RESPONSE OF HIGH DENSITY ENERGY PLANTATION OF *EUCALYPTUS TERETICORNIS* TO BASAL NITROGEN SOURCE, DOSE AND PHOSPHORUS APPLICATION ON AN ALLUVIAL SOIL

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GREWAL, S.S., SINGH, KEHAR & JUNEJA, M. L. 1993. **Response of high density energy plantation of *Eucalyptus tereticornis* to basal nitrogen source, dose and phosphorus application on an alluvial soil.** On a sandy loam alluvial soil (Udic Ustocrepts) of the foothill of north India, response of high density fuelwood plantation (10,000 ha^{1}) of *Eucalyptus tereticornis* to three levels of basal N (0, 25, 50 *g* per plant) from two sources, prilled urea (PU, 46% N) and super granules (SG, 1 *g* of urea briquettes, 46% N) was studied for one rotation of 3.5 *y*. Phosphorus and zinc sulphate at 25 and 10 *g* per plant respectively were uniformly applied to all the treatments. There were no significant growth responses to the nitrogen source. The application of 25 N-PU and 50 N-PU increased air dry pole biomass by 22.2 and 43.0% and annual discounted (12% rate of interest) cash returns by 36 and 64% over control at 42 months of age. The plantation accumulated 373, 17 and 241 *kg* ha^{1} from the available nutrient pool of 1340, 201 and 1015 *kg* ha^{1} of N, P and K initially present in 0-300 *cm* soil depth. The soil profile indicated a deficit of 98 and 204 *kg* ha^{1} of available N and K but a gain of 59 *kg* ha^{1} of available phosphorus. Although the leaf litter turnover and other probable additions narrowed down the overall nutrient deficit created by *Eucalyptus* harvest, it was unlikely that such nutrient-poor soil can support additional rotation without balanced fertilization. As such, tree farming was economicaly more viable than rainfed agriculture under moisture and nutrient stress conditions of this tropical region.

Key words: Nitrogen - *Eucalyptus* - fuelwood production - fertilization - cash returns - nutrient uptake - north India.

GREWAL, S.S., SINGH, KEHAR & JUNEJA, M.L. 1993. **Kesan ladang kayu api *Eucalyptus tereticornis* berketumpatan tinggi terhadap sumber pangkal nitrogen, dos serta applikasi fosforus atas tanah aluvium.** Di kakibukit utara India, pada pasir lom tanah aluvium, gerak balas pertumbuhan ladang kayu api berketumpatan tinggi (10,000 ha^{1}), *Eucalyptus tereticornis,* terhadap 3 paras pangkal N(0, 25, 50 *g* per tumbuhan) dari sumber prilled urea (PU 46% N) dan granul super (SG, 1 *g* urea briquetes, 46% N) dikaji untuk satu giliran pertumbuhan selama 3.5 tahun. Kesemua tumbuhan telah secara seragam diberikan masing-masing 25 dan 10*g* fosforus dan zink sulfat. Tidak ada perbezaan terhadap gerak balas pertumbuhan tanaman yang bersumberkan nitrogen. Applikasi 25 N-PU dan 50 N-PU telah meningkatkan udara kering biojisim pole sebanyak 22.2 dan 43.0% dan diskaun tahunan (kadar faedah 12%) untuk pulangan tunai sebanyak 36 dan 64% dengan mengatasi kawalan pada umur 42 bulan. Tanaman-tanaman ini telah menggunakan 373, 17 dan 241 *kg* ha^{1} dari kolam nutrien yang pada awalnya mengandungi 1340, 201 dan 1015 *kg* ha^{1}N, P, dan K masing-masing, pada kedalaman 0 - 300 *cm* dibawah tanah. Profil tanah telah menunjukkan kekurangan dalam kandungan N dan K sebanyak 98 dan 204 $kg\ ha^{-1}$ masing-masing. Namun demikian, kandungan fosforus telah meningkat sebanyak 56 $kg\ ha^{-1}$. Walaupun turnover sarap daun dan lain-lain bahan mengurangkan defisit nutrien secara keseluruhan yang disebabkan oleh penebangan *Eucalyptus,* agak sukar bagi tanah yang begitu miskin dari segi nutriennya untuk menampung giliran penanaman yang seterusnya tanpa pembajaan. Dengan demikian, ladang pokok lebih mengutungkan dari tanaman pertanian yang bergantung kepada hujan memandangkan situasi kelembapan dan ketegasan nutrient di kawasan tropika ini.

Introduction

Planting of fast-growing tree species has been suggested as a way to minimise fuelwood crisis and to ease pressure on natural forests of the tropics (e.g. Kaul & Mann 1977, Anonymous 1980, Kaul & Gurmurti 1981). Eucalypts are widely planted for fuelwood, pole, paper pulp and as a source of industrial wood in several countries of Africa and Asia because of their fast growth, drought tolerance, coppicing ability and unpalatability to livestock (e.g. Foley & Bernard 1984). In the foothill region of north India, eucalypts farming gained popularity due to frequent failures of rainfed field crops on light textured alluvial soils (Udic Ustocrepts) inherently poor in fertility and low in water holding (Grewal *et al.* 1990). Monsoon planted seedlings suffer heavy casualties in dry post monsoon months when soil moisture becomes limiting. The enhancement of early vigour may help the plants to use rainy season excess moisture and also exploit moisture from deeper soil layers in dry post monsoon months.

The possibilities of improving early vigour of eucalypts by nitrogen fertilization on poor soils have been indicated by several studies conducted in India (Kaul *et al.* 1966) and abroad (Cromer 1971, Mendoza & Glori 1974, Schonau 1977, Hartley 1977). High intensity and long duration monsoon rains cause excessive leaching of nitrogen from soils having high infiltration rates (Goswami & Sehrawat 1982). Slow releasing granules made from urea showed promise of conserving nitrogen in percolating soils at several locations (IRRI 1979). However, information on the relative performance of such a nitrogen source on the establishment of eucalypts in light textured soils is lacking. Moreover, data on the production potential, economic returns, nutrient accumulation and soil fertility depletion by eucalypts in energy plantations are also limited. This information is necessary to advocate a change from high risk rainfed farming to tree farming for fuelwood production and for soil conservation. A field trial was therefore conducted to (i) study the scope of improving eucalypt growth with fertiliser nitrogen, (ii) find out if the slow releasing nitrogen source of super granules is better than commonly used prilled urea, (iii) evaluate production potential and economic returns from eucalypt plantation *vis-a-vis* traditional field crops and (iv) study soil fertility changes on a light textured and drought prone marginal land.

Material and methods

Site and soil

The study was conducted for four years (1985-88) at the Mansa Devi farm of the Central Soil and Water Conservation Research Centre, Chandigarh located in the foothills of north India (30° 45'N, 76° 15'E, 350*m* above sea level). The area represents a typical semi-arid climate with bimodal pattern of monsoon rains. Out of the average annual rainfall of 1100*mm*, 873*mm* (82%) is received during the monsoon season (June-September). The mean daily temperature varies from a maximum of 38.2°*C* in June to a minimum of 6.9°*C* in January. The monthly pan evaporation exceeds monthly rainfall except in the three monsoon months. The mean monthly solar radiation varies from a maximum of 447.4 in May to a minimum of 248.2 $g\ cal\ cm^2$ in January. Annual rainfalls of 789, 1141, 593 and 1736*mm* were received at the experimental site during 1985, 1986, 1987 and 1988 respectively, out of which 686, 905, 313 and 1586*mm* respectively occurred during the monsoon season (Figure 1). Out of the four years of study, 1987 experienced severe drought, 1988 floods and 1986 was a near normal rainfall year. The daily rainfall distribution from 1985 to 1988 shows dry spell and hence soil moisture stress conditions from September 1987 to June 1988, and October 1988 to December 1988 (Figure 1).

The surface soil is a light textured alluvium classified as typic measic hyperthermic Udic Ustocrepts. The soil properties of the 0 - 300 *cm* deep profile were determined acording to the methods described by Jackson (1973) and Piper (1950). The soil pH and electrical conductivity (1:2 soil water, suspension) values indicated the absence of salinity or alkalinity problem in the entire profile (Table 1). The silt and clay were translocated from surface to middle layers (particularly 120-150*cm* depth) thereby making these layers more moisture retentive. The content of finer soil fractions decreased in the lower profile layers. The soil texture was sandy loam throughout. The soil water retention varied mainly according to silt and clay content. Available macro-nutrients were concentrated in different layers, *e.g.* N in 0-150*cm*, P in 180-300*cm* and K in 120-240*cm* depth. The total nutrient pool of 300*cm* deep profile was 1340, 201 and 1015 $kg\ ha^1$ of available N, P and K respectively.

Field layout and treatments

The response to three levels of N [0, 25 and 50 *g* per plant or 0, 250 and 500 $kg\ ha^1$ from two sources, prilled urea (PU), and 1 *g* super granules (SG); both containing 46% N] were studied on *Eucalyptus tereticornis* raised for fuelwood at 1 × 1*m* spacing or 10,000 seedings per hectare. The nursery-raised polybag seedlings of six months age and of 60 to 70*cm* height were transplanted in July 1985 at the onset of the monsoon in 6*cm* wide and 120*cm* deep augerholes filled with the fertilized soil as per treatment. A basal dose of 25*g* of phosphorus and

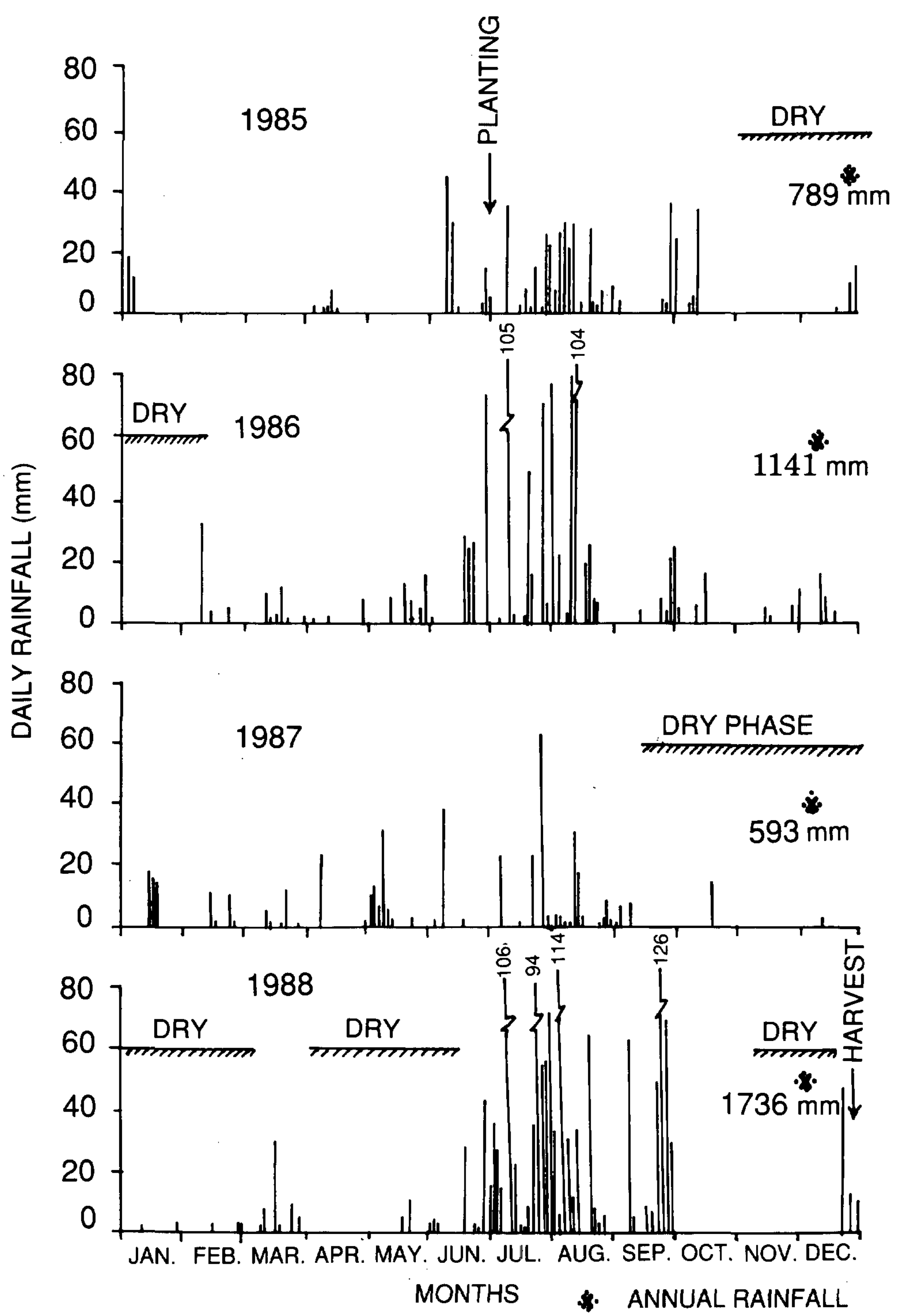

Figure 1. Daily rainfall of four years received in the nitrogen management experiment, Chandigarg

Table 1. The physico-chemical properties of the soil profile

Soil depth (*cm*)	Soil pH (1:2)	EC2 (micro *mhos cm*$^{-1}$)	Mechanical composition % * Coarse sand	Fine sand	Silt	Clay	Soil water (%) 1/3 Bar	15 Bar	Available nutrients (*kg ha*$^{-1}$) N	P	K
0-15	7.1	49	31.7	45.6	12.4	10.3	11.3	3.8	144	12	97
15-30	7.3	62	25.3	46.1	15.0	13.4	11.5	3.2	138	10	97
30-60	8.1	122	23.3	46.7	18.0	12.0	12.1	4.4	166	14	71
60-90	8.3	128	28.1	43.0	15.1	13.8	11.9	4.2	134	7	71
90-120	8.3	148	26.0	42.1	16.8	15.1	16.4	5.2	126	7	90
120-150	8.2	202	22.0	42.1	18.3	17.6	18.0	6.1	132	12	104
150-180	8.2	168	26.8	40.6	15.7	16.9	14.2	6.0	158	12	104
180-210	8.2	148	23.2	46.9	15.9	15.0	16.0	5.4	112	18	86
210-240	8.3	159	27.5	40.7	15.5	16.3	16.6	5.4	82	34	112
240-270	8.3	134	33.1	37.4	14.7	14.8	16.1	5.1	80	34	93
270-300	8.3	123	25.5	48.2	12.0	14.3	10.6	4.0	68	41	90
Total									1340	201	1015

* Soil texture is sandy loam throughout the profile.

10*g* of zinc sulphate per plant were added along with N dose in augerhole soil at planting. The fertilizer was mixed with the soil removed from the augerhole and the same soil backfilled and compacted. Each treatment plot was of 4 × 4*m* size and had 16 plants. The plots were surrounded with 15*cm* high earthen bunds for *in situ* rain water conservation. The five treatments were replicated five times in a randomised block design with each treatment occurring once in each of five complete replications. The treatments were: (i) Control+basal dose of P and zinc sulphate; (ii) 25 N from PU + basal P and ZnSO4 (25N-PU); (iii) 50 N from PU + basal P and ZnSO4 (50N-PU), (iv) 25 N from SG + basal P and ZnSO4 (25N-SG); (v) 50 N from SG + basal P and ZnSO4 (50N-SG). The interplot mixing of applied nitrogen or intrusion from adjacent treatments was not expected because the fertilizer was mixed in augerhole soil and saplings were planted on the top of the hole, thus making the fertilizer immediately available to the emerging plant roots. Moreover, the plant roots tend to remain in the fertilized soil of the augerhole so long as the nutrients are readily available (Grewal & Abrol 1986). A guard row of *E. tereticornis* was also planted along the periphery of the experimental plot. The plantation was kept weed-free by hand-weeding twice in the first and once in the second year of planting. No irrigation was provided throughtout the study.

Observations

Plant growth was periodically measured by recording tree height from ground level to dominating tip by graduated pole and basal diameter/diameter at breast height (DBH) by vernier caliper from all the 16 trees in a treatment plot. The height and DBH measurements of all the 16 plants and those of the central four plants were compared, and no difference was found. This indicated little chances of interplot mixing of nutrients or intrusion from adjoining plots. So data from all the 16 plants were averaged out and used for analysis of variance. All the trees were harvested in December 1988 at 42 months of age. The harvested biomass from each tree was separated into leaf, branch and stem, and its fresh and air dry weights were recorded. Representative samples were oven dried at 70°*C* till constant weight for plant analysis. The disposal of produce was considered in two different ways. In case 1, it was presumed that plantation was harvested by the grower and sold as air dry wood in the form of poles and branches at the market rate. In case 2, the entire standing crop was sold to the paper company at Rs 300 per tonne of green pole weight and the extraction was presumed to be done by the labour of the company (a common practice in the area). The leaves and twigs were left at site but branch wood was given to the labourers by the company and its cost adjusted against their labour wages. In an adjoining plot, summer and winter crops were raised for four years as per the prevalent farming practice to make comparison between the two land uses of traditional agriculture and tree farming. This plot had the same cropping history and similar slope, soil and other site conditions.

The soil samples up to 300 *cm* depth were again drawn at the end of the study for fertility evaluation. The differences in available N, P, K and pH were determined and layerwise gain (+) or loss(-) during the study period was worked out. Just before harvest, samples of leaf litter were collected from all the treatments and their air and oven dry weights recorded. These samples were analysed for N, P and K following Piper (1950). As there were no clear treatment differences in nutrient contents of plant samples, the total nutrient uptake was calculated by multiplying the mean oven dry biomass of the treatments with mean nutrient content and expressed as nutrient accumulation on hectare basis. The annual discounted cash returns with 12% rate of interest and benefit and cost ratios were worked out from discounted cash input and output streams following the procedure described by Mishan (1983). The statistical analysis was carried out by the standard methodology suggested by Cochran and Cox (1959).

Results

Tree growth and biomass production

The plant survival varied from 94 to 100 % among the treatments. There was no significant growth difference between prilled urea and super granules as

Table 2. Height, basal diameter/DBH and harvest biomass of *Eucalyptus* plants under various treatments of nitrogen dose and source

Treatment of N *g*/ plant	Plant height (*cm*) at months age					Diameter(*mm*) at months age					Air dry biomass ($t\ ha^{1}$)				% increase in stem biomass over control
	0	12	16	30	42	0	12 BD	16	30	42 DBH	Leaf	Branch	Stem	Total	
0-N	59	360	506	599	727	11	34	47	54	44	5.07	6.76	38.52	50.35	-
25N-PU	60	386	544	632	756	11	36	51	57	49	6.47	8.35	47.09	61.91	22.2
50N-PU	59	402	563	654	814	12	36	53	62	54	6.16	6.90	55.08	68.14	43.0
25N-SG	59	383	540	626	760	11	35	51	58	49	5.70	6.34	46.68	58.72	21.2
50N-SG	60	405	557	661	764	12	37	54	62	52	5.88	8.05	49.04	62.97	27.3
LSD(0.05)	NS	36	50	46	NS	NS	NS	6	6	NS	NS	NS	6.78	8.06	

PU = Prilled urea; BD = Basal diameter; DBH = Diameter at breast height;
SG = Super granules; NS = Not significant.

Table 3. Economic returns (Rs ha^{1}) from different treatments by method 1

Treatment of N g/ plant	Gross returns* from			Cost of inputs	Total discounted*		B:C ratio	Annual discounted returns	% increase over control
	Pole	Branch wood	Total		Benefits (B)	Costs (C)			
0-N	17719	811	18530	10550	12478	8636	1.44	1098	-
25N-PU	21661	1002	22663	12050	15261	8186	1.86	1510	37.5
50N-PU	25337	828	26163	13550	17618	11314	1.56	1801	64.0
25N-SG	21473	761	22234	12050	14972	8186	1.83	1427	30.0
50N-SG	22558	966	23524	13550	15841	11314	1.40	1293	17.8

Poles @ Rs 460/- and branches @ Rs 120/- per tonne.
* At 12% rate of interest.
One US dollar is equal to Rs 25.

source of nitrogen (Table 2). The height and diameter growth responses to the levels of N were significant between control and 50N-PU or 50N-SG up to the age of 30 months but turned non-significant at 42 months of age. The growth differences between control and 25N-PU and 25N-SG remained non-significant throughout. As such, the addition of 25 and 50*g* N per plant as prilled urea raised the plant height by 4 and 12 % and the DBH by 11 and 25 % over control.

There were no significant differences in leaf and branch weight of these treatments. The stem biomass and total biomass differences were significant with respect to levels in PU and SG except between 25 N-SG and 50 N-SG treatments. The application of 25 and 50*g* N per plant as prilled urea raised air dry stem weight by 8.6 and 16.6 *t* ha^{-1} which was equivalent to an increase of 22.2 and 43.0 % over control (Table 2). Prilled urea as a source of N was not better than super granules at the 25*g* N per plant level but superior at 50*g* N per plant treatment level. The air dry pole biomass per tree was strongly correlated with DBH (R=0.92) rather than with tree height (R=0.78).

Cash returns

When the plantation was presumed to be harvested by the grower and sold as pole and branch wood at the market rate (method 1), the annual discounted cash returns at 12% rate of interest were Rs 1098, 1510 and 1801 ha^{-1} in 0-N, 25N-PU and 50N-PU treatments respectively (Table 3). As compared with control, 25N-PU and 50N-PU treatments increased the discounted cash returns by 37.5 and 64%. The discounted returns were relatively low in SG treatments particularly at 50N-SG level. The overall benefit cost ratio was better in 25N as compared to 50N treatments because of lesser initial investment on fertilization.

When the standing crop was presumed to be sold to the paper mill and cash returns received on green pole weight basis, the annual discounted returns were Rs 1815, 2183 and 2557 ha^{-1} in 0-N, 25N-PU and 50N-PU treatments respectively (Table 4). The returns at 50N-SG treatment remained low in this method also. The overall cash returns and BC ratios appeared better in method 2 as compared to method 1.

In the agricultural land use system, the crop yields were low because of frequent moisture stress. During the drought year of 1987-88, a net loss of Rs 394 ha^{-1} was incurred (Table 5). The four years mean discounted cash return in this system was only Rs 461 $ha^{-1}y^{-1}$. The cash returns from tree farming were much better as compared to the traditional farming.

Nutrient uptake and balance sheet

There was no clear difference in nutrient concentration of leaf, branch and stem samples drawn from different treatments and hence the results were summarised on the basis of pooled values. The concentration of all the nutrients was maximum in the leaf and minimum in the stem (Table 6). In a period of

Table 4. Economic returns from different treatment by method 2

Treatment of N *g*/ plant	Green pole weight (*t* ha^{-1})	Gross returns* (Rs ha^{-1})	Cost of input (Rs ha^{-1})	Total discounted** Benefits (B)	Costs (C)	B:C ratio	Annual discounted returns	% increse over control
0 - N	64.2	19260	7550	12970	6616	1.96	1815	-
25N-PU	77.2	23160	9050	15596	7955	1.95	2183	20.3
50N-PU	90.3	27090	10550	18242	9294	1.96	2557	29.0
25N-SU	77.6	23340	9050	15717	7955	1.98	2218	18.2
50N-SU	80.4	24120	10550	16242	9249	1.76	1985	9.4

* @ Rs 300 per tonne of green pole weight.
** At 12% rate of interest.

Table 5. Crop yields and net returns (Rs ha^{-1}) from traditional cropping system followed under rainfall conditions

Crop year	Crop sequence Summer	Winter	Crop yield (*kg* ha^{-1}) Summer	Winter	Total discounted* Benefits (B)	Costs (C)	B:C ratio	Annual discounted returns
1985-86	Sesame	Rapeseed	128	171	1209	1012	1.19	197
1986-87	Sesame	Taramira	52	337	1794	767	2.34	1027
1987-88	Blackgram	Taramira	201	0	21	415	0.05	-394
1988-89	Cowpea fodder	Taramira	12000	240	1652	637	2.59	1015
Mean					1169	708	1.65	461

(-) Means net loss.
* At 12% rate of interest.

Table 6. Nutrient concentration in leaf, branch and stem of *Eucalyptus* and amount accumulated after 42 *mth* of planting

Plant part	Mean biomass (Oven dry *kg* ha^{-1})	Mean nutrient concentration (%) N	P	K	Nutrient accumulated (*kg* ha^{-1}) N	P	K
Leaf	5388	2.086	0.116	0.85	112	6	46
Branch	6334	0.596	0.038	0.46	47	2	35
Stem	39244	0.546	0.022	0.40	214	9	160
Total	50966	-	-	-	373	17	241

3.5*y*, the energy plantation removed 373, 17 and 241 *kg ha*$^{-1}$ of N, P and K from and soil nutrient pool. At the end of the study, the available N and P content of the *Eucalyptus* profile decreased by 96 and 204 *kg ha*$^{-1}$ and that of field crops by 31 and 40 *kg ha*$^{-1}$ (Table 7). The available phosphorus, however, increased by 57 *kg ha*$^{-1}$ under *Eucalyptus* and 9 *kg ha*$^{-1}$ under field crops during this period. In *Eucalyptus,* the available nitrogen was mostly depleted from 30 to 180 *cm* soil depth and available K from the surface 0-30 *cm* and 90-180 *cm* soil layers. Available P recorded an increase in the entire profile. The reduction in soil pH varied from 0.1 to 1.1 in various layers of the profile. Most of the nutrient depletion took place from the surface 60*cm* soil depth in case of field crops and the reduction in soil pH was marginal in the surface layers only.

At the start of the study, the available nutrient status of 0-300 *cm* soil profile was 1340, 301 and 1015 *kg ha*$^{-1}$ of available N, P and K in both the land use systems as they formed two parts of the same field (Table 8). At the end of the study in 1988, the profile status was changed to 1242, 260 and 811 *kg ha*$^{-1}$ under *Eucalyptus* and 1309, 210 and 975 *kg ha*$^{-1}$ under field crops of available N, P and K respectively. The total uptake by the harvested biomass of *Eucalyptus* (leaf, branch and stem) was 373, 17 and 241 *kg ha*$^{-1}$ and that of field crops only 78, 4 and 31 *kg ha*$^{-1}$ of N, P and K respectively. The entire *Eucalyptus* foliage was not removed from the site but added back to the plot thus making an input of 112, 6 and 46 *kg ha*$^{-1}$ of N, P and K respectively. In addition, 83, 5 and 34 *kg ha*$^{-1}$ of N, P and K respectively were added through litterfall in 42 months of crop stand. Thus against an uptake of 373, 17 and 241 *kg ha*$^{-1}$ of N, P and K respectively, 195, 11 and 80 *kg ha*$^{-1}$ were returned back to the site, yet leaving a short fall fo 178, 6 and 161 *kg ha*$^{-1}$ of N, P and K respectively. The soil profile analysis, however, indicated a loss of 98 and 204*kg ha*$^{-1}$ of N and K and gain of 59 *kg ha*$^{-1}$ of P.

Discussion

Fairly well distributed rains were received during the establishment phase of the plantation particularly during the whole of 1986. As a result, fairly high plant survival was possible even under rainfed conditions. The application of nitrogen through slow releasing source of super granules failed to create significant growth and production differences. These results strengthen the observations earlier made by Rana *et al.* (1984) and Nnadi and Abed (1983). The growth differences between 0-N and 50 N treatments were significant up to 30 months of age probably because of good moisture supply and strong influence of applied nitrogen. In the later period of the study, *i.e.* between 28 and 34 months of age or period from November 1987 to May 1988, there was hardly any rain (Figure 1). The non-availability of moisture caused more uniformity in the treatments and as a result, treatment responses became non-significant. It appears that 50 N-PU and 50 N-SG treatments having higher leaf and branch biomass as compared to control (13.06 *t* in 50N-PU and 13.93 *t* in 50 N-SG as compared to 11.83 *t* in 0-N) may have translocated the photosynthates stored in leaves to other plant

Table 7. Nutrient gain (+) or loss (-) in 42 months of land use under *Eucalyptus* and field crops

Soil depth (*cm*)	Nutrient gain (+) or loss(-) (*kg ha*$^{-1}$)							
	Eucalyptus				Field crops			
	N	P	K	Soil pH	N	P	K	Soil pH
0-15	+5	+13	-37	-0.1	-6	+3	-16	-0.1
15-30	+15	+8	-27	-0.3	-6	+4	-18	-0.2
30-60	-31	+6	-6	-1.1	-15	+3	-2	-0.2
60-90	-4	+4	-2	-0.8	-3	-1	-0	-0.1
90-120	-7	+4	-25	-0.5	-1	0	-4	0
120-150	-16	+6	-36	-0.4	0	0	0	0
150-180	-49	+10	-32	-0.4	0	0	0	0
180-210	-3	+4	-11	-0.4	0	0	0	0
210-240	-4	+2	-12	-0.4	0	0	0	0
240-270	-3	+1	-9	-0.3	0	0	0	0
270-300	-1	+1	-7	-0.2	0	0	0	0
Total	-98	+59	-204	-0.5 (Mean)	-31	+9	-40	-0.1 (Mean)

Table 8. Nutrient balance sheet (*kg ha*$^{-1}$) of two land use systems

Particulars	*Eucalyptus* plantations			Field crops		
	N	P	K	N	P	K
Initial profile status	1340	201	1015	1340	201	1015
Final profile status	1242	260	811	1309	210	975
Profile gain (+) or loss (-)	-98	+59	-204	-31	+9	-40
Total crop uptake	373	17	241	78	4	31
Return through litterfall	83	5	34	-	-	-
Return through harvested foliage	112	6	46	-	-	-
Total return	195	11	80	-	-	-
Balance (uptake-return)	178	6	161	78	4	31

parts under moisture stress conditions before leaf sheding. This may have caused lignification of stem tissues and raised the density of the wood in these treatments. The combined effect of relatively higher height, DBH and lignification of tissues seems to have raised the overall stem biomass in 50-N treatments over control.

Drawing inferences from the studies on fertilization of pines in the cold climate of Scotland, Miller (1981) proposed some guiding concepts in forest farming. He proposed that the tree growth is very much dependent on soil nutrient concentration and response to fertilization can be expected in early stages which comes prior to canopy closure. He further outlined that fertilizers generally benefit the tree and not the site and these benefits are best explained in terms of reduction in rotation length. According to his concept, the height and DBH differences in this study started turning non-significant around 42 months of age when conopy closure started and the plantation was harvested. The gain of 22 and 43% in pole biomass may be presumed to mean reduction in rotation length by 22 and 43% by fertilization at N-25 PU and N-50 PU respectively.

This study has revealed that *Eucalyptus* farming may provide discounted cash returns varying from Rs 1098 in 0-N to Rs 1801 in 50 N-PU treatment in method 1 and Rs 1815 to Rs 2557 $ha^{-1}y^{-1}$ in method 2. These returns were far better than those received from field crops. The returns from *Eucalyptus* farming could be still better but for serious setback it received due to malpractices in its marketing. Saxena (1991) has highlighted the marketing problems of *Eucalyptus* particularly faced by small farmers who are cheated by the greedy contractors. According to his observations, the 1987 drought increased the need for cash flow and sale of *Eucalyptus* saved many poor farmers from utter ruin. The prices of eucalypts wood crashed due to over-supply and malpractices but have started rising again. As compared to the fuelwood price of Rs 460 t^{-1} in 1988, the market price around Chandigarh in 1991 was Rs 650 t^{-1}. Since no viable substitute to *Eucalyptus* has so far clearly emerged, the wood supplies are expected to fall short of demand in due course of time. This is likely to again escalate the eucalypt pole and fuelwood prices.

The perusal of the nutrient balance sheet shows the recoupment from depths beyond 300*cm* which have not been considered in this study. Some additions must have been made through precipitation. As the available soil nutrient pool may have been depleted, the nutrients held in non-available and partly available forms in the soil may have been transformed to available forms. The increased biological activity caused by intensive network of *Eucalyptus* roots, rise in partial pressure of carbon dioxide and consequent decrease in soil pH may have facilitated such nutrient transformations (Goswami & Sehrawat 1982).

In support of this contention, the nutrient inputs through litterfall and precipitation in *Eucalyptus* plantations of some of the relevant studies have been summarised in Table 9. The results of those studies and the data from the present study appear to be in general agreement except for few obvious exceptions caused by soil, site and stand age differences. The laboratory studies conducted by Upadhyay (1982) indicated that in a period of one year, 81.9% of total organic matter, 70% of K and 3.2% of nitrogen were lost through decomposition of *Eucalyptus* leaf litter. But there was a gain of 3.7% of calcium and 11.1% of phosphorus during the process of decomposition. This may explain the reasons of P enrichment and K depletion recorded in this study.

Although the leaf litter turnover and other probable nutrient inputs narrowed down the overall depletion of the soil nutrient pool created by eucalypts harvest, it seems unlikely that such nutrient-poor soil can support additional rotation

Table 9. Nutrient inputs through litter fall and precipitation in *Eucalyptus* stands reported in some studies conducted in India

Description of *Eucalyptus* stand		Annual nutrient inputs (*kg ha*^{1}*y*^{1})			Source
		N	P	K	
		Litter fall			
Age: Density: State: Rainfall:	10 *y* 1575 trees *ha*^{1} Tamil Nadu 2000-2500 *mm*	58	4.0	40	George and Varghese 1990
Age: Density: State: Rainfall:	5 *y* 15405 trees *ha*^{1} Uttar Pradesh 1500 *mm*	14	8	98	Singh 1984
Age: Density: State: Rainfall:	5 *y* 1167 trees *ha*^{1} Uttar Pradesh 2500 *mm*	30	1.6	15	George 1982
Age: Density: State: Rainfall:	12 y 4444 trees *ha*^{1} Tamil Nadu 2500 *mm*	31	0.8	3.4	Venketaramanan *et al.* 1983
Age: Density: State: Rainfall:	3.5 *y* 10000 trees *ha*^{1} Haryana 1100 *mm*	24	1.3	9.7	This study
		Precipitation			
Even-aged stand Dehra Dun Rainfall: 2000 *mm*		3.9	0.4	18.5	George 1978

without balanced N and K fertilization. The addition of 500 *kg ha*[1] of N at 20% efficiency level may be required to recoup the net soil profile deficit of 98 *kg ha*[1]. (Table 7). In this context, turnovers of leaf, bark and small branches during harvest are important to maintain soil fertility levels. The integration of legumes in such plantations may also help in restoring the soil fertility losses.

Conclusion

No significant difference was found between the two sources of nitrogen. The basal application of 25 and 50 *g* nitrogen per plant as prilled urea raised plant height by 4 and 12%, DBH by 11 and 25%, pole biomass by 22 and 43% and discounted cash returns by 37.5 and 64% over control. The energy plantation removed 373,17 and 241 *kg ha*[1] of N, P and K respectively in a period of 3.5 *y* from the soil nutrient pool. The inputs made through litter fall and turn-over of harvested foliage returned 195, 11 and 80 *kg ha*[1] of N, P and K, respectively to the site, yet leaving a shortfall of 178, 6 and 161 *kg ha*[1] of N, P and K respectively. The soil profile, however, indicated a net loss of 98 and 204 *kg ha*[1] of N and K and a gain of 59 *kg ha*[1] of P. It appears that this soil may not be able to support an additional rotation without N and K fertilization. As such, the *Eucalyptus* farming provided much higher net returns than traditional rainfed agriculture.

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