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BIOMASS PRODUCTION AND NUTRIENT ACCUMULATION IN AN AGE SERIES OF *CAESALPINIA SAPPAN* L. PLANTATIONS

K. Vidyasagaran*, E. Imrose Elias Navas and E. S. Nishad

Department of Forest Management & Utilization, College of Forestry, Kerala Agricultural University, Vellanikkara - 680 656, Thrissur (Kerala), India.

Abstract

The present study was conducted on biomass production and nutrient accumulation of *Caesalpinia sappan* L. plantations in different age series. The study revealed that above ground biomass and biomass components is a function of diameter and age. The above ground biomass produced at the age 5, 6 and 7 year was 23.81 t ha^{-1}, 37.80 t ha^{-1} and 44.36 t ha^{-1}, respectively. It is also observed that there was no significant difference in nutrient concentration between trees of a particular age. However, significant variation was observed among components between plantations of different ages. Leaves had the maximum concentration of the nutrients and bole had the lowest. It was also observed that nutrient concentration decreased with increasing age. Among the nutrients, nitrogen registered highest concentration, followed by potassium and phosphorus registered minimum among all components irrespective of age. The nutrient accumulation in the agb as well as biomass components increased with the age of plantation except in the case of bole and branches. The maximum accumulation was found to be in bole and minimum in bark. Nitrogen was accumulated maximum followed by potassium and phosphorus. Nutrient use efficiency increased considerably with advancing age. It was found to be maximum in bole and minimum in leaf. Nutrient use efficiency of phosphorus was received maximum followed by potassium and nitrogen.

Key words : Ecosystem, mineral elements, nutrient dynamics, plantation.

Introduction

Caesalpinia sappan Linn. is a small tree belongs to family Caesalpiniacae. It is cultivated as a medicinal tree in South East Asia including south India, Srilanka, Burma, Indonesia and Malaysia. The wood is bitter and used for the treatment of fever, biliousness, ulcers, Urinary concentrations, blood complaints, haemorrhages, and wounds. *C. sappan* also used for the production of red dye (brazilian dye), which is obtained from its heartwood. The brazilian dye is used for facials which are resistant to light, heat and water as well as being non-irritant. In India Caesalpinia sappan is widely planted in plantations as well as cultivated in the agroforestry systems and field boundaries.

Estimation of biomass stands as a prerequisite for better resource utilization. For biomass studies several plantations were established on different habitats to examine its production potential and also the total biomass so as to identify proper variety, habitat and the management practices leading to higher production (Pathak and Gupta,. 1987). Primary productivity and biomass gain of a plant or in an ecosystem varies with the availability of resources and characteristics of environment in which they grow. Climate inter alia is the strongest ecological factor in determining primary production. Ecosystem productivity is an index, which integrates the cumulative effects of the many processes and interaction. Net production by an individual plant is the amount of organic matter that it synthesises and accumulates in tissue per unit time (Booth and Mac Murtrie, 1988).

Estimation of the essential mineral elements in plants is an important aspect in the study of ecosystem structure. In the case of fast growing species it becomes more essential to study the geochemical cycle of the essential elements in support of their survival in future. Geochemical cycle also provides a basis to evaluate the productivity of the ecosystem. In the forest ecosystem,

**Author for correspondence:* E-mail: vidyakattany@yahoo.com

uptake, retention and distribution of biogenic salts in the plant body is influenced by several factors such as age, type of tree species (Mohsin *et al.*, 2005). Nutrient distribution data provide useful information in assessing the significance of elements in physiological processes in the trees, which affect their overall growth and vitality (Khanna and Ulrich, 1991). The aims of the present investigation were to study the biomass production of *C. sappan* plantations on an age series and to determine the nutrient accumulation in biomass.

Materials and Methods

The present study was conducted in an age series of *Caesalpinia sappan* plantations grown in three districts of Kerala *viz.*, Thrissur, Kozhikode and Palakkad which are situated between 9° 55' to 11o 50' N and 75° 50' to 76° 53' E. Nine plantations belonging to three age groups ranging from 5 to 7 years were studied for nutrient accumulation and these plantations were raised and maintained by farmers as well as government agencies.

Location, climate and soil

The details of location, climate and soil of *Caesalpinia sappan* plantation of three districts are given in table 1.

Table 1 : The location, climatic and soil parameters of the study areas.

S. no.	Distict	Average rain fall (mm)	Temperature (°C)	Soil type
1.	Palakkad	960	21.1-44.0	Inceptisol (Black soil)
2.	Thrissur	2550	21.0-32.0	Laterite alluvium
3.	Kozhikode	3266	21.0-39.6	Laterite

Estimation of biomass production

Field studies were confined to sample plots in the plantations employing stratified average tree technique (Madgwick, 1971). Sample plots of size 10 m x 10 m were laid out and diameter at breast height (dbh) of each tree in the sample plot was recorded. Height of trees was also recorded by using Clinometer.

The trees were grouped into three diameter classes by frequency distribution method and an average tree of each diameter class (Girth classes) was selected for sampling. A total of 21 trees were harvested for estimating above ground biomass. Estimates of dry weight biomass were obtained from the fresh weights of various tissue types and their corresponding moisture contents. The frequency (as percentage) of stems belonging to various girth classes in the entire stand was recorded to calculate the number of trees per ha in each girth class. Biomass of tree parts was summed to obtain the total above ground biomass per tree. The average biomass of component parts per tree was multiplied by the number of trees ha-1 to get biomass on hectare basis.

Phytochemical analysis

Triplicate samples of each biomass components were analyzed for nitrogen (N), phosphorus (P) and potassium (K). The oven-dried samples were powdered and passed through sieves of size ranges from 5mm to 2mm. Samples were used for estimation of N, P and K at different ages. Nitrogen was estimated following the micro-Kjeldahl digestion and distillation method (Jackson, 1958). Phosphorus was estimated after digesting the samples in triple acid mixture (HnO_3 and H_2SO_4 and $HClO_4$ in 10:1:3) and determined following the vanado-molybdo phosphoric yellow colour method by Spectrophotometer (Jackson, 1958). Potassium was estimated after digesting the samples in triple acid mixture (HNO_3 and H_2SO_4 and $HClO_4$ in 10:1:3) and determined by flame photometry (Jackson, 1958).

Total nutrient accumulation on per tree basis was calculated by multiplying the oven dry biomass of tree components with the mean biomass of each plant part by the corresponding nutrient concentrations. Average nutrient accumulation per tree was extrapolated to a hectare by multiplying frequency of trees ha^{-1}.

Results and Discussion

Biomass production

Dry matter production of sample trees was estimated from the samples collected. It was seen that significant variations in above ground biomass (agb) and in the biomass components between ages. Biomass of average trees (average of same ages) are depicted in table 2. Analysis of variance of agb showed that age 5 year is significantly different to an agb at age 7 year, but variations were not observed between age groups 5 and 6 and 6 and 7. In all age groups, total agb and biomass components increased with increasing age. At age 5 years, total agb was 21.43 kg, whereas at age 6 years it increased to 34.02 kg and at 7 years it increased to 39.92 kg. George (1993) reported that agb of *Leucaena leucocephala* was 21.87 kg $tree^{-1}$ at 5 year old plantation. Hence, the amount of agb at 5 year in case of *Caesalpinia sappan* is on par with *Leucaena leucocephala*. Similar trend was observed in case of *Poulownia fortunei* (10.06 to 18.0 kg $tree^{-1}$) from age 1 year to 4 year (Charansingh, 1998). The increasing trend is due to the higher accumulation of

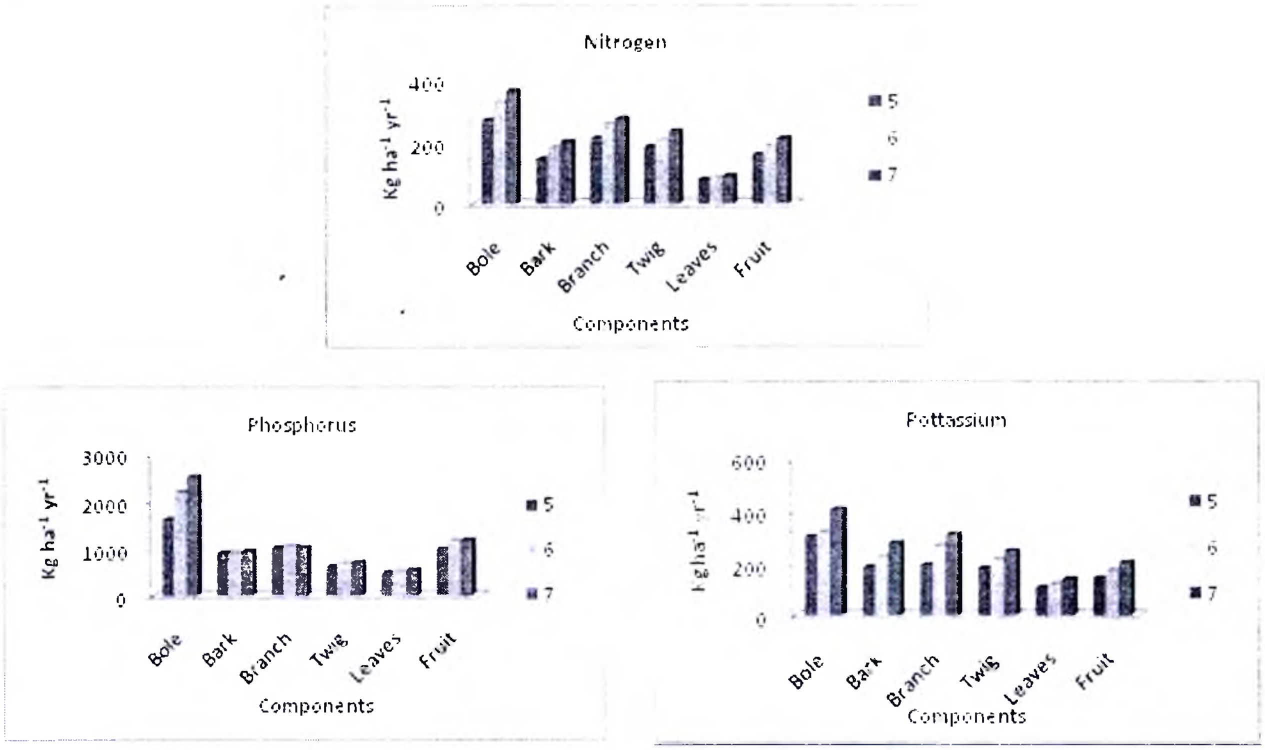

Fig. 1 : Nutrient use of efficiency of *C. sappan* at different ages.

photosynthates with advancing ages. Vidyasagaran (2003) observed that agb produced at age of 7 years in *Casuarina equisetifolia* was 50.9 in kg tree^{-1}, which is a higher value when compare to present study. It may be due to slow growing nature of the *Caesalpinia sappan*. The significant difference in agb from 5 to 7 years showed considerable increase in average tree biomass as indicated with their homogenous mean values. Higher age groups produce more dry matter, which was revealed by Negi and Tandon (1997) in *Eucalyptus hybrid*. Biomass accumulated per tree depends on factors like density, age of the tree and environmental condition in which, it is grown (Landsberg, 1995).

Biomass components of average trees between age groups also showed variation. There was a significant difference between components from 5th and 7th year old plantations. But, between ages 5 and 6 years as well as 6 and 7 years, it showed no significant difference. At the age 5 year, the bole biomass was 8.55 kg, 14.75 kg at age 6 years and 16.24 kg at age 7 years and it also showed that the biomass, at age 5 years was significantly different compared to age 7 years. Above ground biomass increased with increasing age. In the present study, above ground biomass showed an increasing trend from age 5 year to age 7 year (21.43 kg tree^{-1} to 39.92 kg tree^{-1}). The higher bole biomass may be due to the higher accumulation of nutrients in the bole compared to other components. The branch and leaves also indicated significant difference at age 5 years to age 7 years, but in 5 and 6 years as well as 6 and 7 years showed no substantial difference. In twigs and fruits, at age 7 years, biomass showed significant different from 5 and 6 year old plantations. However in bark, there was no significant difference in biomass between ages 5, 6 and 7 years. Biomass components in all age groups had shown an increasing trend from 5 year to 7 years. In all age groups, bole had acquired maximum biomass and bark the lowest (Gurumurthy and Rawat, 1989). Generally, the components showed a decreasing order as bole > branch > twig > fruits > leaves > bark.

In all age groups, bole was recorded maximum biomass and barks the lowest as indicated in the tree level biomass. At age 5 years, the components showed an increasing order in biomass production as bole > branch > twig > fruits > leaves > bark, whereas at age 6 years, fruit biomass was more when compared to twigs and the increasing order as bole > branch > fruits > twig > leaves > bark.

Nutrient dynamics

Nutrient concentration in above ground biomass

The concentration of nutrients for a particular component between different sample trees at a particular age had no significant difference. However, significant

Table 2 : Above ground biomass and biomass components (kg tree^{-1}) of C. sappan at different ages.

Age (years)	Bole*	Barkns	Branch*	Twig**	Leavesns	Fruits**	Total agb*
5	8.55b	0.98a	5.10b	2.42b	2.05b	2.33b	21.43b
6	14.75ab	1.46a	9.16ab	3.05b	2.42ab	3.19b	34.02ab
7	16.24a	1.83a	8.89a	4.70a	3.57a	4.69a	39.92a
CD (0.05)	7.592	0.725	4.483	1.556	1.385	1.174	15.764

* Significant at 5% level, ** significant at 1% level, ns - non significant.
Values with same superscript do not differ significantly between themselves.

Table 3 : Nutrient concentration in biomass components of *C. sappan* at different ages.

Components	Nitrogen (%)			Phosphorus (%)			Potassium (%)		
	Age (Years)			Age (Years)			Age (Years)		
	5	6	7	5	6	7	5	6	7
Bole	0.37a	0.30b	0.25c	0.06a	0.05b	0.04b	0.32a	0.32a	0.21b
Bark	0.67a	0.56a	0.47a	0.11a	0.11a	0.10a	0.52a	0.46b	0.34c
Branch	0.45a	0.38b	0.34b	0.10a	0.10b	0.09b	0.47a	0.38b	0.30c
Twig	0.55a	0.49b	0.38c	0.16a	0.15b	0.14c	0.58a	0.47b	0.37c
Leaf	1.22a	1.16ab	1.04b	0.20a	0.19b	0.18b	0.90a	0.82b	0.70c
Fruit	0.63a	0.54b	0.44c	0.10a	0.09b	0.08b	0.67a	0.58b	0.48c

* Significant at 5% level, ** significant at 1% level, ns - non significant.
Values with same superscript do not differ significantly between themselves.

Table 4 : Nutrient accumulation of *C. sappan* at different ages (Kg ha^{-1}).

Components	Nitrogen			Phosphorus			Potassium		
	Age (Years)			Age (Years)			Age (Years)		
	5	6	7	5	6	7	5	6	7
Bole	35.05a	49.00a	48.80a	5.81a	7.48a	7.19a	31.24a	50.96a	44.07a
Bark	7.26a	8.72a	9.81a	1.18a	1.78a	2.14a	5.76a	7.14a	7.24a
Branch	26.19a	38.85a	35.31a	5.59a	9.61a	9.55a	28.88a	37.67a	31.57a
Twig	14.33a	15.95a	21.60a	4.35b	4.93ab	7.33a	14.63a	15.58a	20.81a
Leaf	28.10a	30.83a	42.67a	4.57a	5.09a	7.34a	20.74a	21.90a	28.44a
Fruit	15.92a	18.56a	24.04a	2.58b	3.00b	4.41a	17.77b	20.39ab	25.31a
Total agb	126.85a	161.91a	182.23a	24.08a	31.89a	37.96a	119.02a	153.64a	157.44a

* Significant at 5% level, ** significant at 1% level, ns - non significant.
Values with same superscript do not differ significantly between themselves.

variation in concentration was observed between ages. Concentration of nitrogen, phosphorus and potassium in various components at different ages are given in table 3. It is observed from the above table 3 that there was considerable variation in the concentration of various elements between different ages. Nitrogen concentration in bole, twig and fruit indicated significant difference between ages 5, 6 and 7 years. Concentration of nitrogen in branches was not significant between ages 6 and 7 years. Same is the case with leaf also. Concentration of nitrogen in bark between different ages did not show significant difference. Concentration of phosphorus in bole, branch, leaf and fruit did not show significant difference between ages 5 and 6 years but there was significant difference between ages 6 and 7 years. Phosphorus in bark did not show variation between all age groups studied, whereas a significant difference in twig concentration was noticed between ages 5, 6 and 7 years. Potassium concentration at different ages indicated significant variation between age groups studied. The K content in different components like bole, branch, twig and fruits showed more or less same value compared to N concentration at different ages. It may be due to the fact that more concentration of potassium is needed for the fruiting. The similar observation has been observed in *Bambusa bambos* (Kumar *et al.*, 2005). However, in bole, the difference was not conspicuous between ages 5 and 6 years, but in ages 5 and 6 years, significant difference with age at 7 years was noted. *Populus deltoides* was also recorded minimum nutrient concentration in bole (Mohsin *et al.*, 2005).

Among various components studied, leaf contributed maximum concentration of nitrogen followed by bark, fruit, twig, branch and bole. This was true to the ages 5, 6, and 7 years. The higher leaf nutrient concentration was also reported in 3 to 7 year old *Populus deltoids*. The higher nutrient concentration in leaves was also reported in many species (Veena *et al.*, 1981; Wang *et al.*, 1991 and Tandon, 1991). The highest concentration of the foliage is assumed to be good indicator for efficient nutrient return to the ecosystem. Foliar concentration is also form good indices of the nutritional status of the plant (Nowoboshi, 1985). Concentration of phosphorus was highest in leaf followed by twigs, bark, branch, fruit and bole. Similarly, leaf contributed maximum concentration of potassium followed by fruit, twig, bark, branch and bole. Among various elements studied, nitrogen contributed highest concentration followed by potassium and least by phosphorous in all the components at different ages (table 3). This trend is supported by Rawat and Singh (1988). Higher concentration of N was also reported in 5 year old *Acacia auriculiformis* N: (2.319) followed by K: (1.082) and P: (0.081) (George, 1993).

Nutrient accumulation

Accumulation of N, P and K in various components and above ground biomass at different ages has been given in table 4. Accumulation of nitrogen in various components at different ages did not show significant difference whereas accumulation of phosphorus in twig showed significant variation between ages 5, 6 and 7 years. In fruits, the difference was observed at age 7 years whereas, in other components did not show significant difference between age groups studied. Potassium accumulation in fruit observed considerable variation between ages 5 and 7 years. However, accumulation in other components did not show significant difference between age groups studied.

The accumulation of various nutrients showed an increasing trend with increasing age. The nitrogen in the total above ground biomass was recorded as 126.85 Kg ha^{-1} at age 5 years and increased to 161.91 Kg ha^{-1} at age 6 years. It is further increased to 182.23 Kg ha^{-1} at the age of 7 years. Potassium and phosphorus followed similar trend. Similarly, an increase of nutrient with age was evident in 3 to 7 year old *Populus deltoides* (Mohsin *et al.*, 2005). The accumulation of nutrient ranged N (300.67 to 621.77 kg ha^{-1}), P (29.73 to 60.69 kg ha^{-1}) K (139.79 to 199.52 kg ha^{-1}). In biomass components also showed the same trend except in bole and branches. It may be due to the low concentration of nutrient in the components like bole and branch. The increasing trend of nutrient accumulation in trees was observed in mature stands of Eucalyptus hybrid (Tandon *et al.*, 1996).

Among various components studied, bole accumulated maximum nutrients and minimum in bark except the phosphorus accumulation at age 6 and 7 years. Where in maximum was accumulated in branch. The maximum accumulation of N, P and K was found to be in the bole (N, 35.05 to 48.80 Kg ha!; P, 6.38 to 7.19 Kg ha^{-1}; K, 33.21 to 44.07 Kg ha^{-1}). It is also evident that the accumulation of the nutrients at 7 year old *Eucalyptus camaldulensis*, in which nutrients were accumulated as N, 63.1 kg ha^{-1} P, 9.92 kg ha^{-1} and K, 45.5 Kg ha^{-1} (Harmand *et al.*, 2004). Similar observation was found in the *Gmelina arborea* (Swamy and Puri, 2005). Nutrients accumulated in various components at different ages are varied. Nitrogen accumulation at ages 5 and 7 years was in the order: bole > leaves > branches > fruit > twig > bark, whereas at age 6 years, the sequence was bole > branches > leaves > fruit > twig > bark. The decreasing order of phosphorus accumulated in various components at age 5 years was bole > branch > leaves > twig >fruit > bark, whereas at age 6 and 7 years, the accumulation in branch become maximum and the decreasing order was, branch > bole > leaf > twig > fruit > bark. Potassium accumulation at different components was showed same sequence in all ages, the decreasing order was bole > branch > leaves > fruit > twig > bark. This downward trend was also reported in *Eucalyptus globulus* and *Eucalyptus tereticornis* (Singh, 1984). The decreasing trend from ages 6 to 7 years is due to the lower biomass production in bole and branches at age 7 years.

Among various elements, nitrogen contributed maximum accumulation in biomass followed by potassium and least by phosphorus except in fruits. Similar observation was reported in the *Acacia mearnsii* (Caldeira *et al.*, 2002). But in the components, it was true for nitrogen and potassium. The components like branch and twig in the initial years and fruit in all ages, K accumulated more, it may be due to the fact that higher K accumulation required for the fruiting. The similar observation has been noticed in *Tectona grandis* and *Melia azadirach* (Adu-Anning, 1995).

The nutrient accumulation in g tree^{-1} also showed the same sequence as noticed in the kg ha^{-1} basis. In both cases after six years, there was no considerable increase in nutrient accumulation. As noticed in biomass, nutrients also exhibited a levelling off in the accumulation of nutrients at age 6 years.

Nutrient use efficiency

Nutrient use efficiency is expressed as a quotient of standing biomass divided by above ground nutrient pool. It is the total biomass synthesised per unit of nutrients utilised. The study of such nutrients for each component at different ages showed an increasing trend with increasing ages (fig. 1). The quotient for nitrogen ranged as 190.41 at 5 year to 243.43 at 7 year; Phosphorus was 995.13 to 1168.60 at ages 5-7 years; Potassium ranged 202.74 to 281.76 at ages 5-7 years. Among the biomass components, nutrient use efficiency was maximum recorded in bole and least by leaf.

Among the nutrients, phosphorous constituted maximum nutrient efficiency followed by potassium and least by nitrogen except in bole at age 6 years, branch and twig at age 5 years and fruit in all age groups, where in nitrogen showed maximum nutrient use efficiency when compared to potassium (fig. 1).

Nutrient use efficiency of total above ground biomass and biomass component increased in all nutrients with increasing ages. An increasing trend of nutrient use efficiency with increasing ages was reported by Bargeli (1995) in *Eucalyptus*. Nutrient use efficiency of *C. sappan* showed a decreasing order in bole between ages 5 and 6 years, agb and branch between 6 and 7 years (fig. 1). Similar trend in efficiency of P noticed from 4 to 8 year old *Leucaena leucocephala* (1359 to 1027) plantations (Singh and Toky, 1993).

References

Adu-anning, Anglaaere and Nwoboshi (1995). Growth, Energy Yield and Nutrient Uptake of some fuel wood Species in the Sudan Savanna of Ghana. *J.Tree Sci.*, **14(1)** : 23-31.

Bargali, S. S. (1995). Efficiency of nutrient utilization in an age series of Eucalyptus tereticornis plantations in the Tarai belt of Central Himalaya. *J.Trop.Forest Sci.*, **7(3)**: 383-390.

Booth, T. H. and R. E. Mac Mutrie (1988). Climatic Change and Pinus radiata plantations in Australia. Green House Planning for Climate Change (G.IPearman. ed.). *E. J. Brill Leidep.*, 534-545 pp.

Caldeira, M. V. W., M. V. Schumacher and P. Spathelf (2002). Quantification of nutrient content in above-ground biomass of young *Acacia mearnsii* De Wild. provenance Bodalla. *Peter Spathelf.*, **48** : 141-145.

Charansingh, Dhyani, S .K., N. Kumar and R. C. Dhiman (1998). Establishment and evaluationof *Paulownia fortunei* for biomass production on degraded bouldery riverbed lands in Doon valley, India. *Indian Forester,* **124(5)** : 578-589.

George, S. J. (1993). Biomass production and resource partitioning in silvi-pastoral systems. *M.Sc.Thesis*, Kerala Agricultural University, Vellanikkara, Kerala. 139 p.

Gurumuthi, K. and P. S. Rawat (1989). Time trend studies on biomass production in high density plantation of Casuarina equisetifolia. Proceedings of national seminar on Casuarina, Neyveli. Pp. 35-44.

Harmand, J. M., C. F. Njiti, R. F. Bernhard and H. Puig (2004). Aboveground and belowground biomass, productivity and nutrient accumulation in tree improved fallows in the dry tropics of Cameroon. *For. Ecol. Manage.*, **188** : 249-265.

Jackson, M. L. (1958). Soil chemical analysis. Asia Publishing House, New Delhi. pp.489.

Kadeba, O. (1991). Above ground production and nutrient accumulation in an age sequences of Pinus caribaea stands. *Forest Ecol. Manage.*, **41** : 237-248.

Khanna, P. K. and B. Ulrich (1991). Ecochemistry of temperate deciduous forests. In: Rohrig, E and Ulrich, B. (Eds.). Ecochemistry of the world 7. *Temperate Deciduous Forests*. pp. 29-31.

Kumar, B. M., G. Rajesh and K. G. Sudheesh (2005). Aboveground biomass production and nutrient uptake of thorny bamboo (*Bambusa bambos* (L) Voss) in the home gardens of Thrissur, Kerala. *J. Trop. Agric.*, **43(1-2)** : 51-56.

Landsberg, J. J., S. Linder and R. E. Mcmurtrie (1995). Effects of global change on managed forests. A strategic plan for research on managed forest ecosystems in a globally changing environment. Global Change and Terrestrial Ecosystems. *Core Project of the IGBP*, Canberra, pp.1-17.

Madgwick, H. A. I. (1971). The accuracy and precision of estimates of the dry matter in stems, branchs and foliage in an old field Pinus virginiana stand. In: Young, H.E. (Ed.). Forest Biomass studies. Life sciences and Agricultural Exp. Station, Univ. of Maine, Orono, U.S.A. pp105-109.

Mohsin, F., R. P. Singh and K. Singh (2005). Nutrient Uptake of Poplar plantation at various ages of growth in isolated and intercropped stands under Agroforestry system. *Indian Forester*, **131**: 681-693.

Negi, M. S. and V. N. Tandon (1997). Biomass and nutrient distribution in an age sequence of Populus deltoides ecosystems in Haryana. *Indian Forester*, **123 (2)** : 111-117.

Nwoboshi, L. C. (1985). Biomass and nutrient uptake and distribution in a *Gmelina arborea* pulpwood plantation age series in Nigeria. *J. Trop. For. Resources*, **1(1)**: 53-62.

Pathak, P. S. and S. K. Gupta (1987). Productivity of *Leucaena leucocephata* (Lam.) De Wit. on moist was Leland. *J. Tree*

Sci., 6(2) : 50-55.

Rawat, Y. and J. S. Singh (1988). Structure and function of oak forests in Central Himalaya. I Dry matter dynamics. *Ann. Bot.*, **62** : 397-411.

Singh, R. R (1984). Nutrient cycle in *Eucalyptus tereticornis* Smith. Plantations. *Indian Forester*, **1** : 76-85.

Singh, V. and O. P. Toky (1993). Photosysnthetic and nutrient use efficiencies in energy plantations in arid region of North-Western India. *J. Tree Sci.*, **12(1)**: 7-12.

Swamy, S. L. and S. Puri (2005). Biomass production and C-Sequestration of *Gmelina arborea* in plantation and agroforestry system in India. *Agrofor. sys.*, **64**: 181-195.

Tandon, V. N., M. C. Pande, H. S. Rawat and D. C. Sharma (1991). Organic productivity and mineral cycling in plantations of *Populus deltoides* in Tarai region of U.P. *Indian Forester*, **119(8)** : 596-607.

Tandon, V. N., M. S. Negi, D. C. Sharma and H. S. Rawat (1996). Biomass production mineral cycling in plantation ecosystems of Eucalyptus hybrid in Harayana. distribution and cycling of nutrients. *Indian Forester*, **124(1)** : 30-38.

Veena, J. A., V. H. Vanbretler, J. J. Olie and M. H. Friss (1981). Nitrogen and energy balance of a short rotation poplar forest system. *Neth. J. Agric. Sci.*, **29(2)** : 163-172.

Vidyasagaran, K. (2003). Biomass production and nutrient cycling in *Casurina equesitifolia* plantation in the coastal plains of Kerala. *PhD Thesis*. ICFRE. 213p.

Wang, D. F., H. Bermann, E. Asiel, Lugo and D. B. Richard (1991). Comparison of nutrient use efficiency and biomass production in five tropical tree taxa. *Forest. Ecol. Mgmt.*, **46** : 1-21.