica	*G. arborea*	1.60 ± 0.01[b]	0.147 ± 0.008[a]
	T. bellerica	0.92 ± 0.01[b]	0.098 ± 0.002[a]
T. grandis : D. strictus	*T. grandis*	1.0 ± 0.03[a]	0.103 ± 0.004[a]
	D. strictus	1.70 ± 0.02	0.112 ± 0.006

Values in a column for a species suffixed with different letters are significantly different from each other at P < 0.05.

with *P. pinnata* exhibited greater height, diameter and volume than *T. bellerica* interplanted with *G. arborea* (Tables 2 and 3).

In non-legume : non-legume combination, *A. indica* grown with only species *P. emblica* had shown greater height, diameter and volume in comparison to its neighbouring partner species (Table 3).

Foliar N and P concentration

The foliar N concentration in *A. catechu* ranged between 2.02 and 2.11%, the value being higher when the species was grown with *P. pinnata* than when grown with *A. lebbeck* (Table 4). The same pattern was followed by foliar P concentration which ranged between 0.147 and 0.152% (Table 4).

The foliar N and P concentration in *P. pinnata* ranged between 2.0 to 2.12% and 0.134 to 0.156%, respectively (Table 4). *P. pinnata* when grown with *G. arborea* had greater foliar N and P concentrations than when interplanted with *T. bellerica* (Table 4). The lowest foliar N and P concentrations were recorded in this species when it was grown with legume *A. catechu* (Table 4).

The foliar N concentration in *G. arborea* ranged between 1.60 and 1.75%, the value being higher when the species was grown with the legume *P. pinnata* than when grown with non-legume *T. bellerica* (Table 4). The same pattern was followed by foliar P concentration which ranged between 0.147 and 0.160% (Table 4).

The foliar N and P concentration in *T. grandis* ranged between 0.92 to 1.0% and 0.094 to 0.103%, respectively (Table 4). *T. grandis* when grown with *D. sissoo* had greater foliar N and P concentrations than when interplanted with *L. leucocephala* (Table 4). The highest foliar N and P concentrations were recorded in this species when it was grown with the non-legume *D. strictus* (Table 4).

The foliar N concentration in *T. bellerica* ranged between 0.92 and 1.04%, the value being higher when the species was interplanted with the legume *P. pinnata* than when interplanted with the non-legume *G. arborea* (Table 4). The

Table 5. Annual height, diameter and volume increments in woody species of various species combination in mixed plantations raised on mine spoil; Mean ± 1 S.E.

Species combination/ Species group	Species	Height (m)	Diameter (cm)	Volume (cm^3)
Legume vs Legume				
A. catechu : A. lebbeck	*A. catechu*	0.38 ± 0.02^a	0.68 ± 0.05^a	1707 ± 329^a
	A. lebbeck	0.28 ± 0.02	0.51 ± 0.04	1768 ± 530
A. catechu : P. pinnata	*A. catechu*	0.29 ± 0.03^b	0.91 ± 0.04^b	2489 ± 334^a
	P. pinnata	0.28 ± 0.02^a	0.47 ± 0.04^a	1349 ± 292^a
Legume vs Non-legume				
D. sissoo : T. grandis	*D. sissoo*	0.41 ± 0.02	0.52 ± 0.04	2479 ± 521
	T. grandis	0.19 ± 0.01^a	0.42 ± 0.02^a	613 ± 85^a
L. leucocephala : T. grandis	*L. leucocephala*	0.68 ± 0.05	0.89 ± 0.08	5854 ± 1777
	T. grandis	0.14 ± 0.01^b	0.27 ± 0.02^b	373 ± 91^a
P. pinnata : G. arborea	*P. pinnata*	0.37 ± 0.02^b	0.98 ± 0.06^b	5008 ± 775^b
	G. arborea	0.47 ± 0.05^a	0.73 ± 0.09^a	8279 ± 2720^a
P. pinnata : T. bellerica	*P. pinnata*	0.32 ± 0.02^{ab}	0.80 ± 0.06^c	2362 ± 373^c
	T. bellerica	0.19 ± 0.01^a	0.40 ± 0.03^a	647 ± 160^a
Non-legume vs Non-legume				
A. indica : P. emblica	*A. indica*	0.26 ± 0.02	0.49 ± 0.03	1456 ± 332
	P. emblica	0.21 ± 0.01	0.32 ± 0.02	448 ± 79
G. arborea : T. bellerica	*G. arborea*	0.34 ± 0.02^b	0.86 ± 0.08^a	2228 ± 452^b
	T. bellerica	0.15 ± 0.02^a	0.45 ± 0.08^a	437 ± 155^a
T. grandis : D. strictus	*T. grandis*	0.22 ± 0.02^a	0.57 ± 0.04^c	1483 ± 323^b
	D. strictus	0.04 ± 0.0004	0.12 ± 0.01	111 ± 16

Values in a column for a species suffixed with different letters are significantly different from each other at $P < 0.05$.

same pattern was followed by foliar P concentration which ranged between 0.098 and 0.103% (Table 4).

The non-legume *A. indica* grown in a single combination with *P. emblica* had a greater foliar N and P concentration than it's neighbouring partner species in mixed plantation of non-legume : non-legume combination (Table 4).

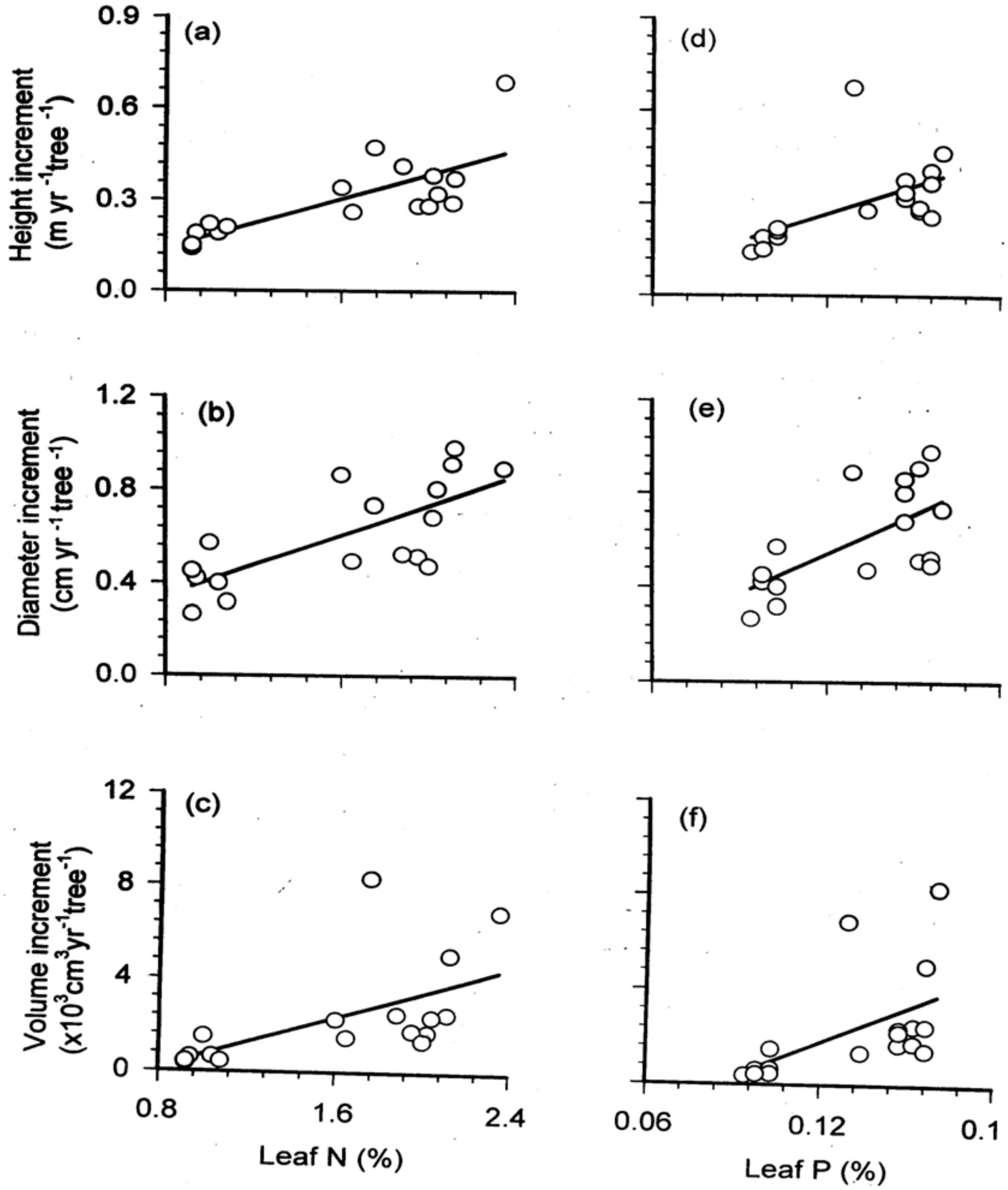

Fig. 1. Relationships between leaf nutrient status and growth parameters. Regression equations are (a) Height increment Vs Leaf N : Y = -0.02 + 0.202 X (r^2 = 0.59, P <0.01), (b) Diameter increment Vs Leaf N : Y = 0.091+0.32 X (r^2=0.54, P<0.01), (c) Volume increment Vs Leaf N : Y =-1.95+2.678 X (r^2=0.36, P<0.05), (d) Height increment Vs Leaf P: Y= -0.099+3.07 X (r^2 =0.34, P<0.05) (e) Diameter increment Vs Leaf P : Y =-0.14+5.66 X (r^2=0.42), P<0.01), (f) Volume increment Vs Leaf P : Y = -4.106+49.12 X (r^2=0.299, P<0.05).

Growth rates (height, diameter and volume increments)

The per tree annual diameter and volume increments were greater in the legume *A. catechu* grown with *P. pinnata* while the per tree height increment was greater in *A. catechu* grown with *A. lebbeck* (Table 5). Analysis of variance revealed significant effect of species (d.f.1;28) on height increment (F=6.46; P=0.016) and diameter increment (F=13.43; P=0.001) but the effect on volume increment was not significant.

The per tree annual height, diameter and volume increments were greater in *P. pinnata* grown with *G. arborea* than *P. pinnata* grown with *T. bellerica* (Table 5). The lowest per tree height, diameter and volume increments in *P. pinnata* were recorded when the species was grown with another legume *A. catechu* (Table 5). Analysis of variance revealed significant effect of species (d.f. 2; 42) on height increment (F = 4.06; P = 0.024), diameter increment (F=24.97; P = 0.000) and volume increment (F=12.98; P = 0.000).

The per tree annual height and volume increments were greater in *G. arborea* grown with *P. pinnata* but the diameter increment was greater in *G. arborea* when grown with *T. bellerica* (Table 5).

The per tree annual height, diameter and volume increments were greater in *T. grandis* grown with *D. sissoo* than *T. grandis* grown with *L. leucocephala* (Table 5). Among the three combinations, the highest annual height, diameter and volume increments were recorded in *T. grandis* grown with non-legume *D. strictus* (Table 5). Analysis of variance revealed significant effect of species (d.f. 2; 42) on height increment (F=8.15; P=0.001), diameter increment (F=22.44; P=0.000) and volume increment (F=8.54; P=0.000).

The per tree annual height and volume increments were greater in *T. bellerica* grown with the legume *P. pinnata* but the diameter increment was greater in *T. bellerica* grown with the non-legume *G. arborea* (Table 5).

The per tree annual height diameter and volume increments were comparatively greater in non-legume *A. indica* grown in only one combination with *P. emblica* in mixed plantation of non-legume : non-legume combination (Table 5).

Relationships between leaf nutrient status and growth rates

Height, diameter and volume increments have had significant positive relationship with foliar N and P concentrations (Fig. 1).

Discussion

The study revealed that the effect of N_2 fixing species as neighbour is not always beneficial for the growth of non-N_2 fixing species. *T. grandis* exhibited poor performance when grown with legumes *D. sissoo* and *L. leucocephala* but its growth was significantly greater when grown with the non-legume *D. strictus*. Thus both the fast growing leguminous species suppressed the growth of slow growing *T. grandis*. Studies in young developing mixed stands by Cole & Newton (1986, 1987) indicated that the competition for resources and resulting suppression of Douglas-fir by N_2-fixing alder out weighed any positive effect that the N_2-fixing alder may have on Douglas-fir growth. Other studies have also reported that in mixed plantations the fast growing species suppress the growth of companion species (Dawson & Gordon 1979; De Bell & Radwan 1979; Hansen & Dawson 1982). Initial size differences in mixed plantations play a role in determining the competition hierarchy (Shainsky & Radosevich 1992). Newton *et al.* (1968) reported that the difference in height growth rate sustained over time was probably the most important factor in determining alder's competitive superiority over Douglas-fir. Alder's ability to grow tall and produce copious leaf area at heights above the Douglas-fir allowed it to preempt light, as well as soil moisture and thus reduce Douglas-fir growth.

In contrast to the result obtained for *T. grandis,* the growth of non-legumes *G. arborea* and *T. bellerica* was greater when these species were grown with the legume *P. pinnata* than when grown with non-legumes. This suggested a positive effect of N_2 fixing legumes on growth of non-legumes. Several studies have indicated that mixed stands of N_2 fixing and non-fixing species are more productive than the monoculture components (de Wit *et al.* 1966; Trenbath 1976; Vandemeer 1989). Heilman (1983) found that the Douglas-fir growth was improved when interplanted with N_2 fixing alder. Similarly, black alder, a non-leguminous N_2 fixing tree, increased the growth of associated hybrid poplar in mixed plantation (Côté & Camire 1984; Hansen & Dawson 1982). In young plantation containing alder, height growth of *Populus* spp. increased from 23 to 56% (Côté & Camiré 1985; De Bell & Radwan 1979; Hansen & Dawson 1982). Joshi & Singh (1998) reported better growth in oak in the presence of N_2 fixing alder than when the oak was grown alone. Benefits from N_2 fixation are more likely to occur on sites that are less fertile (Binkley 1983). This may be the reason behind better growth of non-legume *G. arborea* and *T. bellerica* in combination with N_2 fixing legume because mine spoils are nutrient poor habitats. On degraded soils, N_2 fixing woody species could have long term effects on improvement in growth of non-N_2 fixing woody species. Kendle & Bradshaw (1992) reported a decrease in growth of associate species with increasing distance from N_2 fixing species. In a mixed plantation experiment, conifers suffered in the presence of alder at fertile site but were transformed into super dominants at infertile sites (Binkley & Greene 1983; Miller & Murray 1978), indicating that crop tree response to N_2 fixation varies with site fertility. In contrast to this, other studies suggest that low fertility enhances competition between N_2 fixing and non-fixing species (de Wit *et al.* 1966; Stern & Donald 1962).

The legume *P. pinnata* exhibited better growth with non-legume in mixed plantation. This suggests that the legume and non-legume companionship is not only beneficial to non-legume but is also advantageous for legume. The poor performance of *P. pinnata* with *A. catechu* suggests that perhaps both the legumes competed for same resource, hence the growth of *P. pinnata* was reduced when planted with *A. catechu.* Competition for resource is a dominant process influencing performance of species in mixed plantations (Cole & Newton 1986, 1987; Shainsky & Radosevich 1992). Pair of species which have both a large competitive effect on and a large competitive response to one another probably use, and are limited by the same resources (Miller & Werner 1987). In mixed plantation, nitrogen may mediate interaction between and within species in at least two distinct ways. First, because the nitrogen fixer utilizes a different source of nitrogen (the atmosphere) from that of the non-fixer (the soil), potential exists for reduced competition between species through resource partitioning. Second, facilitation may occur through the addition of fixed nitrogen to the system, and enhanced availability to the non-fixer. A wide range of results in mixed species plantings, indicating a variety in balances between competition and facilitation has been observed (Trenbath 1976; Vandermeer 1989).

A. catechu planted with legumes, showed better growth with *P. pinnata* than with *A. lebbeck.* Greater N_2 fixation rate has been reported in *P. pinnata* than in *A. lebbeck* (Singh *et al.* 1995).

Foliar N concentration was higher in leguminous species than that in non-leguminous species. The greater foliar N concentration in the leguminous species is due to their N_2 fixing attribute. The significantly greater N concentration in *G. arborea* and *T. bellerica* grown with leguminous trees suggests that N_2 fixing leguminous species have ability to improve the foliar N status of the companion species in mixed plantation. N_2 fixing species improve the foliar N status of non-N_2 fixing companion species in mixed plantations (Côté & Camiré 1987). On the other hand, N_2 fixing legumes *D. sissoo* and *L. leucocephala,* as neighbouring species, reduced the foliar N concentration in *T. grandis* suggesting that N_2 fixers may not always have a positive effect on foliar N status of non-N_2 fixing companion species in mixed plantation.

In the study, greater growth was accompanied by increased foliar N and P concentrations. A positive and significant relationship existed between the growth rates (height, diameter and volume increments) and foliar N and P concentrations. Evidently, higher leaf nutrient status increases the photosynthetic efficiency of trees, particularly on nutrient poor soils. N supply can affect plant growth and productivity by altering both leaf area and photosynthetic capacity (Frederick & Camberato 1995; Sinclair 1990). The photosynthetic capacity of leaves is related to their N content primarily because the proteins of the Calvin cycle and thylakoids represent the majority of leaf N (Evans 1989). Several workers have reported the existence of a relationship between foliar nutrients and plant growth (Haines *et al.* 1979; Lamb 1976; Leyton & Armson 1955; Mader & Thompson 1969; Singh & Singh 2001).

It can be concluded that in mixed plantation, effect on and response to one another will differ from species to species and this aspect needs to be evaluated before recommending a particular species combination for mixed plantation.

Acknowledgements

The author is indebted to Prof. J.S. Singh, Department of Botany, Banaras Hindu University, for guiding this study. Thanks are also due to University Grants Commission, New Delhi, for granting GATE Fellowship.

References

Binkley, D. 1983. Ecosystem production in Douglas-fir plantations : interaction of red alder and site fertility. *Forest Ecology and Management* **5:** 215-227.

Binkley, D. & S. Greene. 1983. Production in mixture of conifers and red alder : the importance of site fertility and stand age. pp. 112-117. *In* : R. Ballard & S.P. Gessel (eds.) *IUFRO Symposium on Forest Site and Continuous Productivity*. USDA Forest Service General Technical Report PNW-163, Portland.

Binkley, D., K.A. Dunkin, D. S. De Bell & M.G. Ryan. 1992. Production and nutrient cycling in mixed plantation of *Eucalyptus* and *Albizia* in Hawaii. *Forest Science* **38:** 393-408.

Cole, E.C. & M. Newton. 1986. Fifth year responses of Douglas-fir to crowding and non-coniferous competition. *Canadian Journal of Forest Research* **16:** 727-732.

Cole, E.C. & M. Newton. 1987. Nutrient, moisture and light relation in 5-year old Douglas-fir plantation under variable competition. *Canadian Journal of Forest Research* **17:**181-186.

Côté, B. & C. Camiré. 1984. Growth, nitrogen accumulation and symbiotic dinitrogen fixation in pure and mixed plantings of hybrid poplar and black alder. *Plant and Soil* **78:** 209-220.

Côté, B. & C. Camiré. 1985. Nitrogen cycling in dense plantings of hybrid poplar and black alder. *Plant and Soil* **87:** 195-208.

Côté, B. & C. Camiré. 1987. Tree growth and nutrient cycling in dense plantings of hybrid poplar and black alder. *Canadian Journal of Forest Research* **17:** 516-523.

Dawson, J. O. & J.C. Gordon. 1979. Nitrogen fixation in relation to photosynthesis in *Alnus glutinosa*. *Botanical Gazette* **140:** S70-S75.

De Bell, D.S., C.D. Whitesell & T.H. Schubert. 1989. Using N_2 fixing *Albizia* to increase growth of *Eucalyptus* plantations in Hawaii. *Forest Science* **35:** 64-75.

De Bell, D.S. & M.A. Radwan. 1979. Growth and nitrogen relations of coppiced black cottonwood and red alder in pure and mixed plantings. *Botanical Gazette* **140:** S97-S101.

de Wit, C.T., P.G. Tow & G.C. Ennik. 1966. Competition between legumes and grasses. *Verslagen van Landboukundige Onderzeokingen* **67:** 3-30.

Evans, J.R. 1989. Photosynthesis and nitrogen relationships in leaves of C_3 plants. *Oecologia* **78:** 9-19.

Frederick, J.R. & J.J. Camberato. 1995. Water and nitrogen effects on winter-wheat in the South-Eastern Coastal Plain. II. Physiological responses. *Agronomy Journal* **87:** 527-233.

Funk, D.T., R.T. Schlesinger & F. Jr. Ponder. 1979. Autumn-Olive as a nurse plant for black walnut. *Botanical Gazette* **140** (Supp.): S110-S114.

Haines, S.G., L.W. Haines & G. White. 1979. Nutrient composition of Sycamore blades, petioles, and whole leaves. *Forest Science* **25:** 154-160.

Hansen, E.A. & J.O. Dawson. 1982. Effect of *Alnus glutinosa* on hybrid *Populus* height growth in a short rotation intensively cultured plantation. *Forest Science* **28:** 49-59.

Heilman, P. 1983. Effects of surface treatment and interplanting of shrub Alder on growth of Douglas-fir on coal spoils. *Journal of Environmental Quality* **12:** 109-113.

Iverson, L.R. & M. K.Wali. 1982. Reclamation of coal mined lands : the role of *Kochia scoparia* and other pioneers in early succession. *Reclamation and Revegetation Research* **1:** 123-160.

Jackson, M.L. 1958. *Soil Chemical Analysis*. Englewood NJ : Prentice-Hall.

Jobidon, R. & J.R. Thibault. 1982. Allelopathic growths inhibition of nodulated and unnodulated *Alnus crispa* seedlings by *Populus balsamifera*. *American Journal of Botany* **69:** 1213-1223.

Joshi, A. & S.P. Singh. 1998. Responses of *Quercus leucotrichophora* and *Alnus nepalensis* seedlings along a nutrient gradient. *Tropical Ecology* **39:** 117-123.

Kendle, A.D. & A.D. Bradshaw. 1992. The role of soil nitrogen in the growth of trees on derelict land. *Arboricultural Journal* **16:** 103-122.

Lamb, D. 1976. Variations in the foliar concentrations of macro and microelement in fast growing tropical eucalypt. *Plant and Soil* **43:** 477-492.

Leyton, L. & K.A. Armson. 1955. Mineral composition of the foliage in relation to the growth of Scots pine. *Forest Science* **1:** 210-218.

Mader, D.L. & B.W. Thompson. 1969. Foliar and soil nutrients in relation to sugar maple decline. *Soil Science Society of American Proceedings* **33:** 794-800.

Miller, R.E. & M.D. Murray. 1978. The effects of red alder or growth of Douglas-fir. pp. 286-306. *In* : D.G. Briggs, D.S. De Bell & W.A. Alkinson (eds.) *Utilization and Management of Alder.* USDA Forest Service General Technical Report PNW-70. Portland.

Miller, T.E. & P.A. Werner. 1987. Competitive effects and responses between plant species in a first year old-field community. *Ecology* **68:** 1201-1210.

Newton, M., B.A. E1 Hassan & J. Zavitkovski. 1968. Role of red alder in western Oregon forest succession. pp. 73-84. *In* : J.M. Trappe, J.F. Franklin, R. F. Tarrant & G.H. Hassan (eds.) *Biology of Alder.* Proceedings of a symposium held at North-West Scientific Association. 40th Annual Meeting United States Forest Service Pacific North-West Forest and Range Experiment Station. Pullman, Washington, USA.

Schlesinger, R.C. & R.D. Williams. 1984. Growth response of black walnut to interplanted trees. *Forest Ecology* **9:** 235-243.

Shainsky, L.J. & S.R. Radosevich. 1992. Mechanisms of competition between Douglas-fir and Red alder seedlings. *Ecology* **73:** 30-45.

Sinclair, T.R. 1990. Nitrogen influence on the physiology of crop yield. pp. 41-55. *In* : R. Rabbinge, J. Goudriaan, H. van Keulen, F.W.T. De Vries, Penning & H.H. van Laar (eds.) *Theoretical Production Ecology : Reflection and Prospects.* Wageningen. Netherlands : Pudoc.

Singh, A. 1999. *Revegetation of Coal Mine Spoil : Influence of Nutrient Amendenent and Neighbouring Species on Growth Performance and Foliar Nutrient Dynamics of Woody Species*. Ph.D. Thesis Banaras Hindu University, Varanasi, India.

Singh, A. & J.S. Singh. 2001. Comparative growth behaviour and leaf nutrient status of native trees planted on mine spoil with and without nutrient amendment. *Annals of Botany* **87:** 777-787.

Singh, J.S. & A.K. Jha. 1993. Restoration of degraded land : an overview. pp. 1-9. *In* : J.S. Singh (ed.) *Restoration of Degraded Land : Concepts and Strategies.* Rastogi Publications, Meerut, India.

Singh, J.S., K.P. Singh & A.K. Jha. (eds.). 1995. *An Integrated Ecological Study on Revegetation of Mine Spoil : Concept and Research Highlights.* Interim report of an S&T project sponsored by the Ministry of Coal, Government of India through CMPDI, Ranchi, Department of Botany, Banaras Hindu University, Varanasi, India.

Snedecor, G.W. & W.G. Cochran. 1968. *Statistical Methods.* Oxford and IBH Publishing Co., New Delhi, India.

Stern, W.R. & C.M. Donald. 1962. Light relationships in grass-clover swards. *Australian Journal of Agricultural Research* **13:** 599-614.

Trenbath, B.R. 1976. Plant interactions in mixed crop communities. *In*: R.I. Papendick, P.A. Sanchez & G.B. Triplett (eds.) *Multiple Cropping.* American Society of Agronomy, Special Publication **27:** 129-170.

Van Sambeck, J. W., R.C. Schlesinger. F. Ponder & W.J. Rietveld. 1985. Actinorhizal species as a nurse crop for black walnut. pp. 157-263. *In*: J.O. Dawson & K.A. Majercus (eds.) *Central Hardwood Forest Conference,* University of Illinois, Urbana II.

Vandermeer, J. 1989. *The Ecology of Intercropping.* Cambridge University Press, Cambridge, England.

Younger, P.D. & L.A. Kapustaka. 1983. N_2 (C_2H_2)ase activity by *Alnus incana* ssp. *rugosa* (Betulaceae) in the northern hardwood forest. *American Journal of Botany* **70:** 30-39.

Zavitkovski, J. & K.D. Stevens. 1972. Primary productivity of red alder ecosystems. *Ecology* **53:** 235-242.