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Bioproductivity and nutrient cycling in bamboo and acacia plantation forests

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Abstract

This study mainly aimed to investigate the bioproductivity and nutrient cycling processes in plantation forests of bamboo and acacia. In India, multipurpose tree (MPT) species are extensively planted to meet the increasing demand for fuel and industrial wood. The bioproductivity studies of bamboo showed that the total biomass increased with age (2.2 t/ha/year 1) up to six years (297.8 t/ha/year 6) and then decreased (15.6 t/ha/year 10). With acacia, the total biomass increased from 1.8 t/ha/(year 1) to 5.0 t/ha/(year 3) and 10.9 t/ha/(year 5). In general the biomass increased with increase of diameter and height. Nutrient cycling in the plantation on an annual basis was worked out. A complete harvest of bamboo in 6 years removes 2341 kg/ha of nitrogen, 22 kg/ha of phosphorus, 2653 kg/ha, of potassium, 1211 kg/ha of calcium and 1356 kg/ha of magnesium. A total harvest of above ground biomass of acacia in 3 years removes (kg/ha) 91.74 N, 2.53 P, 73.41 K, 110.45 Ca, 14.06 Mg, and in 4 years removes (kg/ha) 227.47 N, 7.34 P, 181.04 K, 284.15 Ca, and 38.89 Mg.

Keywords: Bioproductivity; Nutrient cycling; Bamboo; Acacia; Plantations

1. Introduction

Multipurpose tree species are extensively raised to meet the increasing demands for fuel and industrial wood and have assumed much importance due to successful afforestation of the barren areas in the country. To assess the growth performances of a species, it is important to study the productivity and nutrient dynamics, (George, 1977). Biomass studies are important to judge the performances of the species in terms of total biological production and to assess the nutrient drain during harvest (Negi, 1984). Many studies have reported the biomass and nutrient dynamics in several forest species (George, 1977; Shanmughavel, 1995; Anbazhagan, 1998). This study was mainly aimed to study the bioproductivity and nutrient cycling of planted bamboo and acacia.

2. Methods

2.1. Bamboo plantations

2.1.1. Study area

The study site of plantation of *Bambusa bambos* was located at Kallipatty between 11°8′ and 12° of latitude and 76°59′ and 77°47′ longitude, 540 m above m.s.l. The soil was an alfisol and had a pH between 7.4 and 7.8. The concentrations of nitrogen, phosphorous, potassium, calcium and magnesium were 3800, 360, 3600, 1600 and 1800 kg/ha, respectively. The mean temperature was 31°C and annual rainfall was about 600 mm.

2.1.2. Preparation of nursery and planting

A nursery bed of 10 m × 5 m was prepared and filled with a mixture of soil and sand (3:1). Seedlings, raised by tissue culture techniques, were procured from Chithode, Erode and Tamil Nadu. When they were about 7 cm in height, seedlings were removed from their polythene bags, and about 25–30 seedlings were transplanted in the nursery bed. The seedlings were irrigated 2–3 times a day. Care was taken to avoid excess saturation. Nursery beds were provided with a coconut thatch to protect the seedlings from direct sunlight.

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2.1.3. Transplantation

The seedlings in the nurseries were carefully uprooted and transplanted on to the field during August (after about 9 months). The seedlings were planted at 6 m × 6 m spacing in a 3 ha area with a total of 277 seedlings/ha. The transplanted seedlings were irrigated 2 h regularly twice a day. Weeding was done as and when required. After one year, the irrigation was restricted to 15 days interval. Care was taken to avoid water logging and the area was protected against rodents and grazing and browsing animals.

2.1.4. Production of culms

All transplanted seedlings produced rhizomes, from which lateral culms emerged which are the chief components of the total biomass yield. The total number of culms developed from the rhizomes constituted a clump. The productivity of bamboo was assessed by the number of culms produced per annum. At a given site production of new culms depended on the culms of the previous year, the degree of congestion and the clump age.

2.2. Acacia plantations

2.2.1. Study site

The study area (1 ha) of *Acacia holsericea* plantation is located in the foot hills of Maruthamali (11°1′N latitude and 76°93′E longitude) near Bharathiar University, Coimbatore, at an altitude of 410 m above m.s.l. This area has red soils with pH between 7 and 7.6 and electrical conductivity 0.2 mho. The environmental temperature ranged from 27.9°C to 35.7°C with an annual rainfall of 55–650 mm. The soil nitrogen, phosphorus, potassium and magnesium, were 98, 7.6, 175, 70 and 77 kg/ha, respectively.

2.2.2. Plantation details

Seedlings obtained from the Institute of Forest Genetics and Tree Breeding (IFGTB), Coimbatore were used for this study. Seedlings were planted at a spacement of 2 m × 2 m with a total of 2500 seedlings/ha. The transplanted seedlings were adequately irrigated for a month, after which irrigation was stopped and watering left to the monsoon. Nearly 80% of the seedlings survived and grew well.

2.3. Biomass studies

2.3.1. Bamboo

To estimate the total biomass, 15 culms were randomly selected from each age group of plantations. For economy reasons, rhizomes were excavated only from three samples of each age to a total of 18. After felling, the total height of each culm, diameter at breast height (DBH), basal diameter, the number of nodes, were measured and the plants sub-divided into four main components leaves, branches, culm and rhizome. For determination of underground biomass rhizomes were excavated by making a trench around the culm. Fresh weight of the culms and rhizomes were determined in the field and sub-samples were then oven dried (103 ± 2°C) to a constant weight. From the oven dry weight of the samples, the total standing biomass (t/ha) of each age group was calculated. The annual biomass production (total biomass divided by age) and mean periodic production (the difference between biomass measurement of two stands in sequence divided by the age interval) and net primary productivity were estimated (Kadeba, 1991).

2.3.2. Acacia

Field studies were conducted using the stratified tree harvesting method (Art and Marks, 1971). The total number of trees present in the entire study area was counted. The basal diameter, DBH and height of all standing trees within the entire plot (1 ha) were recorded. The entire diameter range in each plantation was divided into three diameter classes designated as A, B and C. The sample trees were selected as being nearest to the average of each class (Ovington et al., 1967).

In each plantation 18 sample trees (6 from diameter class) were felled. Immediately after felling the tree height was recorded and sub-divided into phyllodes, twigs, branches and main bole. For estimating root biomass, a pit was dug out around the tree and care was taken to excavate the entire root of each sample tree. The fresh weight of the components was estimated in the field and representative samples of phyllodes, twigs, branches, main bole and root samples were collected and brought to the laboratory. They were oven dried at 80°C for 48 h, for estimating the dry weight. From the oven dry weight of the samples, the total standing biomass (t/ha) of each age group was calculated.

2.3.3. Nutrient analysis

Nitrogen and phosphorus were estimated (Armstrong et al., 1967) using a Technician Auto analyzer – II (Gedko international, UK), in a kjeldlatherm digestion system KT 408 (Bonn) at 400°C for 3 h. One gram sample was digested with 2.5 g potassium sulphate and 5 ml conc. H_2SO_4. After digestion and cooling, the sample was diluted and used for the analysis of nitrogen and phosphorus. K, Ca, Mg were determined using an atomic absorption spectrophotometer (Perkin Elmer 5000 USA) after wet digestion of a 1 g sample with triple acid mixture (10 ml of conc. HNO_3, 4 ml of $HClO_4$ and 1 ml of conc. HCl). The digested samples were filtered through Whateman No. 42 filter paper and made up to 100 ml with distilled water and this solution was stored and used for analysis (Issac and Johnson, 1975).

3. Results and discussion

3.1. Biomass studies

3.1.1. Bamboo

3.1.1.1. Organic matter in sample culms. In plantation bamboo, above ground biomass increased concomitant with DBH and height. In natural forests the culm biomass of *Phyllostachys edulis*, *Phyllostachys reticulata*, was found to be less than their counterparts of plantation stands. The culm biomass of *Dendrocalamus strictus*, *Bambusa arundinaceae*, and *Melocanna baccifera* was higher than *Phyllostachys* species (Ueda, 1960). In comparison with natural forest, plantation bamboo showed 19–85% more culm biomass.

With regard to the percentage contribution of leaves, branches and culms components to the above ground biomass, the plantation age was an important factor. The percentage contribution of leaf (7–1%) decreased with increasing age. No definite trend existed for branch. The percentage contribution of rhizome to grand total biomass correlates with leaf (Othman, 1993).

3.1.1.2. Total biomass. Annual biomass yield of 3–4 year old, air-dry plantation bamboo/ha was 6–7 t/ha for *Bambusa vulgaris* and 1.0 t for *Gigantochloa aspera* (Chinte, 1965). The above ground biomass of *Gigantochloa scortechnii* from Malaysia was 36.36 t/ha in a 3-year old plantation (Othman, 1993). This is lower than 3-year old plantation stand (47.48 t/ha) of this study at Kallipatty.

3.1.1.3. Below ground and above ground biomass ratio. The below- and above-ground biomass ratio between 1 and 6 years of plantation bamboo varied from 0.69 to 0.04. This ratio varies with plant species and age (Kaul et al., 1983).

3.1.1.4. Net primary production. The net primary production and mean annual biomass accumulation depended on stand age. In 5-year plantation bamboo 124.08 t/ha/yr was attained.

3.1.1.5. Dry-organic matter density. The dry-organic matter density approximately ranged between 1 and 10 kg/m^3 i.e., higher than in other bamboo species (0.52–0.88 kg/m^3) including *Gigantochloa scortechnii* (0.54–0.55 kg/m^3) (Othman, 1993).

3.1.2. Acacia

3.1.2.1. Dry matter production of sample tree. The proportion of the biomass of main bole, branch, twig, phyllode and root changed with tree size and stand age. As the stand age increased, the main bole weight constituted an increasing proportion of the total biomass, varying from about 40% (year 1)–59% (year 5) (DBH class C). In contrast, the proportion of total biomass channeled to branches, twig and phyllodes decreased with stand age, which corroborates the results of other studies (Bradstock, 1981; Jokela et al., 1981; Pinyopusarerk, 1989; Kadeba, 1991).

3.1.2.2. Total biomass. The total above ground standing biomass in *Acacia holosericea* plantations was in the order of 1.5, 10.3 and 24.1 t/ha at the year 1, 3 and 5, respectively, which indicated a proportional increase of biomass with age. Compared to *Acacia* species, *A. auriculiformis*, *Acacia Senegal*; *A. auriculiformis*, *A. julifera*, *A. shirlefera*, *A. shirleji*, and *A. ampliceps* (Sahoo et al., 1991; Osman et al., 1992) the present estimates were 1.5–3.5 folds lower. This perhaps may be due to low rainfall in the study area. So it may be inferred that the biomass accumulation of acacia species ultimately depends on the rainfall. Compared with other tree species 16.3 t/ha in *Leucaena leucocephala* in the year 5 (Pandey et al., 1989); 18.11 and 21.9 t/ha *E. citridora* in the year 7 (Hossian et al., 1997); 22.5 t/ha in the year 5 *Populus deltoids* (Negi, 1984), the estimated biomass was 1.5 times higher. The below- and above-ground biomass ratio between year 1 and 5 plantations varied from 5.3 to 5.5. The young plant (year 1) developed vast lateral roots from their below ground parts and provided the much needed water and nutrient requirements to the plant. In older plants (year 5) the aerial parts were more developed than under ground parts (Kushalapa, 1984).

3.2. Nutrient cycling

3.2.1. Bamboo

Nutrient cycling in the plantations on an annual basis was worked out. Of the total uptake 94% N, P, Ca and Mg was retained in the non-photosynthetic biomass and 6% returned. A complete harvest (above ground biomass) of *B. bambos* at the age of 6 years removed 2431 kg/ha, of N, 222 kg/ha of P, 2653 kg/ha of K, 1211 kg/ha of Ca and 1356 kg/ha Mg from the site. Studies on the nutrients uptake and their accumulation revealed that essential nutrients were removed from the soil at the rate of 62–74%. Thus the present study stresses the importance of the application of the external fertilizers after the harvest of the biomass components.

3.2.2. Acacia

The estimated gross annual accumulation of nutrients of the *A. holosericea* stand was found in decreasing order of Ca (284.15 kg/ha), N (222.47 kg/ha), K (181.04 kg/ha), Mg (38.89kg/ha) and P (7.34kg/ha). The transfer of nutrients in the litter was in order of N (12%), Mg (10.2%), P (8.5%), Ca (6.5%) and K (6.2%). Similar nutrient cycling had been observed in *A. nilotica*, *A. auriculiformis* (Chaturvedi and Behal, 1996), *A. catechu* (Singh and Singh, 1993), *A. saligna* and *A. cyclops*

(Stock et al., 1995) and *A. magnium* (Xu et al., 1994). The cycling of nutrients is an annual process controlled by litter fall. Unlike *E. globules*, *E. grandis*, *D. sisso*, *P. patula* (Madgwick et al., 1977; Turner and Lambert, 1983) nutrients in *A. holoseicea* are utilized more than returned.

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References

Armstrong, E.Au, Sterns, C.R., Strickland, J.D.H., 1967. Mineral component analysis. Deep Resi., 381–389.

Art, H.W., Marks, P.C., 1971. A summary table of biomass and net annual primary production in forest ecosystems of the World. in: Young, H.E. (Ed.), Forest Biomass studies, Life Sciences and Agricultural Experiment Station, University of Maine, Orono, Maine, US.

Anbazhagan. M., 1998. Bioproducivity and nutrient cycling in *Acacia holosericea*. Ph.D. Thesis, Bharathiar University, Coimbatore, India.

Bradstock, R., 1981. Biomass in age series of *Eucalyptus grandis* plantations. Aust. For. Res. 11, 111–127.

Chaturvedi, A.N., Behal, A.M., 1996. Biomass production trials on a sodiac site. Ind. For. 112, 439–455.

Chinte, F.O., 1965. Bamboos in plantation. For. News 16, 33–39.

George, M., 1977. Organic productivity and nutrient cycling in *Eucalyptus hyprid* plantations. Ph.D. Thesis, Meerut University, Meerut.

Hossian, M.K., Islam, S.A., Zashimuddin, M., Tarafdar, M.A., Islam, Q.N., 1997. Growth and biomass production of some *Acacia* and *Eucalyptus* species in degenerated sal forest areas Bangladesh. Ind. For. 123, 211–217.

Issac, R.A., Johnson, W.C., 1975. Colloborative study of wet and drytechniques for the elemental analysis of plant tissue by atomic absorption spectrometer. J. Assoc. Agri. Chem., 58–436.

Jokela, E.J., Shanon, C.A., White, E.H., 1981. Biomas and nutrient equations mature *Betula papyrifera* Marsh. Can. J. For. Res. 11, 298–304.

Kadeba, O., 1991. Above ground biomass production and nutrient accumulation in an age sequence of *Pinus caribea* stands. For. Ecol. Manage. 41, 237–248.

Kaul, O.N., Sharma, D.C., Tandon, V.N., 1983. Biomass distribution and productivity in popular. Ind. For. 109 (1), 822–828.

Kushalapa, K.A., 1984. Biomass of Mysore gum trees in Jedigenahally, Karanataka. Ind. For. 110, 854–860.

Madgwick, H.A.L., Jackson, D.S., Knight, P.J., 1977. Above ground dry matter, energy and nutrient contents of trees in an age series of *Pinus radiata* plantations. N. Z. J. For. Sci. 7, 445–468.

Negi, J.D.S., 1984. Biological productivity and cycling of nutrient in managed and managed ecosystems. Ph.D. Thesis, Garward Univ., Srinagar.

Othman, A.R., 1993. Culm composition and above ground biomass of *Gigantochloa scortechnii* stands. Paper presented to the International Symposium on Industrial use of Bambos Beijing, China.

Osman, K.T., Hauge, S.M.S., Forkan, M., Mai, F., 1992. Above ground biomass and nutrient distribution in *Acacia auriculiformis*, Diphero carputs turbinatus and *Pinus caribea* plantations at Chittagong University Hills. Ind. For., 193–197.

Ovington, J.D., Forest, W.G., Armstrong, J.S., 1967. Tree biomass estimation. in: Symposium in Primary Productivity and Mineral Cycling in Natural Eco-systems. ASSO. Ecol. Soc., America, pp. 4–31.

Pandey, M.C., Tanden, V.N.T., Rawat, H.S., 1989. Biomass production and nutrient distribution in five year old plantation ecosystem of fodder species in Rajasthan. Ind. For. 115, 793–801.

Pinyopusarerk, K., 1989. Growth and survival of Australian tree species of field traisl on Thailand. In trees for the tropics. D.J. Boland 109-127. ACIAR Monograph no. 10. Canberra, Australia:ACIAR.

Sahoo, A.K., Mohanty, P.K., Das, P., 1991. Role of plant population on growth, dry matter production and energy accumulation pattern of *Acacia auriculiformis*, Orissa. J. Agri. Res. 4, 3–4.

Shanmughavel, P., 1995. Studies on organic productivity nutrient distribution, nutrient cycling, pulp and paper characteristics of plantation Bamboo (*Bambusa bambos* (L) Voss). Ph.D. Thesis, Bharathiar University, Coimbatore, India.

Singh, L., Singh, J.S., 1993. Improtance of short-lived components of dry tropical forest for biomass production and nutrient cycling. Veg. Sci. 4 (5), 681–686.

Stock, W.D., Wienand, K.T., Baker, A.C., 1995. Impacts of invading N_2 fixing *Acacia* species an patterns of nutrient cycling in two cape ecosystems: evidence from soil incubation studies and natural abundance values. Oecologia 101 (3), 375–382.

Turner, J., Lambert, 1983. Nutrient cycling in a 27 years old *Eucalyptus grandis* plantation in New South Wales. For. Ecol. manage. 6, 155–168.

Ueda, K., 1960 . Studies on the Physiology of bamboo with reference to practical application. Tokyo Resource Bureau. Sci. Techniques Agency, Prime Ministers Office. No. 34.

Xu, D.P., Yang. M.Q., Zeng, Y.T., Li, W.X., Brown, A.G., 1994. Above ground net primary production and nutrient cycling of a young plantation of *Acacia mangium*(in Guangdong). Australian tree species research in China. in: Proceedings of an International Workshop held at Zhanghov Fujian Province, PRC, pp. 185–190.