CHANGES IN SOIL PROPERTIES AND FOLIAGE NUTRIENT COMPOSITION IN DIFFERENT AGE CLASSES OF *EUCALYPTUS CAMALDULENSIS* PLANTATION

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SINGH, G. & SINGH, B. 2002. Changes in soil properties and foliage nutrient composition in different age classes of *Eucalyptus camaldulensis* plantation. A study was carried out on the changes in soil properties and foliage nutrients of *Eucalyptus camaldulensis* plantation in arid areas to determine the effect of establishing plantations on the fertility of a desert soil and their management. Distributions of soil organic matter (SOM), nutrients, pH and their influences on growth and foliage nutrient composition were investigated in a randomly selected block plantation representing different age classes, namely, 4 years (Y_4), 6 years (Y_6), 8 years (Y_8), 10 years (Y_{10}), 12 years (Y_{12}) and 18 years (Y_{18}). Height and diameter at breast height (dbh) of the stand ranged from 9.2 to 25.7 m and 9.4 to 21.5 cm respectively, depending on the age of the stand. Foliage nutrients were in order of Ca > N > K > Mg > P and differed considerably between different ages. Foliage N and P increased until Y_{12} and decreased afterwards. The other nutrients did not show any clear trend of increasing/decreasing except for Mn and Fe. Changes in canopy size and nutrient mobilisation during tree development were important in foliage nutrient compositions. This is due to change in biogeochemistry of the soil, particularly the amount of SOM which increased with increasing age of the stand. Soil organic matter and nitrogen (NH_4-N + NO_3-N) were significantly higher in the 0–15 cm layer compared with the 15–30 cm layer. Soil nutrients were significantly higher in the plantation area compared with the non-planted control plot. Soil pH, PO_4-P, Ca, Mg and K concentrations decreased with stand age whereas SOM, NH_4-N, NO_3-N, Cu, Zn and Mn increased. There was a general decrease in basic cations; however, SOM, NH_4-N and NO_3-N increased in the soil. The study thus suggested that plantations require fertiliser application and/or thinning after 12 years to manage the problem of nutrient depletion.

Key words: *Eucalyptus camaldulensis* plantation - Indian arid zone - irrigated plantation - stand age - foliage - soil nutrients

SINGH, G. & SINGH, B. 2002. Perubahan ciri-ciri tanih dan komposisi nutrien daun di ladang *Eucalyptus camaldulensis* yang berbeza kelas umur. Kajian dijalankan terhadap perubahan ciri-ciri tanih dan nutrien daun di ladang *Eucalyptus camaldulensis* di kawasan gersang untuk menentukan kesan penubuhan ladang ke atas kesuburan dan pengurusan di tanah gurun. Taburan bahan organik tanih (SOM), nutrien, pH dan pengaruhnya terhadap pertumbuhan dan komposisi nutrien daun dikaji di ladang yang dipilih secara rawak dan mewakili kelas umur yang berbeza iaitu 4 tahun (Y_4), 6 tahun (Y_6), 8 tahun (Y_8), 10 tahun (Y_{10}), 12 tahun (Y_{12}) dan 18 tahun (Y_{18}). Ketinggian dan diameter aras dada (dbh) dirian masing-masing adalah antara 9.2 hingga 25.7 m dan 9.4 hingga 21.5 cm, bergantung pada umur dirian. Nutrien daun berada dalam susunan Ca > N > K > Mg > P dan amat berbeza pada kelas umur yang berlainan. Kandungan N dan P dalam daun meningkat sehingga Y_{12} dan menurun selepas itu. Nutrien lain tidak menunjukkan trend peningkatan atau penurunan yang jelas kecuali Mn dan Fe. Perubahan saiz kanopi dan pergerakan nutrien sewaktu tumbesaran pokok adalah penting dalam komposisi nutrien daun. Ini dikaitkan dengan perubahan dalam biogeokimia tanih, terutama jumlah SOM yang meningkat apabila meningkatnya umur dirian. Bahan organik tanih dan nitrogen (NH_4-N + NO_3-N) lebih tinggi dengan bererti di dalam lapisan 0–15 cm berbanding lapisan 15–30 cm. Nutrien tanih lebih tinggi dengan bererti di ladang berbanding di petak kawalan yang tidak ditanam. Nilai pH dan kepekatan PO_4-P, Ca, Mg dan K tanih menurun mengikut umur dirian manakala SOM, NH_4-N, NO_3-N, Cu, Zn dan Mn meningkat. Terdapat penurunan secara umum dalam kation asas; bagaimanapun, SOM, NH_4-N dan NO_3-N meningkat di dalam tanih. Oleh itu kajian ini mengesyorkan bahawa ladang perlukan pembajaan dan/atau penjarangan selepas 12 tahun untuk mengelakkan masalah kekurangan nutrien.

Introduction

Forests differ from agricultural crops with respect to the quantity and composition of litters as well as the rooting pattern of vegetation. The total supply of litter in forest stands often exceeds agricultural crops (Alriksson & Olsson 1995). In forest and plantations, atmospheric deposition and translocation of nutrients from deeper soil layer by tree roots can affect the nutrient pool. Further, plantations are also associated with different kinds of vegetation depending on tree species and site conditions as well as stand age and canopy closure. In a closed canopy forest, the recovery of nutrients from shed foliage accounts for significant proportions of the annual nutrient demands for new growth. However, in desert soil, which is a nutrient-poor site, trees may be dependent on efficient conservation of nutrients through retranslocation and nutrient cycling.

Irrigated plantations have been raised on massive scale on the desert sand at IGNP (Indira Gandhi Nahar Pariyojana) command area to protect the canal from siltation by sand deposition as well as to green the desert, increase biomass production and to improve the climate. Afforestation is an alternative land use system under which plants provide substantial return in form of fuel and fodder during crop failure due to low and erratic rainfall and frequent drought and famine in the area (Rao 1996). Both sides of the canal are planted with *Eucalyptus camaldulensis*, the main species, *Dalbergia sissoo* and *Acacia nilotica*, covering an area of about 1.8×10^6 ha.

Afforestation causes a change in microclimate and land use pattern in the area (Pant & Hingane 1988). Afforestation with *Eucalyptus* may affect soil fertility. Changes in soils associated with the planting of this species are: (1) physical and chemical changes (Srivastava 1993), (2) composition of nutrients (Jha *et al.* 1996) and (3) an increase in organic matter content (Negi & Sharma 1985, Singh *et al.* 1993). There were no systematic studies of the effect of desert afforestation on growth, soil organic matter content and the foliar elemental concentrations.

The purpose of the study was to determine the effect of establishing *E. camaldulensis* plantations on the fertility of desert soil and to suggest management practices to solve the problem of mortality in the plantations.

Materials and methods

Description of study area

Block plantations of *E. camaldulensis,* established by the forest department from seedlings, were of age 18, 12, 10, 8, 6 and 4 years at the start of this study in December 1996. The stands were marked as Y_{18}, Y_{12}, Y_{10}, Y_8, Y_6 and Y_4 respectively. The site was prepared for long furrow irrigation using tractor and the seedlings were planted on the side of ridges. The plantation was initially irrigated nine times in the first year and six times yearly in the next two years and lastly three times yearly until the fifth year of plantation for proper establishment. No further irrigation was provided after the fifth year. Total quantity of irrigation water was not estimated. There was only one block plantation of each age covering an area of about 6 to 12 ha. The stands are randomly located along the Indira Gandhi Canal in the districts of Bikaner (28° 00' N–73°18' E) and Jaisalmer (26° 54' N–70° 55' E) in the north-western part of Rajasthan. The soil of the site is loamy sand underlain with calcareous layer at 75 to 125 cm depths and is alkaline-saline in nature. The soil was virgin desert land before the commencement of the canal. The vegetation in open areas is sparse with occasional desert shrubs like *Calligonum polygonoides, Leptadenia pyrotechnica* and *Aerva pseudotomentosa.* However, most of the area is barren sandy tract. The soil has little organic matter, available nitrogen and phosphorus and has a low water-holding capacity. Mean annual rainfall for Bikaner and Jaisalmer districts are 286 mm and 185 mm respectively, with very high coefficient of variation. The maximum temperature lies between 48 and 52 °C and minimum between 0 and 4 °C.

Sampling design and sample collection

Eucalyptus camaldulensis stands of representative area of 6 to 12 ha of each age (4, 6, 8, 10, 12 and 18 years) were randomly selected in December 1996 from the plantation in 50 km stretch. Further, three blocks of 18×18 m^2 covering 36 trees at a spacing of 3×3 m were randomly marked from each stand. Similarly, three random blocks of the same size were also marked in an open area 100 m away from each plantation edge, to observe differences in soil nutrient between the planted and the open (non-planted) area. Thus, a total number of 36 blocks were laid out randomly from the entire area (covering planted (18) and non-planted areas (18)). These blocks were marked for recording observations and drawing inferences.

The trees in each block were measured for height and stem diameter at breast height (dbh). Soil samples were collected from each block in January 1997 at 0–15 and 15–30 cm layers. Five soil samples, four from the root zone of a central four trees and one sample from the centre of these four trees were collected and mixed in equal proportions to form a composite sample of each layer. Similarly soil samples were also collected from the open areas. Thus a total number of 72 soil samples for two depths were collected. Soil samples were air-dried and passed through a 2-mm mesh sieve and subjected to various analysis. Foliage samples were also collected in January 1997 from the same trees in each block from the lower, middle and top layers of the canopy and mixed in equal proportions to form a composite sample of each block. Foliage samples were dried thoroughly at 80 ± 5 °C, ground and passed through a 2-mm sieve and kept for analytical purposes.

Chemical analysis

Soil pH and electrical conductivity (EC) were determined in 1:2 soil:water ratio. Organic matter was determined by the partial oxidation method. Available nitrogen was determined after 2 M KCl extraction using Tecator Model Enviroflow-5012 autoanalyser. Extractable phosphorous was determined by the Olson's extraction method (Jackson 1973). For determination of macro- and micronutrients soil samples were extracted with 0.1 N HCl. Elemental concentrations in foliage were estimated after acid digestion. Total nitrogen and phosphorus contents were determined using Tecator Model Enviroflow-5012 autoanalyser, after acid digestion (H_2SO_4) using copper sulphate and potassium sulphate as catalyst (Jackson 1973). Ca, Mg, Cu, Zn, Mn and Fe were estimated in absorption mode and K and Na in emission mode using double beam atomic absorption spectrophotometer.

Statistical analysis

All the data collected were analysed using the SPSS package. Soil data of open areas were tested for significant variations in nutritional behaviour using stand classes as the main effect. It was hypothesised that both the planted and open areas would be similar in nutritional status before the time of plantation and the changes in soil properties in plantation area was due to the effect of plantation. Since the sampling plots were randomly selected from each age stand, the differences in the foliage nutrient compositions among different age stands were tested using one-way ANOVA, with nutritional parameter of three sampling plots of each stand as the dependent variable and plantation age as the main effect. Variations among the stands were tested as error. Standard error of means were calculated to estimate variations within stand. Since the soil samples were excavated using simple random sampling, soil nutrient parameters were analysed using a radomised block split plot design using INDOSTAT package. Mean soil data was the dependent variable. The stand ages in planted and its associated unplanted areas were the main plot factors while soil depth was the subplot factor. Variation between the stand ages was the error terms. Foliage and soil nutrient data were correlated with stand age.

Results

Stand growth

There were significant differences in the plant height due to the effect of stand age (Table 1). The height of the stands varied from 9.2 m in stand Y_4 to 25.70 m in Y_{18}, showing positive correlation of height with stand age (r = 0.95, n = 18, p = 0. 002). The minimum dbh recorded was in Y_4 with a value of 7.4 cm and maximum was 21.5 cm in Y_{18}.

Plant nutrients

Foliage concentrations of all the nutrients differed significantly ($p < 0.05$) with respect to age of the stand (Table 2). Maximum concentrations of P and Fe were recorded in Y_{18} stand whereas Ca, Mg, and Zn showed their highest concentrations in Y_{12} stand, although they did not differ significantly with the foliage in Y_{18} stand. Foliage concentration of N was maximum in Y_8 and minimum in Y_{18} stand. The level of K and Mn were the highest in Y_4. The differences in the concentration of Cu between Y_4, Y_6, Y_8 and Y_{10} were not significant. P, N, K, Cu and Zn did not show any significant correlation of increase or decrease with the age of stand. Foliage concentrations of Ca (r = 0.876, p = 0.022), Mg (r = 0.896, p = 0.016) and Fe (r = 0.935, p = 0.006) showed positive correlations with age of the stand, whereas, Mn showed decreasing trend with age of the stand.

Soil properties

Soil nutrients of the planted area determined at 0–15 cm and 15–30 cm soil layers did not show significant differences compared with the control plots (non-planted) (Table 3) . However, soil organic matter (SOM), available PO_4-P, NH_4-N and NO_3-N were significantly higher in plantation compared with the non-planted area. Soil pH, Ca, Mg, K and Mn were lower in the plantation compared with the control plots. Concentrations of Cu and Zn were low in planted area initially, but increased after Y_{10} when compared with the control plot. Considering the

Table 1 Influence of stand age on height and diameter at breast height (dbh) of afforested *Eucalyptus camaldulensis*

Stand age	Y_4	Y_6	Y_8	Y_{10}	Y_{12}	Y_{18}	F value	p value
Height (m)	9.20	14.80	15.70	19.30	22.27	25.70	360.86	0.000
SEm	0.23	0.27	0.32	0.26	0.30	0.44		
Dbh (cm)	9.43	12.70	13.37	16.13	17.87	21.50	202.21	0.000
SEm	0.12	0.15	0.26	0.15	0.26	0.56		

soil depth, SOM, available PO_4-P, Zn and Fe were higher in 0–15 cm layer whereas the reverse trend was observed for pH, available NH_4-N, NO_3-N, extractable Ca, Mg, Cu and Mn compared with 15–30 cm layer.

In different age stands, there were significant decreases in soil pH ($p < 0.001$), Ca, Mg, and K, believed to be due to increase in SOM and utilisation of these mineral elements for the production of biomass. Further, as the stands aged, SOM, Cu, Zn and Mn decreased probably due to decreased litter fall from the trees. Soil available PO_4-P was lower in the older stand and NH_4-N and NO_3-N showed an increasing trend.

Correlation of stand age with soil and foliage nutrients

Mean height (r = 0.961, p = 0.002) and dbh (r = 0.984, p = 0.000) of the stand showed significant positive correlation with stand age, clearly indicating biomass increase with the stand age. Increases in SOM (r = 0.969, p = 0.001 in 0–15 cm layer and r = 0.965, p = 0.002 in 15–30 cm layer)were believed to be due to increased litter accumulation. Positive correlations were also obtained for Cu (r = 0.975, p = 0.001 and r = 0.851, p = 0.021), Mn (r = 0.923, p = 0.009 and r = 0.908, p = 0.012) and NH_4-N (r = 0.828, p = 0.042 and r = 0.880, p = 0.021 in 0–15 and 15–30 cm layers respectively). These indicated that these parameters increased with age of the stand through accumulation of litter and thus organic matter. NO_3-N showed positive correlation in the 0–15 cm layer only. Results also showed that pH (r = 0.874, p = 0.023 in 15–30 cm layer), PO_4-P (r = - 0.841, p = 0.036 in 15–30 cm layer) and Ca (r = - 0.929, p = 0.007 and r = - 0.904, p = 0.013 in 0–15 and 15–30 cm layers respectively) showed significant negative correlation with the age of the stand.

Table 2 Influence of stand age on foliage nutrient compositions of *Eucalyptus camaldulensis* plantation

Stand	Foliage nutrient composition								
age	N	P	Ca	Mg	K	Cu	Zn	Mn	Fe
Y_4	8.58	0.84	19.47	2.35	14.47	9.65	109.5	85.00	435.0
SEm	0.06	0.04	0.28	0.04	0.73	0.06	1.70	5.90	2.41
Y_6	8.94	0.86	19.25	2.54	9.93	9.75	105.88	70.00	405.9
SEm	0.19	0.03	0.24	0.04	0.15	0.21	2.82	3.02	10.35
Y_8	10.65	0.92	20.83	3.21	8.56	9.75	121.50	59.80	450.8
SEm	0.38	0.02	0.13	0.09	0.09	0.14	3.27	1.67	3.97
Y_{10}	10.38	0.96	20.83	3.21	8.56	9.75	130.25	46.13	460.8
SEm	0.25	0.03	0.19	0.06	0.07	0.08	3.01	1.49	6.77
Y_{12}	9.19	0.75	22.56	3.65	8.26	6.38	137.13	44.75	469.9
SEm	0.41	0.02	0.79	0.08	0.08	0.05	3.50	0.87	4.51
Y_{18}	7.62	1.25	22.24	3.58	10.69	5.80	104.30	40.50	540.0
SEm	0.37	0.14	0.64	0.03	0.70	0.15	2.11	13.2	16.28
F value	14.17	7.48	9.46	78.76	8.52	3.44	23.58	34.84	26.44
P value	0.000	0.002	0.001	0.000	0.001	0.037	0.000	0.000	0.000

N, P, Ca, Mg and K are in g kg^{-1}; Cu, Zn, Mn and Fe are in mg kg^{-1}
Values are means with standard error of mean.

Table 3 Split plot ANOVA statistics of soil data under the canopy of *Eucalyptus camaldulensis* plantation

Site	Soil layer	Soil parameters											
		pH		SOM		NH_4-N (mg kg^{-1})		NO_3-N (mg kg^{-1})		PO_4-P (mg kg^{-1})		Ca (g kg^{-1})	
		P	C	P	C	P	C	P	C	P	C	P	C
Y_4	0–15	8.83	8.91	0.58	0.28	2.18	1.26	1.14	0.37	11.45	2.19	16.54	17.19
	15–30	8.90	8.87	0.44	0.18	0.96	2.78	2.42	1.20	7.53	4.75	17.45	17.68
Y_6	0–15	8.58	8.90	0.62	0.30	2.97	1.28	1.30	0.38	6.20	2.31	17.04	17.06
	15–30	8.69	8.88	0.48	0.19	0.79	2.88	3.57	1.24	5.20	4.80	17.14	17.70
Y_8	0–15	8.33	8.91	0.68	0.30	2.53	1.28	1.37	0.38	7.65	2.37	16.92	17.16
	15–30	8.66	8.83	0.50	0.21	2.48	2.46	2.81	1.26	4.82	4.78	17.01	18.79
Y_{10}	0–15	8.27	8.90	0.70	0.29	3.22	1.46	1.63	0.41	7.12	2.80	16.06	17.16
	15–30	8.66	8.59	0.50	0.19	2.50	2.94	2.53	1.30	4.53	4.82	17.00	17.85
Y_{12}	0–15	8.11	8.91	0.69	0.30	2.46	1.46	2.69	0.47	8.83	2.60	14.27	17.06
	15–30	8.64	8.76	0.51	0.19	2.21	2.93	3.02	1.31	4.36	5.01	15.27	18.22
Y_{18}	0–15	8.42	8.76	0.88	0.29	4.93	1.30	4.29	0.40	4.83	2.21	12.29	17.31
	15–30	8.52	8.67	0.61	0.18	3.27	2.75	2.88	1.28	3.59	5.01	10.12	18.18
ANOVA		F value	p value	F value	p value	F value	p value	F value	p value	F value	p value	F value	p value
F value	Age	10.96	0.000	10.15	0.000	72.52	0.000	153.1	0.000	36.45	0.000	22.63	0.000
	Site	73.33	0.000	1001.1	0.000	806.9	0.000	4536.9	0.000	1097.1	0.000	112.3	0.000
	Depth	2.54	0.124	226.9	0.000	170.4	0.000	901.4	0.000	1.00	0.330	109.3	0.000
	A × S	2.49	0.050	8.26	0.000	127.8	0.000	116.0	0.000	90.4	0.000	14.41	0.000
	S × D	17.23	0.000	17.88	0.000	2349.5	0.000	1.33	0.261	714.6	0.000	2.27	0.150
	A × D	0.40	0.846	1.07	0.390	26.00	0.000	85.34	0.000	6.43	0.000	7.35	0.000
	A × S × D	0.86	0.522	1.10	0.390	38.9	0.000	86.2	0.000	3.75	0.012	8.72	0.000

A: age, S: planted and associated non-planted sites, D: soil depth, P: planted area, C: non-planted or control area

continued

Table 3 (continued)

Site	Soil layer	Soil parameters Mg (g kg^{-1})		K (g kg^{-1})		Cu (mg kg^{-1})		Zn (mg kg^{-1})		Mn (mg kg^{-1})		Fe (mg kg^{-1})	
		P	C	P	C	P	C	P	C	P	C	P	C
Y_4	0–15	0.55	0.55	0.48	0.61	0.20	0.26	0.90	1.33	22.10	39.31	13.30	14.21
	15–30	0.56	0.62	0.49	0.46	0.33	0.36	0.94	0.72	24.70	29.99	12.79	13.60
Y_6	0–15	0.53	0.55	0.48	0.62	0.18	0.25	0.90	1.54	23.70	38.40	13.30	13.50
	15–30	0.60	0.89	0.51	0.48	0.31	0.33	0.90	0.80	23.70	30.30	10.80	13.30
Y_8	0–15	0.52	0.54	0.57	0.60	0.25	0.24	0.94	1.36	24.80	36.32	13.41	13.89
	15–30	0.63	0.63	0.49	0.52	0.29	0.30	0.88	0.69	26.60	31.88	10.80	11.47
Y_{10}	0–15	0.63	0.55	0.58	0.64	0.31	0.22	1.03	1.59	28.41	43.47	13.90	14.10
	15–30	0.58	0.70	0.54	0.52	0.39	0.30	0.94	0.75	32.40	32.80	10.20	12.91
Y_{12}	0–15	0.52	0.53	0.65	0.64	0.39	0.26	1.10	1.56	34.10	44.60	12.10	12.91
	15–30	0.51	0.69	0.56	0.56	0.38	0.36	0.90	0.64	44.20	33.40	10.60	11.49
Y_{18}	0–15	0.48	0.56	0.43	0.56	0.49	0.31	1.87	1.71	71.90	49.39	13.19	11.86
	15–30	0.44	0.64	0.41	0.53	0.44	0.40	1.61	0.86	45.00	38.20	11.27	11.47
ANOVA		F value	p value	F value	p value	F value	p value	F value	p value	F value	p value	F value	p value
F value	Age	3.78	0.010	17.97	0.000	64.39	0.000	105.1	0.000	112.8	0.000	1.22	0.331
	Site	72.20	0.000	19.74	0.000	13.02	0.001	30.51	0.000	10.24	0.001	27.57	0.000
	Depth	41.16	0.000	48.46	0.000	171.6	0.000	742.8	0.000	67.09	0.000	116.09	0.000
	A × S	6.42	0.001	2.95	0.030	11.98	0.000	59.53	0.000	23.86	0.000	1.52	0.220
	S × D	13.95	0.001	15.24	0.000	11.06	0.003	402.4	0.000	44.78	0.000	7.76	0.010
	A × D	1.56	0.340	1.94	0.124	5.95	0.001	10.87	0.000	28.93	0.000	3.95	0.010
	A × S × D	1.20	0.339	4.53	0.005	10.5	0.000	1.82	0.147	20.2	0.000	5.24	0.002

A: age, S: planted and associated non-planted sites, D: soil depth, P: planted area, C: non-planted or control area

Discussion

Foliage nutrient concentrations differed significantly among the selected stand, which might be due to differences in the ages of the stand and/or due to the changes in the soil chemistry of the plantations. Efficient conservation and storage of nutrients in the trees also play important roles in the process of stand development, which vary with stand age through various developmental stages of tree crop. Differences in foliage nutrient composition are attributed to the effect of nutrient and water supply for growth. The young plantations were well supplied with nutrients and water (during early five years of irrigation), thus rapidly increasing leaf area and assimilated photosynthates resulting in high C/N ratio (low N and P). High concentrations of K, Mn and Cu in Y_4 were attributed to higher uptake of these elements from the soil and/or due to low retranslocation. This is also supported by the low concentrations of these nutrients in the plantation area of Y_4 compared with the respective values in the non-planted area (Table 3). Tree canopy closed with age leading to competition for light and water (as irrigation was discontinued after five years). This affected carbon assimilation and hence decreased C/N ratio and increased N concentration as observed in Y_{10} and Y_{12}. Light limitations induce increase in concentration of nutrients such as nitrogen (Hollinger 1989). Matson and Waring (1984) also observed that light limitations increased the ratio of free amino acid:total N. Increased water stress coupled with aridity of the area might have influenced leaf ageing, absorption and retranslocation of the nutrients thus decreased foliage N, K, Cu and Mn. Higher retranslocation of N (50%) and K (68%) have also been reported in older stand of Corcisan pine compared with only 16 and 24% respectively in the young stand (Miller 1986). Earlier studies have also shown that nutrient concentration in conifer foliage vary considerably with tree age, position in the crown, foliage age, season of the year and site condition (Mead & Pritchett 1974, Johnson *et al.* 1991). Increased concentrations of Ca, Mg and Fe might be due to soil water stress and continuous accumulation of these elements with age of the leaves. The chemical composition of deciduous tree foliage also indicated that Ca and Mg levels increased markedly during growing season and continue to rise during leaf fall or senescence (Rulhan & Singh 1987, Verma & Mishra 1989). Higher concentration of Fe has also been reported in many species of arid zones (Sharma *et al.* 1984).

The important mechanism in building up the nutrient level in soil is the increase of soil organic matter and the other nutrients through addition of tree litter. Such accumulation in forest floor depends on the amount of litter production and its rate of decomposition (Miller 1984). The increase in SOM in plantation compared with non-planted area in both layers (but higher in 0–15 cm layer) was believed to be due to higher litter fall, which might be influenced by the arid climate of the area. Accumulation of SOM and immobilisation of nutrients have also been reported by van Cleave and Viereck (1981) over a period of natural forest succession. Low SOM content in young plantations is due to less litter accumulation because, unlike in old stand, the rate of foliage production here is greater than its rate of loss. Low availability of NO_3-N, Cu, Zn and Mn in Y_4 is probably due to greater absorption under high availability of soil water. Increase in soil organic matter and N content with age is probably due to higher leaf litter returns and subsequent decomposition and mineralisation.

Decreased soil pH, available PO_4-P and extractable Ca, Mg and K concentrations with stand age is the result of increase in SOM and consequent humus and organic acid formation (Srivastava 1993). Increased SOM and decreased soil pH with increasing stand age may influence the availability and absorption of these elements for their utilisation in biomass production. Transformation of PO_4-P into organic P and its complexation with Ca, Mg, Fe and Al during low soil water availability may also be responsible for decreased concentration of these ions in older stands (Rokima & Prasad 1991). Decrease in soil K with increasing stand age may be due to higher potassium absorption by *Eucalyptus* species (George & Varghse 1991). Low K returns in form of leaf litter because of higher retranslocation (Miller 1986) and reduction of K fixation due to increased SOM may also be responsible for the decrease in soil K concentration. Irrigation activities in the early five years may have caused leaching of some salts from upper soil layers to lower horizon. This may affect soil pH and availability of these ions in the soil. Binkley *et al.* (1989) reported a drop in pH by 0.3 to 0.8 units in an old field of loblolly pine at 5 and 25 years of age. The decline in extractable Ca, Mg and K in the soil of the loblolly pine stand was 20 to 80%. The increased availability of Cu, Zn and Mn may be due to increased SOM through litter accumulation over time. The availability of Mn, Cu and Zn from insoluble form to more available form for plant nutrition with increasing SOM have also been reported (Jeffery & Urens 1983).

Conclusions and recommendations

The results indicated that plantation in desert areas increases the biomass production significantly under irrigated condition. However, with increasing age, the competition for light and soil resources affected foliage nutrient composition. There was a decrease in some nutrients in the older age plantations. Discontinuing of irrigation coupled with dry environmental condition affected nutrient absorption, mobilisation and retranslocation and thus nutrient composition of soil and the foliage. The decrease in foliage N, K, Cu and Mn and soil Ca, Mg, K and PO_4-P with increasing age of the tree indicated the nutritional problem. The management implications may be fertiliser applications along with irrigation in later age. In general, accumulated nutrients stored in the top 0–15 cm layer of mineral soil will be beneficial for soil improvement and ecosystem sustainability. However, the older stand may suffer from nutrient depletion, which affect growth and stand development. Nevertheless, these observations are only restricted to the plantations of *E. camaldulensis.* Research should also be replicated to study the effect of other species on soil with varying texture.

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References

ALRIKSSON, A. & OLSSON, M. T. 1995. Soil changes in different age classes of norway spruce (*Picea abies* (L.) Karsten) on afforested farmland. *Plant and Soil* 168: 103–110.

BINKLEY, D., VALENTINE, D., WELL, C. & VALENTINE, U. 1989. An empirical analysis of the factor contributing to 20 years decrease in soil pH in an old field plantation of loblolly pine. *Biogeochemistry* 7: 139–154.

GEORGE, M. & VARGHSE, G. 1991. Nutrient cycling in *Eucalyptus globulus* plantation. III. Nutrients retained returned uptake and nutrient cycling. *Indian Forester* 117(2): 110–116.

HOLLINGER, D. Y. 1989. Canopy organisation and foliage photosynthetic capacity in a broad leaved evergreen montane forest. *Functional Ecology* 8: 53–62.

JACKSON, M. L. 1973. *Soil Chemical Analysis.* Prentice Hall of India, Delhi.

JEFFERY, J. J. & URENS, N. C. 1983. Copper and zinc species in the soil solution and effects of soil pH. *Australian Journal of Soil Research* 21: 479–488.

JHA, M. N., DIMRI, B. M. & GUPTA, M. K. 1996. Soil nutrient changes under different aged *Eucalyptus* monoculture. *Indian Forester* 122(1): 55–60

JOHNSON, J. E., BURGER, J. A., RATHFON, R. A., KREH, R. E. & FERET, P. P. 1991. Foliar nutrient comparisons of Pitch pine, loblolly pine and the pitch x loblolly hybrid. *Plant and Soil* 132: 1–9.

MATSON, P. A. & WARING, R. H. 1984. Effect of nutrient and light limitations on montane Hemlock: susceptibility to laminated root rot. *Ecology* 65: 1517–1524.

MEAD, D. J., & PRICHETT, W. L. 1974. Variation of N, P, K, Ca, Mg, Mn, Zn and Al in slash pine foliage. *Commonwealth Soil Science and Plant Analysis* 5: 291–301.

MILLER, H. G. 1984. Dynamics of nutrient cycling in plantation ecosystem. Pp. 53–78 in Bowen, G. D. & Nambiar, E. K. S. (Eds.) *Nutrition of Plantation Forests.* Academic Press, London.

MILLER, H. G. 1986. Carbon x nutrient interactions: the limitations to productivity. *Tree Physiology* 169–225–232.

NEGI, J. D. S. & SHARMA, S. C. 1985. Biomass and nutrient distribution in an age series of *Eucalyptus hybrid* plantation in Tamil Nadu. I. Distribution of organic matter. *Indian Forester* 111(2): 1111–1121.

PANT, G. B. & HINGANE, L. S. 1988. Climatic changes in and around the Rajasthan desert during the 20th century. *Journal of Climatology* 8: 391–409.

RAO, A. S. 1996. Climatic changes in the integrated tracts of Indira Gandhi Canal Region of Arid Western Rajasthan, India. *Annals of Arid Zone* 35(2): 111–116.

ROKIMA, J. & PRASAD, B. 1991. Integrated nutrient management. II. Transformation of applied P into inorganic P fraction in relation to its availability and uptake in calcareous soil. *Journal of Indian Society of Soil Science* 39: 703–709.

RULHAN, P. K. & SINGH, S. P. 1987. Dynamics of nutrients and leaf mass in central Himalayan forest trees and shrubs. *Ecology* 68: 1974–1983.

SHARMA, B. K., DHIR, R. P. & DUTTA, B. K. 1984. Mineral nutrient elements in natural vegetation of arid Rajasthan. II. Microelements. *Annals of Arid Zone* 23: 235–241.

SRIVASTAVA, A. K. 1993. Changes in physical and chemical properties of soil in irrigated *Eucalyptus* plantation in Gujarat state. *Indian Forester* 119: 227–231.

SINGH, O., SHARMA, D. C. & RAWAT, J. K. 1993. Production and decomposition of leaf litter in sal, teak, *Eucalyptus* and *Poplar* forests in Uttar Pradesh. *Indian Forester* 119(2): 112–121.

VAN CLEAVE, K. & VIERECK, L. A. 1981. Forest succession in relation to nutrient cycling in the boreal forest of Alaska. Pp. 184–211 in *Succession: Concept and Application.* Springer, New York.

VERMA, K. S. & MISHRA, V. K. 1989. Nutrient dynamics studies in species of western Himalaya. I. Micronutrient in *Robinia pseudotomentosa* and *Grewia optiva. Indian Journal of Forestry* 12: 96–100.