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Site Depletion and Resource Conservation in *Eucalyptus* Hybrid Plantation Ecosystems of Punjab, India

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ABSTRACT

The present study was conducted in 4 Forest Divisions of Punjab namely Amritsar, Hoshiarpur, Ludhiana and Patiala. Biomass (t ha^{-1}) was estimated through complete harvesting of 23 trees of various ages (18 – 30 years), density (232 – 740 trees ha^{-1}), diameter (12.7 cm to 49.75cm) and height (14.4 to 41.5 m). Total biomass ranged from 112.98 t ha^{-1} to 531.09 t ha^{-1} and the productivity ranged from 3.77 t ha^{-1} yr^{-1} at Amritsar (Kamalpur I) to 17.71 t ha^{-1} yr^{-1} at Patiala. Biomass of various plant components ranged as; leaf biomass (1.08 kg tree^{-1} to 29.95 kg tree^{-1}), twig biomass (1.62 to 31.92 kg tree^{-1}), branch biomass (6.36 to 151.56 kg tree^{-1}), bark (8.32 to 168.77 kg tree^{-1}), bole biomass (55.88 to 1911.41 kg tree^{-1}), root biomass / Below Ground Biomass (BGB) (9.36 to 397.20 kg tree^{-1}). N accumulation in the total biomass varied from 81.10 kg ha^{-1} to 675.93 kg ha^{-1}, P from 11.87 kg ha^{-1} to 52.65 kg ha^{-1}, K from 83.94 kg ha^{-1} to 547.47 kg ha^{-1}, Ca from 109.63 kg ha^{-1} to 1010.22 kg ha^{-1} and Mg from 6.92 kg ha^{-1} to 62.98 kg ha^{-1}. These variations are also attributed to the variability in the total biomass (kg ha^{-1}) produced by the stands. Considering the percentage contribution of different nutrients to total nutrients (kg ha^{-1}) it is found that the maximum contribution of Ca (33.55 % to 59.68%) is followed by N (12.18 to 33.62%), then K (17.34 to 28.96%), P (1.77 to 4.04%) and Mg (1.36 to 5.70%), respectively. Losses of N, P, K, Ca and Mg have been up to 675.93 kg ha^{-1} (up to 33.62%) of N, 52.65 kg ha^{-1} (up to 4.04%) of P, 547.47 kg ha^{-1} (up to 28.96%) of K, 1010.22 kg ha^{-1} (59.68%) of Ca, 62.98 kg ha^{-1} (5.7%) of Mg. Ca is the major element removed from the stand after harvesting and removal of bark, which accumulates major portion of it e.g. bark represents up to 12.27 % of biomass and contains 28.25 to 59.68 % of Ca. Hence complete harvesting will critically affect the amount of nutrients including Ca.

Key words:

Nutrient loss, complete harvesting, site depletion, resource conservation, *Eucalyptus* hybrid, Punjab

INTRODUCTION

For proper management of ecosystem and to increase their productivity, it is necessary to ascertain the total nutrient uptake, the promotion of nutrients removed permanently from the site by exploitation and the total quantity of nutrients retained in the soil. Sixty to seventy percent of nutrients, taken up by the tree are held in the green foliage. A substantial amount of nutrients taken up by the above ground components of the tree is returned to soil through litter fall. The litter fall in plantation ecosystem increases during early years, peaks and then decreases with increasing age. Restitution of elements to soil by litter fall increases with the increase in productivity of a forest ecosystem. Understory shrubs and ground vegetation is important in total turnover.

Biomass studies are essential to estimate the net primary productivity, understand the nutrient dynamics, organic and energy transfers, predicting the effects of tree utilization, management procedures or other disturbances on the productivity and stability of forest stands. These studies are of special interest to the grower as they help to judge the performance of the species in terms of total biological production and also to assess the nutrient drain on tree harvesting of the species for commercial purposes on the total biomass. The increase in nutrient content of standing crop with stand age has direct bearing on the total biomass of the stand.

There has been a marked increase in the number of studies on forest biomass during the past decades with the realisation that total organic production is important instead of considering the forest a production system of stem wood. This is probably due to increasing pressure placed on forests by the community for different forest products, search for renewable source of raw materials etc. In addition to the productive role, the growing concern of well being of forest ecosystems has resulted in the appearance of numerous publications on forest biomass throughout the world (Porade 1980; Bradstock 1981), including India (George 1977; Chaturvedi, 1983; Kushalappa 1984; Negi 1984; Negi and Sharma, 1987; Pande et al. 1986, 87, 89; Negi et al 1988; Pal and Raturi 1991; Sharma et al. 1988; Tandon et al. 1988; Negi and Sharma 1996; Rawat 1996; Rawat and Negi 2004; Rawat 2006), but in most of the studies only above ground biomass has been estimated / calculated.

In Punjab *Eucalyptus* hybrid was planted extensively during the 1980s on forests along roadsides, canals and drains. It was estimated that over 3% of the net sown area in Punjab had come under *Eucalyptus* (Dogra and Sandhu, 1984). The species has been found to be quite suitable for plantations on semi-arid tracts (Dogra and Upadhyay 2005).

MATERIALS AND METHODS

Study Sites

Punjab state has an area of 50,362 km^2 and is located between 29^{o}30' and 32^{o}32' N Latitude and 73^o 55' and 76^o 50' E Longitude. The present study was conducted in *Eucalyptus* hybrid plantations of different ages at Thapar Engineering College Patiala, Doraha, Dholbaha, Katour, Kharkan, two sites at Kamalpur in 4 Forest Divisions of Punjab namely Amritsar, Hoshiarpur, Ludhiana and Patiala as shown in the map 1 below.

Biomass assessment

Stratified tree technique method of Art and Marks (1971) was used to harvest the sample trees. Temporary sample plots of various sizes (10m x 10m, 20m x20m and 30m x 30m) were laid out in all the plantations of the species and the diameter of all the standing trees in the sample plot were measured. The entire diameter range was then divided into different diameter classes. Heights of 15 representative sample trees of all diameter classes were recorded. Three sample trees from each diameter class (close to the mean diameter of that diameter class) were harvested for biomass assessment. Total 23 trees were felled from different sites.

All the tree components (leaves, twigs, branches, bark, bole) including roots were separated immediately after felling and their fresh weights recorded in the field. The representative samples of each tree component (100 g each of leaves, twigs, branches, bark, fruit and root) were taken for oven dry weight estimation and chemical analysis for different macronutrients in the Laboratory. The bole portion of the sample trees was cut into 2m long sections (billets) for convenience of weighing. Approximately 5-cm broad disc was removed from the base of each billet for estimation of fresh and dry weights and nutrient analysis.

Litter production

Litter production was studied by laying out

10 quadrats of 1 m x 1 m size in each block plantation. The litter was collected seasonally and categorized into leaf, twig and bark litter. Annual litter production was calculated on the basis of seasonal production of litter.

Nutrient analysis of plant components

The representative samples of all the tree components and litter samples were digested with wet digestion method of Piper (1942) for analysis of Phosphorus (P), Potassium (K), Calcium (Ca) and Magnesium (Mg). P was estimated by 'Molybdate blue' method (Vogel 1961) and K and Ca were estimated by 'EEL' Flame Photometer as per Vogel, (1961), whereas Mg was estimated by 'Thizole yellow' method of Young and Gill (1951) by using colorimeter. Nitrogen (N) was estimated by 'Macro Kjeldahl' method.

Nutrient accumulation

The per cent nutrient concentration, weight (kg tree^{-1}) of all the tree components and number of total trees present per hectare were used for calculating nutrient accumulation kg ha^{-1}.

RESULTS AND DISCUSSIONS

Biomass and Productivity

Sample trees with their age, mean diameter, height, number of trees per hectare, biomass (kg tree^{-1} and t ha^{-1}) of all the sample trees have been depicted in the Table 1. As is evident from the table, these plantations show a range of variation in their age (18 – 30 years), density (232 – 740 trees ha^{-1}), diameter (12.7 cm to 49.75cm), height (14.4 to 41.5 m) and total biomass (112.98 t ha^{-1} to 531.09 t ha^{-1}). The variation in biomass depends on combination of factors including size of tree, density (spacing)/ no. of trees per plot and variation of locality factors.

The results show direct relationship of biomass with diameter and height of the tree. More the diameter and height more is the biomass in most of the cases, although number of trees per hectare also plays significant role in assessing the total biomass of an area as can be seen in the Table 1.

Productivity of a stand depends on the total biomass and age of the stand; biomass in turn is dependent on diameter / height and number of trees present in a stand. Hence, with variation in all these parameters the values of productivity also changes as is clear from the Table 1. The productivity has ranged from 3.77 t ha^{-1} yr^{-1} at Amritsar (Kamalpur I) to 17.71 t ha^{-1} yr^{-1} at Patiala.

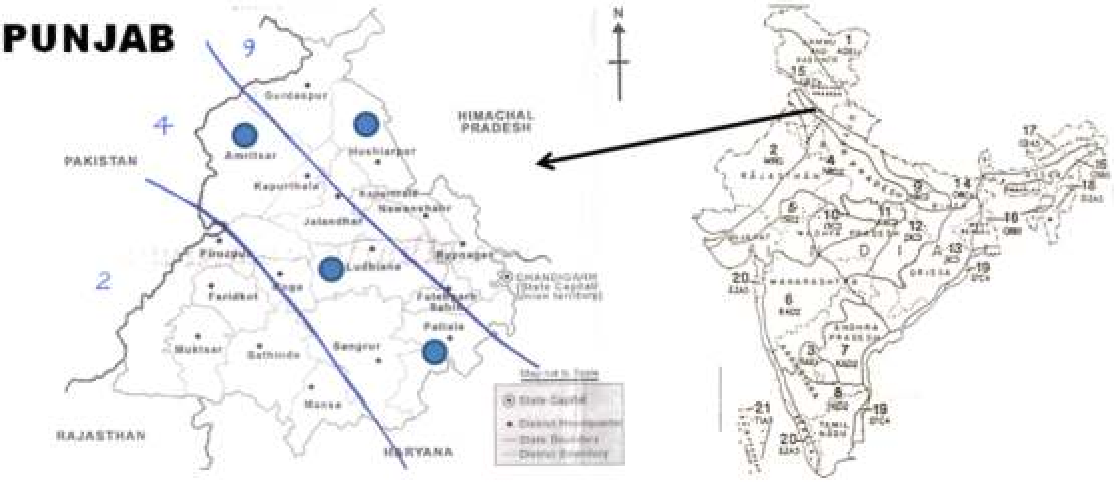
The variation in other biomass components are: leaf biomass (1.08 kg tree^{-1} to 29.95 kg tree^{-1}), twig biomass (1.62 to 31.92 kg tree^{-1}), branch biomass (6.36 to 151.56 kg tree^{-1}), bark (8.32 to 168.77 kg tree^{-1}), bole biomass (55.88 to 1911.41 kg tree^{-1}), root biomass / Below Ground Biomass (BGB) (9.36 to 397.20 kg tree^{-1}) and total biomass (72.41 to 2255.30 kg tree^{-1}). Most of the upper range of all the biomass components are at Patiala at the age of 30 years whereas the lower range has been varying component wise (Rawat, 2006).

Negi (1984) has compared biomass/ productivity of man-made (*E.* hybrid) and natural forest of Sal (*Shorea robusta*) and concluded that man-made forests are highly productive as compared to natural forests. Gurumurty et al. (1984) studied the biomass production and energy conversion efficiency by *Eucalyptus* hybrid at different ages (ranging from 12 to 36 months) in Gujarat (Density 5587 plants ha^{-1}). The total biomass production ranged from 5 t ha^{-1} (12 months) to 66 t ha^{-1} (36 months).

Extensive studies on biomass and productivity of *Eucalyptus* hybrid plantations grown in Uttar Pradesh (some parts in present Uttarakhand) were carried out by George (1977). About 24 plantations of different age groups of *Eucalyptus* hybrid grown in different agroclimatic regions were studied for their biomass and productivity and the maximum biomass obtained was 358 t ha^{-1} (age 12 years, density 1335 trees ha^{-1}) with an average annual production of 21.5 t ha^{-1} yr^{-1} and 16.1kg tree^{-1} yr^{-1}. Biomass and productivity for a range of plantations of different age groups and few plantations of same age 9 and 10 years grown at different agroclimatic regions of Uttar Pradesh / Uttarakhand are compared in the table 2

Site depletion through harvesting

Nutrients are constantly being added or removed from the ecosystems by artificial or natural processes. It is through the dynamic and rather complex system of bio-geo-chemical cycling



Map. 1 Map showing Punjab with its Forest Divisions

Table 1: Biomass (t ha^{-1}) and productivity (t ha^{-1} yr^{-1}) of *Eucalyptus* hybrid at different sites of Punjab

Forest Div. (Agro climatic zone)	Locality / Site	Trees	Age (Yrs)	Mean dia. (cm)	Height (m)	Biomass (kg tree^{-1})	No. of trees ha^{-1}	Biomass (t ha^{-1})	Productivity (t ha^{-1}yr^{-1})
1.Patiala (4)	T.E.C.Patiala	1	30	19.00	24.30	385.04	256	98.57	3.29
		2	30	30.00	35.55	1198.05	160	191.69	6.39
		3	30	49.75	36.10	2646.50	91	240.83	8.03
					Total	4229.59	507	531.09	17.71
2.Ludhiana (4)	Doraha	4	28	17.80	16.40	136.71	175	23.92	0.85
		5	28	23.10	25.10	341.18	49	16.72	0.60
		6	28	28.80	37.10	648.21	133	86.21	3.08
		7	28	38.50	41.15	1449.13	203	294.17	10.51
					Total	2575.23	560	421.02	15.04
3.Hoshiarpur (9)	Dholbaha	8	18	13.60	16.70	91.04	130	11.84	0.66
		9	18	17.80	22.40	239.73	232	55.62	3.09
		10	18	26.70	24.10	564.47	247	139.42	7.75
					Total	895.24	609	206.88	11.50
	Katour	11	30	42.50	33.80	1620.15	48	77.77	2.59
		12	30	17.60	22.70	238.89	105	25.08	0.84
		13	30	26.80	29.20	701.89	129	90.54	3.02
					Total	2560.93	282	193.39	6.45
	Kharkan	14	30	27.70	26.20	634.06	234	148.37	4.95
		15	30	12.70	17.90	90.21	52	4.69	0.16
		16	30	17.70	22.50	212.51	61	12.96	0.43
		17	30	21.50	23.90	388.07	90	34.93	1.16
					Total	1324.85	437	200.95	6.70
4.Amritsar (4)	Kamalpur I	18	30	13.50	14.40	89.11	16	1.43	0.05
		19	30	22.50	24.25	402.02	168	67.54	2.25
		20	30	35.00	27.50	916.93	48	44.01	1.47
					Total	1408.06	232	112.98	3.77
	Kamalpur II	21	30	31.80	28.20	876.76	60	52.61	1.75
		22	30	39.00	29.00	963.64	79	76.13	2.54
		23	30	40.10	28.90	1547.35	48	74.27	2.48
					Total	3387.75	187	203.01	6.77

that the soil organic matter and nutrient supplies are replenished and maintained thereby ensuring continuous productivity of the site. Fig. 1 depicts the average percentage concentration of different nutrients in different plant components at different sites. The highest percentage of N (1.33%), P (0.08%), Mg (0.05%) was in the leaf, while fruit had maximum percentage of K (1.05%) and bark showed the highest Ca (1.25%). The highest value of N in leaf is followed by bud/fruit (0.09/0.84%), then by root (0.41%), then by twig (0.34%), branch and bark (0.32%) and lowest in bole (0.15%).

Similarly P concentration in leaf followed by buds, bark, twig/branch, bole and root. In case of K the descending order is fruit, leaf, bud, bark, twig, branch, root and bole, respectively. Ca concentration is highest in bark than in twig, leaf, root, bole, branch, fruit and buds, respectively. The highest concentration of Mg in leaf was followed by bark, twig, branch-fruit-buds-roots and bole. The high percentage of Ca in the bark of *Eucalyptus* (smooth barked species) has been reported by George (1977) and Negi (1984) also.

Nutrient accumulation (kg ha^{-1})

It is observed that the amount of nutrient accumulated is directly related to the biomass produced by different components of different stands and the concentration of different nutrient elements in the various tree components. As such, the nutrient accumulation in different tree components varied considerably. On unit area basis the amount of various nutrients accumulated in the total biomass varies from (N) 81.10 kg ha^{-1} to 675.93 kg ha^{-1}, (P) 11.87 kg ha^{-1} to 52.65 kg ha^{-1}, K- 83.94 kg ha^{-1} to 547.47 kg ha^{-1}, Ca- 109.63 kg ha^{-1} to 1010.22 kg ha^{-1} and Mg – 6.92 kg ha^{-1} to 62.98 kg ha^{-1}. These variations are attributed to the variability in the total biomass (kg ha^{-1}) produced by the stands. Considering the percentage contribution of different nutrients to total nutrients (kg ha^{-1}) it is found that the maximum contribution of Ca (33.55 % to 59.68%) is followed by N (12.18 to 33.62%), then K (17.34 to 28.96%), P is 1.77 to 4.04% and Mg 1.36 to 5.70%, respectively (Table 3).

Estimation of Resource conservation

The perception of forest ecosystems as having multiple functions for satisfying diverse and vital human needs for air, water and food was superseded with the growth of one-dimensional scientific forestry, which had only objective of maximization of the production of commercially valuable timber and wood while ignoring the other ecological and environmental objectives of forest resources (Shiva and Bandopadhyaya 1984).

A more comprehensive forest management has to be multi-dimensional and has account of the diverse economic utilities and functions of forest resources. In a disturbed /degraded plantation removal of associate species, litter from forest floor and all the parts of a tree after harvesting poses tremendous influences on the site quality. The nutrients particularly, which are removed from the site along with these plant parts, can be replenished to some extent if these non-utilizable parts are left on the site after harvesting. Hence, site conservation becomes very important to manage any ecosystem of an area.

The forest sites after removal of complete plant parts become nutrient poor, which is replenished through many natural and cyclic inputs of nutrients as;

a. Through litter, b. Through canopy wash and c. Through understory vegetation

a. Through litter

There are two peaks of litter fall in *Eucalyptus* species, the first during April-may and the second during September-November or even later. The bimodal peaks of litter fall in India are also reported by George (1977), Negi (1984), Sharma and Pandey (1989) etc.

Leaf litter contributed 46.44 - 70.86 %, twig litter 14.73-32.80% and bark litter 7.72-20.76% to total litter in the present study which is less as compared to other studies conducted earlier. Annual litter fall and nutrient return under *E.* hybrid plantations of the study are compared with results reported earlier (Table 4).

The nutrient content of litter fall varies with foliage production and nutrient concentration of leaves. Foliage production and nutrient concentration in foliage depends on site conditions. Table 5 shows nutrient concentrations in foliage of *E.* hybrid at various sites in India along with results

Table 2: Biomass and Productivity of different age group plantations of *Eucalyptus* hybrid in U.P./Uttarakhand and Punjab

Age (yrs)	Density (trees ha^{-1})	Biomass (t ha^{-1})	Productivity (t ha^{-1} yr^{-1})
U.P. / Uttarakhand			
5	1167	57	11.4
6	1482	101	16.8
7	1399	99	14.1
8	764	116	14.5
9	1289	122	13.6
10	102 3	137	13.7
11	1048	142	12.9
12	1335	258	21.5
13	860	123	9.5
			Tewari (1992)
Punjab			
18	740	335.76	17.2
28	560	421.03	15.0
30	507	531.09	17.70
			Rawat (2006)

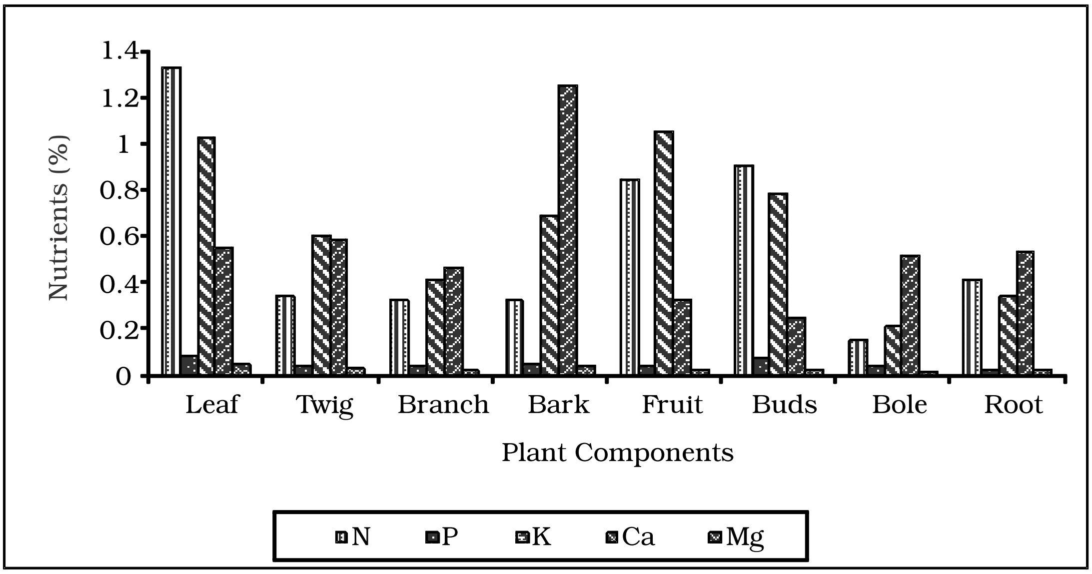


Fig. 1. Nutrients concentration (%) of *Eucalyptus* hybrid in different tree components

Table 3: Nutrient accumulation (kg ha^{-1}) in different tree components of *Eucalyptus* hybrid

	Tree components						Total	
	Leaf	Twig	Branch	Bark	Bole	Root	kg ha^{-1}	%
Site: -TEC Patiala								
N	44.39	13.99	62.69	59.84	309.74	185.29	675.93	33.62
P	2.32	1.28	6.75	5.57	32.51	4.21	52.65	2.62
K	41.29	22.39	61.72	95.12	198.51	128.44	547.47	27.23
Ca	26.50	27.99	81.98	186.10	149.92	202.13	674.61	33.55
Mg	4.31	2.45	4.34	7.00	29.39	12.63	60.12	2.99
						Total	2010.77	100.00
Site: -Kamalpur (Amritsar)								
N	25.68	14.21	39.94	30.14	113.03	48.47	271.47	16.04
P	1.63	1.25	4.58	4.45	13.93	4.04	29.89	1.77
K	14.09	12.09	50.34	75.74	157.93	43.85	354.03	20.92
Ca	6.26	14.17	73.91	127.58	695.97	92.32	1010.22	59.68
Mg	0.41	0.38	3.47	5.86	15.48	1.44	27.04	1.60
						Total	1692.65	100.00
Site: -Doraha (Ludhiana)								
N	14.12	5.00	18.32	14.14	101.09	53.29	205.97	18.63
P	0.98	0.47	2.04	3.49	14.73	2.80	24.50	2.22
K	12.93	4.54	19.38	2.92	120.50	31.41	191.69	17.34
Ca	5.28	3.78	19.38	19.23	522.18	50.49	620.34	56.12
Mg	0.45	0.47	1.84	47.09	10.04	3.09	62.98	5.70
						Total	1105.48	100.00
Site: -Dholbaha (Hoshiarpur)								
N	23.88	4.77	12.75	11.45	59.12	29.35	141.32	16.84
P	1.64	0.60	2.33	2.62	9.10	2.83	19.12	2.28
K	12.88	13.94	26.21	29.43	103.95	39.60	226.01	26.94
Ca	9.37	7.68	17.95	71.49	298.38	35.36	440.22	52.47
Mg	0.53	0.44	1.80	1.13	6.98	1.41	12.29	1.46
						Total	838.96	100.00
Site: -Katour								
N	19.07	2.84	14.21	16.53	69.59	31.35	153.59	12.18
P	1.29	0.84	3.05	2.11	19.32	1.08	27.68	2.20
K	16.49	5.22	18.27	40.29	252.49	32.43	365.19	28.96
Ca	9.21	4.68	20.30	47.11	572.89	43.24	697.43	55.31
Mg	0.23	0.23	1.02	1.76	10.32	3.54	17.10	1.36
						Total	1260.98	100.00
Site: -Kharkan								
N	11.73	2.90	6.03	7.49	34.91	18.04	81.10	27.63
P	0.70	0.39	1.17	2.34	6.08	1.19	11.87	4.04
K	9.54	4.45	8.81	15.82	29.18	16.14	83.94	28.60
Ca	3.85	4.11	11.67	29.67	27.09	33.24	109.63	37.36
Mg	0.17	0.11	0.32	1.33	4.52	0.47	6.92	2.36
						Total	293.46	100.00

Table 4: Litter fall and nutrient return under *E.* hybrid plantations in India

Forest	Age	Litterfall ($t\ ha^{-1}\ yr^{-1}$)	Nutrient content ($kg\ ha^{-1}\ yr^{-1}$)					Source
			N	P	K	Ca	Mg	
E. hybrid (U.P.)	5	3.4	31	2	16	40	5	George, 1977
E. hybrid (U.P.)	7	3.8	32	2	17	44	6	George, 1977
E. hybrid (U.P.)	10	6.2	57	4	29	72	10	George, 1977
E. hybrid (U.P.)	14	7.1	56	5	40	96	10	Sharma and Pandey, 1989
E. hybrid (Punjab)	18-30	3.6-5.4	21-42	1-3	10-29	35-75	3-8	Rawat, 2006

Table 5: Foliar concentration of nutrients in *Eucalyptus* hybrid of some States of India.

Plant Species	Foliar concentration (Percentage oven-dry weight)					Source
	N	P	K	Ca	Mg	
Eucalyptus hybrid (U.P.)	1.90	0.15	1.03	1.45	0.29	George (1977)
Eucalyptus hybrid (U.P.)	1.92	0.17	1.07	1.70	0.30	George (1977)
Eucalyptus hybrid (U.P.)	1.88	0.16	1.04	1.47	0.30	Negi (1984)
Eucalyptus hybrid (T.N.)	1.91	0.11	0.87	1.41	0.27	Negi and Sharma (1985)
Eucalyptus hybrid (T.N.)	1.80	0.09	0.80	1.26	0.33	Negi and Sharma (1985)
Eucalyptus hybrid (T.N.) Coppiced	1.82	0.10	0.79	0.97	0.40	Negi and Sharma (1985)
Eucalyptus hybrid (Bihar)	1.28	0.04	0.61	0.53	0.20	Pande *et. al.* (1987)
Eucalyptus hybrid (Karnataka)	1.22	0.05	0.53	0.38	0.30	Pande *et. al.* (1987)
Eucalyptus hybrid (W.B.)	1.79	0.09	0.91	1.36	0.31	Gupta and Raturi (1984)
Eucalyptus hybrid (Punjab)	1.33	0.08	1.02	0.55	0.05	Rawat (2006)

of present study.

b. Through Canopy wash

Interception studies carried out in a *Eucalyptus* forest in Australia by Smith (1974) reported that 10.6% of the total precipitation was intercepted by canopy. In *E.* hybrid interception is less as compared to other species reports George (1978). Shape, structure and nature of foliage, canopy architecture, nature of bark is some of the important factors, which influence stem flow, through fall and interception. As *E*. hybrid has light foliage and smooth bark they conduct more water as stem flow and through fall, with a little amount is intercepted.

Through fall, stem flow and rainfall are major pathways of nutrient input and nutrient cycling. There are only a few studies on leaching of nutrients by canopy wash and on atmospheric input in eucalypt and other forest trees in India (George 1977, Negi andSharma 1996).

George (1977) reported that in *E.* hybrid forests of U.P. Ca, K, N, Mg and P returned to soil in 41, 28, 24, 6 and 1 percentage, respectively, through canopy wash. For Punjab it is essential to conduct a study on stem flow, through fall and interception, their nutrient status etc to know the amount of nutrients being added to soil as canopy wash or through rain.

c. Through understory vegetation

In *E.* hybrid plantations of present study the aboveground biomass of understory vegetation estimated ranged from 0.85 - 1.3 t ha^{-1} yr^{-1}. Negi (1984) has reported 3 - 5 % contribution of total biomass and percentage contribution of nutrients to main crop as; N 6-8%, P 6-9%, K 11-17%, Ca 2-3% and Mg 3-4%. In the present study amount of litter fall is less as compared to other studies conducted in U.P. (George 1977; Negi 1984). Foliar concentration of nutrients is also low. Hence, nutrient return through litter fall (in total) and through leaf fall is also less in the present study of Punjab.

Nutrient losses through harvesting in any plantation may reduce long term productivity through reduction in nutrient availability. In the present study losses of N, P, K, P, Ca and Mg have been upto 675.93 kg ha^{-1} (upto 33.62%) of N, 52.65 kg ha^{-1} (upto 4.04%) of P, 547.47 kg ha^{-1} (upto 28.96%) of K, 1010.22 kg ha^{-1} (59.68%) of Ca, 62.98 kg ha^{-1} (5.7%) of Mg in *E*. hybrid plantations of Punjab.

Judd's (1996) model predicts net losses of nutrients upto 395 kg ha^{-1} of N, 35 of P, 969 of Ca over 80 years forest rotation and upto 376 kg ha^{-1} of N, 24 kg ha^{-1} of P, 209 kg ha^{-1} of K, 550 kg ha^{-1} of Ca and 54 kg ha^{-1} of Mg over 20 years plantation rotation of *Eucalyptus* of Australia. In addition to this Ca is the major element removed from the stand after harvesting and removal of bark, which accumulates major portion of it e.g. bark represents up to 12.27 % of biomass and contains 28.25-59.68 % of Ca in Punjab. The harvesting will critically affect the amount of nutrients including Ca.

CONCLUSION

Nutrient loss through biomass removal is one of the direct effects of harvesting trees. It is also well established that short rotation harvesting, removes larger proportion of nutrients, as compared to slow growing species, even after completing their rotation. The present trend of removing all the tree components (wood and other parts) from the forests and the adaptation of short rotation could significantly reduce the capacity of many marginally deficient soils to replace the nutrient removal in harvest. Thus there is considerable scope of minimizing the losses of nutrients in plantations through adoption of conservative management practices.

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