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Dry matter dynamics, storage and flux of nutrients in an aged eucalypt plantation

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Abstract. The net primary productivity and nutrient cycling in a 25-yr-old eucalypt plantation has investigated and compared with an 8-yr-old eucalypt plantation (rotation period for the region) and adjacent natural forest. The biomass of 25-yr-old plantation was two times higher than of 8-yr-old plantation but the primary productivity values were similar. The nutrient return to the soil throuht litter fall and decomposition rate of leaves were higher than that of 8-yr-old plantation. The nutrient concentration in the soil of 25-yr-old plantation was higher than that 8-yr-old plantation and lower than that of adjacent natural forest.

Introduction

During the last two or three decades *Eucalyptus* has been planted over a large area after clearfelling the natural forests in the Central Himalayan tarai belt (an exposed zone with a pronounced deposition of finer material and abundant surface water)to meet an increasing demand for pulp wood and other wood products. A few studies have been made on biomass, net primary productivity and soil changes in eucalypt grown under very short rotations (Bradstock 1981, Frederick *et al.* 1985 a,b, Bargali and Singh 1991, Bargali *et al.* 1992 a,b,c, Bargali *et al.* 1993 a,b). Presented here are the changes in biomass, NPP and soil characteristics in a long rotation plantation of *Eucalyptus tereticornis* (=*E. hybrid*; i.e. 25-yr-old) planted after clearfelling the mixed broad leaved natural forest. The data have been compared with an 8-yr-old plantation with similar density studied earlier (Bargali and Singh 1991) to document the changes in ecosystem properties that may occur with age, such as net primary productivity biomass accumulation rate, nutrient use efficiencies and soil nutrient status. Retranslocation of nutrients during senescence of tree parts is reported to increase with age (Bargali *et al.* 1992 b). The starting conditions of all these plantations including 25-yr-old plantation were the same i.e., all these plantations were grown on initially similar soils and planted after clearfelling the similar natural forest (Bargali 1990). We expect that with increasing biomass and canopy cover soil, might better conserved.

Study site

The study site is located between 29°30' and 29°12' N and between 79°20' - 79°23' E at an altitude of 240 m in the tarai belt of Central Himalaya. The climate of this area is subtropical monsoon with an annual rainfall of 1593 mm (average value for the period 1985 - 1989). About 86% of rain occurs from mid-June to September, while there is a long dry season from early October to mid-June. The mean monthly temperature ranges from from 14°C in January to 31°C in June. Geologically the area is characterized by sedimentary deposits (sandstone), from the tertiary period. Details of geology and original vegetation is given in Bargali *et al.* (1993 a).

Material and methods

The density of the present plantation was 2,000 trees ha^{-1}, with plant to plant and row to row distances of 1.25 and 4 m, respectively. Trees in 0.25 ha area of the replicated sample plots were measured for dbh (1.37 m) and distributed in dbh classes. Shrub vegetation was sampled by ten 2 x 2 m quadrats, which were randomly distributed. The analysis of herb layer was accomplished by using 10 randomly placed quadrats of 1 x 1 m. Based on the field observation five diameter classes of *Eucalyptus* trees were recognized, 15.0 - 20.0, 20.1 - 25.0, 25.1 - 30.0, 30.1 - 35.0 cm. Fifteen trees (three individuals of each diameter class) were harvested. The roots were dug out to 2 m dept within an area extending 1 m in radius around the base of each tree. The tree was then felled into the space between adjoining individuals. After morphometric measurements, the stump root was detched. The aboveground part of the tree was separated into the bole, branches, twigs, foliage and reproductive parts. The root system was categorized into stump, lateral and fine roots. Fresh weight of all components was determined in the field. Preweighed composite samples from upper, middle and lower strata (about 500 g fresh weight) of each component were brought to the laboratory and oven dried at 60°C to constant weight. Multiplication by appropriate factors yielded the weights of the different components. Linear regression analysis related the dry weight of each component to diameter at breast height.

Three individuals of average size for each shrub species were harvested and the roots were recovered upto 50 cm depth. The harvested shrub material was separated into foliage, stem and root. The biomass of the herb layer was determined when it was at its peak during September and October. Fresh and dry weights were determined for each shrub and herb component.

The estimate of mean biomass (by components) for each diameter class was multiplied by the number of trees in that diameter class and stand biomass was calculated by summing the biomass value across the diameter classes. Average biomass of each shrub species was multiplied by the number of individuals (ha^{-1}) in the stand.

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The sum of biomass of trees, shrubs and herbs yielded the total standing biomass of the vegetation on the site.

Data for forest floor material were collected from 10, 50 x 50 cm randomly placed quadrats once in each season, i. e., rainy, winter and summer. All the live and dead herbaceous shoots in each quadrat were first harvested at ground level. The material on the forest floor was then collected carefully, avoiding contamination with soil as much as possible, and categorized into: fresh leaf litter, partly decomposed litter, woody litter and micellaneous litter (material other than the above). The collections were brought to the laboratory separately by category and ovendried weights were determined.

The litter input was measured by placing ten litter traps randomly on the forest floor in each site. Each trap was 50 x 50 cm with 15 cm high wooden sides. The litter was collected at monthly intervals during the study period, separated into leaf, wood, bark and reproductive parts. The samples were oven dried and weighed.

Twenty five individuals were marked in September 1987 and remeasured for increase in diameter in September 1988. Using the regression equations, the biomass of different components of trees was calculated using the dbh measurements for 1987 (B_1) and 1988 (B_2). The Net change in biomass ($B = B_2 - B_1$) yielded the annual biomass accumulation. The sum of the B values for different components yield net biomass accretion in the trees. To the foliage biomass accumulation was added the annual leaf fall to represent annual leaf production. Wood bark and fruit (= reproductive parts) litter fall values were added to the biomass accumulation in twig, bark and reproductive parts, respectively. The death of main roots is rare in actively growing trees but considerable mortality occurs in fine roots. Following Kalela (1954) it was assumed that the mortality in fine roots is equivalent to one-fifth of leaf litter fall.

The annual increment in the diameter of ten average sized individuals of shrubs was recorded in September 1988. Increase in biomass of these shrub species was calculated using the regression equations and this is added to the foliage biomass assuming 100% turnover of leaves in 1 year, to obtain net annual production. Summing net production values of all species, the total shrub production for a site was obtained. The biomass (above- and below ground) and herbs on all sites was determined during their peak growth in September 1987. This value was assumed equal to net herb production. The sum of net production values of trees, shrub and herb layers yielded the total net primary production of the plantation site.

The ovendried samples of different components of trees, shrubs and herbs were analyzed for nutrients. Total N was determined by a Kjel Auto Vs-KTPN analyzer based on micro-Kjeldahl technique (Peach and Tracey 1956). Phosphorus was determined by spectrophotometer and K by flame photometer (Jackson 1958). The total amount of nutrients in the vegetation was obtained from the amounts in the different components. The amount of nutrients in each stratum (0-10, 10-20, 20-30 cm) of soil was obtained from bulk density, soil volume and nutrient concentration values. The amounts of nutrients estimated in all three strata were summed to obtain total

Biomass component	Intercept (a)	Slope (b)	r^2
Bolewood	1.870	2.673	0.988
Bolebark	-0.251	0.316	0.974
Branches	-4.468	0.852	0.974
Twigs	0.436	0.075	0.885
Foliage	-0.243	0.450	0.957
Reproductive parts	0.149	0.079	0.890
Stump root	-0.384	0.765	0.986
Lateral root	1.550	0.105	0.864
Fine root	0.054	0.020	0.960

Table 1. Allometric relationships between the biomass of tree components (Y, Kg/tree) and diameter at breast height (X, cm) for 25-yr-old *Eucalyptus tereticornis* plantation (n = 15). The equation used was y = a + bx. All equations are significant at P < 0.01.

	Biomass	Productivity
Tree layer		
Bolewood	133.7 ± 14.6	4.67(25.1)
Bole bark	14.9 ± 3.4	1.06(5.7)
Total bole	148.6 ± 21.4	5.73(30.8)
Branches	32.5 ± 3.6	1.49(8.0)
Twigs	4.5 ± 0.8	2.88(15.5)
Foliage	21.4 ± 6.7	5.40(29.0)
Reproductive parts	4.1 ± 0.9	0.63(3.4)
Stump root	36.4 ± 5.2	1.34(7.2)
Lateral root	8.2 ± 1.9	0.18(0.9)
Fine root	1.1 ± 0.3	0.96(5.2)
Total	256.8 ± 36.7	18.61
Shrub layer		
Stem	2.4 ± 0.4	0.35(39.8)
Foliage	0.3 ± 0.05	0.26(29.5)
Roots	1.8 ± 0.5	0.27(30.7)
Total	4.5 ± 1.2	0.88
Herb layer		
Aboveground	1.4 ± 0.3	1.44(85.7)
Belowground	0.2 ± 0.01	0.24(14.3)
Total	1.6 ± 0.4	1.68
Total vegetation	262.9 ± 43.6	21.17

Table 2. Biomass (t ha^{-1} ± se) and net primary productivity (t ha^{-1} yr^{-1}) of different components of 25-yr-old *Eucalyptus tereticornis* plantation. Values in parentheses are the percentage of the total.

Components	Forest floor		Litter fall*
Fresh leaf litter	0.62	(10.3)	4.61 ± 0.62
Partially decomposed litter	1.85	(30.7)	
Woody litter	0.46	(7.6)	3.25 ± 0.48
Herbaceous live	0.98	(16.2)	
Herbaceous dead	0.06	(1.0)	
Misellaneous litter	2.06	(34.2)	0.49 ± 0.09
Total	6.03		8.35

Table 3. Biomass of forest floor and litter fall components (averaged across seasons t ha^{-1}) in 25-yr-old *Eucalyptus tereticornis* plantation. Values in parentheses are the percentage of the total. * Presented as mean ± se.

nutrient content upto 30 cm depth.

Nutrient uptake was computed by multiplying the value of net primary productivity of different components by their respective nutrient concentration. The amount of nutrients transferred to the forest floor via litter fall was calculated similarly.

Percentage retranslocation of nutrents from senescing leaves to the perenial tissues was calculated following Ralhan and Singh (1987) i. e., 100 x (nutrient mass in mature leaf-nutrient mass in senesced leaf)/nutrient mass in mature leaf).

	N	P	K
Bole wood	0.063±0.002	0.007±0.0002	0.054±0.002
Bolebark	0.271±0.010	0.024±0.0006	0.429±0.013
Branches	0.230±0.022	0.023±0.001	0.321±0.016
Twigs	0.492±0.008	0.061±0.006	0.516±0.006
Foliage	1.210±0.106	0.065±0.007	0.852±0.010
Reproductive parts	1.701±0.128	0.127±0.032	1.096±0.069
Stump root	0.086±0.012	0.008±0.001	0.252±0.003
Lateral root	0.092±0.009	0.009±0.0006	0.349±0.006
Fine root	0.143±0.012	0.012±0.002	0.508±0.009
Shrub layer			
Stem	0.530±0.041	0.065±0.003	0.298±0.019
Foliage	1.310±0.120	0.125±0.006	0.641±0.011
Roots	0.326±0.018	0.035±0.001	0.210±0.016
Herb layer			
Aboveground	1.841±0.150	0.106±0.018	0.816±0.108
Belowground	0.952±0.061	0.053±0.009	0.261±0.042

Table 4. Concentration of nutrients (%) in different components 25-yr-old *Eucalyptus tereticornis* plantations.

	25-yr-old plantation	8-yr-old plantation	1-yr-old plantation	Adjacent natural forest
Concentration (%)				
N	0.206±0.03	0.165±0.00	0.212±0.02	0.226±0.015
P	0.008±0.00	0.005±0.00	0.009±0.00	0.012±0.001
K	0.140±0.02	0.104±0.02	0.157±0.01	0.169±0.011
Content (kg ha^{-1})				
N	7129.4	7091.8	7125.4	7266.5
P	276.9	226.5	314.4	373.1
K	4851.1	2495.1	5259.0	5446.6
Moisture content (%)	32.6	28.3	31.4	37.8

Table 5. Comparison of soil nutrients and moisture (%) (upto 30 cm depth) between 25-yr-old (present study) and 8-yr-old, 1-yr-old and adjacent natural forest (Bargali *et al.* 1993a).

Results

Biomasss

Certain diamensions for sampled trees and regression parameters for allometric equations developed in the present study are given in Table 1. The biomass of each component and of the total tree was significantly related to the respective dbh.

The total tree biomass was 256.8 t ha^{-1}, of which 58% was in bole and 20% in roots (mainly stump root). Foliage contributed 8%. The shrub and herb (rainy season peak) biomass value were 4.5 and 1.6 t ha^{-1} and the total plantation biomass was 262.9 t ha^{-1} (Table 2). The seasonal mean total forest floor biomass was 6.03 t ha^{-1} (Table 3).

Litter fall

The year-round litter fall was recorded. However, there was more litter fall (about 55% of the total annual litter fall) during the warm and dry months of year (March-June). Of the total litter fall (8.35 t ha^{-1}), 55.2% was leaf litter 38.9% was wood and 5.8% was miscellaneous components (bark + reproductive parts) (Table 3).

Net primary productivity

The net primary production of trees was of 18.61 t ha^{-1} yr^{-1} (Table 2). Of the total tree net production 30.8% was distributed in bole, 8.0% in branches, 15.5% in twigs, 29% in foliage, 3.4% in reproductive parts and about 13.2% in roots (7.2% in stump root, 0.9% in lateral root, and 5.1% in fine roots).

The shrub layer production was about 0.88 t ha^{-1} yr^{-1} (69.3% above ground and 30.7% below ground) and the total herbaceous net production was 1.68 t ha^{-1} yr^{-1}. The sum of the tree, shrub and herb layers, that is, the net production of the stand was 21.17 t ha^{-1} yr^{-1} (87.9% trees, 4.1% shrubs, and 8% herbs).

	N	P	K
Tree layer			
Bolewood	84.2	9.36	72.2
Bole bark	40.4	3.58	63.9
Branches	74.5	7.47	104.3
Twigs	22.1	2.74	23.2
Foliage	259.9	13.9	182.3
Reproductive parts	69.7	5.21	44.9
Stump root	31.3	2.91	91.7
Lateral root	7.5	0.74	28.6
Fine root	1.6	0.13	5.6
Total	590.2	46.04	616.7
Shrub layer			
Stem	12.7	1.56	7.1
Foliage	3.9	0.37	1.9
Roots	5.9	0.63	3.8
Total	22.5	2.56	12.8
Herb layer			
Aboveground	25.8	1.48	11.4
Belowground	1.9	0.11	0.5
Total	27.7	1.59	11.9
Total vegetation	640.4	50.19	641.4

Table 6. Standing state of nutrients (kg ha^{-1}) in different components of 25-yr-old *Eucalyptus tereticornis* plantations.

		% retranslocation	Amount of retranslocation (Kg ha^{-1} yr^{-1})
Leaves	N	25.1	16.4
	P	12.3	0.4
	K	62.9	28.9
Twigs	N	25.2	3.6
	P	90.2	1.6
	K	90.3	13.4
Bark	N	11.4	0.3
	P	66.7	0.2
	K	88.1	4.0
Reproductive parts	N	42.7	4.6
	P	79.5	0.6
	K	78.5	5.4

Table 7. Nutrient retranslocation during senescence of plant parts of 25-yr-old *Eucalyptus tereticornis* plantation.

The ratio of biomass to NPP, termed the biomass accumulation ratio, was about 14, falling within the range generally found for early successional forests.

Nutrient concentration

Table 4 shows concentration of N, P and K in different components of trees, shrubs and herbs. The pattern was as follows: trees « shrubs « herbs. In trees, the concentration of all nutrients examined was highest in reproductive parts, followed by leaves, twigs, bole bark, branches, bole wood. In the belowground components, the order was stump root < lateral root < fine root.

The concentration and content of nutrients (Table 5) in the soil of the present plantation were slightly lower than 1-yr-old Eucalyptus plantations and adjacent natural forest but significantly ($P < 0.01$) higher than an 8-yr-old plantation (rotation period).

Standing state of nutrients

The relative contribution to the standing state of nutrients in the aboveground components was generally in the order: foliage > bole (wood + bark) > branches > reproductive parts > twigs; and in the belowground: stump root > lateral root > fine roots. The nutrient storage in understory vegetation was 3.8 - 8.2% (Table 6).

Retranslocation of nutrients

The percentage retranslocation from senescing leaves was 25% for N, 12% for P and 63% for K and the amount (Kg ha^{-1} yr^{-1}) of these nutrients was 16.4 N, 0.4 P and 28.9 K (Table 7).

	N	P	K
Tree layer			
Bolewood	2.94	0.33	2.52
Bole branch	2.87 (2.57)	0.25 (0.05)	4.55 (0.55)
Branches	3.43	0.34	4.78
Twigs	14.17 (10.57)	1.76 (0.16)	14.86 (1.46)
Foliage	65.34 (48.94)	3.51 (3.11)	46.01 (17.11)
Reproductive parts	10.72 (6.12)	0.80 (0.2)	6.90 (1.5)
Stump root	1.15	0.11	3.38
Lateral roots	0.17	0.02	0.63
Fine roots	1.37	0.12	4.87
Total	102.16 (77.26)	7.24 (4.44)	88.50 (36.8)
Shrub layer			
Stem	1.85	0.23	1.04
Foliage	3.41	0.32	1.66
Roots	0.88	0.09	0.57
Total	6.14	0.64	3.27
Herb layer			
Aboveground	26.51	1.53	11.75
Belowground	2.28	0.13	0.63
Total	28.79	1.66	12.38
Total vegetation	137.09 (112.19)	9.54 (6.74)	104.15 (52.45)

Table 8. Nutrient uptake (kg ha^{-1} yr^{-1}) by different components of 25-yr-old *Eucalyptus tereticornis* plantation.

	N	P	K
Tree layer			
Leaf litter	0.904±0.059	0.057±0.005	0.316±0.028
Wood litter	0.368±0.032	0.006±0.001	0.050±0.003
Bark litter	0.240±0.060	0.008±0.000	0.051±0.013
Reproductive litter	0.974±0.086	0.026±0.006	0.236±0.031
Shrub litter			
Leaf litter	1.306±0.064	0.130±0.026	0.649±0.062
Herb litter			
Leaf litter	1.838±0.178	0.102±0.012	0.820±0.083

Table 9. Concentration (%) of nutrients in litter fall of different components of 25-yr-old *Eucalyptus tereticornis* plantation.

	N	P	K
Tree layer			
Leaf litter	41.67	2.63	14.57
Wood litter	10.10	0.16	1.37
Bark litter	1.21	0.04	0.27
Reproductive litter	4.75	0.13	1.15
Total	57.73	2.96	17.36
Shrub layer			
Leaf litter	3.92	0.39	1.95
Herb layer			
Leaf litter	25.73	1.43	11.48
Total	87.38	4.78	30.79

Table 10. Amount of nutrients (Kg ha^{-1} yr^{-1}) in litterfall of different component of 25-yr-old *Eucalyptus tereticornis* plantation.

Nutrient uptake

The gross uptake of nutrients by vegetation and after adjustment for internal recycling are given in Table 8. Of the total nutrient uptake about 66-70% occurred in tree layer, 5-9% in shrub layer and 25-26% in herb layer. The amount (kg ha^{-1} yr^{-1}) of net nutrient uptake (after adjustment for internal recycling) by vegetation were 112.9 for N, 9.5 for P and 104.1 for K.

Nutrient return through litter fall

The concentration and amount of nutrients return through litter fall are given in Tables 9 and 10, respectively. Litter falling from the trees to the forest floor is normally regarded as the main route by which nutrients move from the canopy to the soil. Of the total nutrient return through total litter fall, 82-93% was by leaf litter fall and 7-18% by other litter fall (twigs, bark and reproductive parts).

Discussion

Table 11 shows the comparison of dry matter dynamics between 25-yr-old and 8-yd-old *Eucalyptus* plantation and natural sal forest *(Shorea robusta)* of the region. Generally 8-yr-old felling cycling is followed for *Eucalyptus* plantations in the region. Though the biomass of 25-yr-old plantation was more than twice as much as that in the 8-yr-old Eucalyptus plantation but net primary productivity values were similar. Interestingly the natural sal forest has also similar productivity. The litter fall is greater than that of 8-yr-old plantation and natural sal forest. The net nutrient uptake, foliar nutrient concentration, nutrient concentration in leaf litter and retranslocation of nutrients from leaves in 25-yr-old plantation were similar to that of 8-yr-old plantation and lower than that of natural sal forest, whereas, the nutrient return to the soil through litter fall was higher than that of 8-yr-old plantation. Nitrogen uptake efficiency (net nitrogen uptake/root biomass) nitrogen use efficiency (net primary productivity/net nitrogen uptake) and NPP/FSC (net primary productivity /foliar standing crop) are lower than that of 8-yr-old plantation. The decomposition rate of leaves in this plantation was greater than that of 8-yr-old plantation (see details Bargali *et al.* 1993 b) and lower than sal forest. Compared to 8-yr-old plantation, soil moisture and soil nutrient conditions in 25-yr-old plantation were better, and appear to have accounted for faster litter decomposition (Berg *et al.* 1987 and Upadhyay and Singh 1989).

Comparison of soil nutrients are shown in Table 5. None of the plantations approached the soil nutrient status of natural forest of the study area. The age-series data suggest that subsequent to replacement with plantation the soil nutrient level declined continuously upto 8-yr-old age (Bargali *et al.* 1993 a), whereafter it increased at 25-yr-old age (see Table 5). Most reports on soil changes following the replacement of the indigenous forest canopy with exotics in tropical environments are usually occur during the first 8-10 years of plantation development (Cornforth 1970, Babalola and Samie 1972, Lundgren 1978, Chijoke 1980, and Kadba and Aduayi 1985). Site preparation techniques prior to the planting induce some initial soil changes (Bargali *et al.* 1993a). After the clear-felling the reorganization of vegetation starts and concludes when rates of internal ecosystem processes and ecosystem exports such as water, particulate matter and nutrients approach levels characteristic to the previous ecosystem. Bormann and Likens (1981) stated that not all the processes return to the former levels simultaneously and this occurs about 15 years after cearfelling when the rate of decline of organic matter in the forest floor reaches a null point and the forest floor begins to accumulate biomass.

During the reorganization period, there is a loss of biological regulations and the biogeochemical parameters are grossly altered for a short time. Compaired to 8-yr-old plantation biomass accumulation was markledly higher in the 25-yr-old plantation, but was still in the range attributed to early successional communities (Whittaker 1975). Though the two eucalypt plantations displayed similar net primary productivities,the older plantation required greater foliar standing crop and net nutrient uptake than the younger plantation. Thus productive efficiency of leaves at stand level and nutrient use efficiency declined with age. Evidently, as leaf mass increases after 8-years light dispersion into crown becomes less efficient as more self shadding of leaves occurs.

To conclude, the better soil conservation and soil nutrient enrichment, mainly due to greater standing crop and crown cover and nutrient return through litter fall, are the major gains of raising an aged eucalypt plantation. However, cost of nutrient productivity in terms of nutrient use and leaf mass becomes significantly higher from 8-yr-old to 25-yr-old of age.

Parameters		25-yr-old *Eucalyptus tereticornis* plantation (Present study)	8-yr-old *Eucalyptus tereticornis* plantation (Bargali and Singh 1991)	Natural forest (Singh and Singh, 1987)
Total biomass (t ha^{-1})		262.9	126.7	291.5-716.9
Total NPP (t ha^{-1} yr^{-1})		21.2	23.4	22.0
Biomass accumulation ratio		13.8	5.9	30.0
Litter fall (t ha^{-1})		8.3	6.5	6.6
Net Nutrient uptake	N	112.2	107.0	125.0
(Kg ha^{-1} yr^{-1})	P	6.7	6.7	10.0
Foliar nutrient	N	1.2	1.2	1.7
concentration (%)	P	0.07	0.07	0.3
Foliar nutrient	N	0.90	0.91	1.26
concentration in litter (%)	P	0.06	0.06	0.09
Retranslocation of	N	25.1	25.2	38.6
nutrients from leaves (%)	P	12.3	18.1	40.6
Nitrogen uptake efficiency (Kg kg^{-1} yr^{-1})		0.002	0.003	-
Nitrogen use efficiency (Kg kg^{-1} yr^{-1})		241	302	-
NPP/FSC (yr^{-1})		0.87	2.17	-
Nutrient return to	N	87.4	75.6	-
the soil by litter fall (Kg ha^{-1} yr^{-1})	P	4.8	4.3	-
Decomposition rate of leaf (% day^{-1})		0.242	0.223	0.253

Table 11. Comparison of biomass, productivity and nutrient parameters in 25-yr-old and 8-yr-old (a rotation period) *Eucalyptus tereticornis* plantations and a natural sal *(Shorea robusta)* forest.

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