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Biomass and Net Primary Productivity in Three Different Aged Butea Forest Ecosystems in Western India, Rajasthan

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Abstract: The study was conducted to estimate the biomass and net primary productivity of different age grouped (5, 10 and 15-year-old) *Butea monosperma* forest ecosystems in western India, Rajasthan (located between 23°49' to 25°28' N latitudes and 73°0' to 75°49' E longitudes) from June 2007 to May 2008. The vegetation biomass, forest floor biomass, tree litter fall and net primary productivity (NPP) of trees and shrubs were estimated and it is found that the tree biomass and net primary productivity increased with increasing age of the forest stand, whereas the herb biomass and net primary productivity decreased significantly ($P < 0.01$) with increase in the forest age. The biomass of trees increased with age from 183.7 ± 3.21 to 298.3 ± 3.57 t ha^{-1} while shrub biomass ranged from 4.9 ± 1.61 to 6.3 ± 1.38 t ha^{-1} and the herb biomass fluctuated from 1.7 ± 1.64 to 2.1 ± 1.81. The tree layer NPP varied from 17.2 to 29.3 t ha^{-1} year^{-1} where the NPP of the shrub layer was 0.88 to 1.6 t ha^{-1} year^{-1}. The productivity of the herb layer was fluctuating from 2.3 to 3.1 t ha^{-1} year^{-1}. The all values of biomass and NPP of trees, shrubs and herbs were low in 5-year-old, moderate in 10-year-old and high in 15-year-old forest stands. The total forest biomass increased from 190.7 t ha^{-1} in the 5-year-old to 306.3 t ha^{-1} 15-year-old forest and net primary productivity from 21.1 t ha^{-1} year^{-1} in the 5-year-old to 33.2 t ha^{-1} year^{-1} in the 15-year-old forest.

Key words: *Butea monosperma* Lam • Biomass • Forest floor biomass • Litter fall • Net primary productivity

INTRODUCTION

Butea monosperma Lam. is a small to medium- sized, tropical and sub tropical tree, 5 to 15 (max.20) m tall, up to 45 cm dbh. *B. monosperma* is amongst the principal economic tree species commonly recommended for plantation programmes in dry tropical regions for soil and water conservation as well as for fuel wood and fodder production. Estimation of biomass and productivity are essential for determining the status and flux of biological materials in an ecosystem and for understanding the dynamics of the ecosystem [1]. However, the biomass and productivity of tree species varies from place to place due to variation in climate, soil, temperature and rainfall. Teller [2] pointed out that forest floor biomass plays a significant role in the structure and functioning of forest ecosystems by acting as a nutrient reservoir and improves the infiltration rate and water holding capacity of soils. The quantity of tree biomass per unit area of land constitutes the primary data needed to understand the flow of materials and water thorough forest ecosystem [3]. Lieth and Whittaker [4] pointed out that if forest biomass is to be measured and analysed in its proper way as a part of production, this gives an overall picture of ecosystem functioning. According to Lodhiyal and Lodhiyal [5], the rising demand of energy from renewable sources has generated new ideas and turn attention to woody biomass production system.

The increasing trends of plantations of an indigenous tree species are widely gaining popularity due to their higher biomass accumulation per unit area, better nutrient conservation efficiency and suitability in nutrient poor

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sites. Nirmal Kumar *et al.* [6, 7] have been already carried out quantification and decomposition studies in dry tropical teak forests of Rajasthan. Some studies have been made over a long time regarding the biomass production of leguminous indigenous forest in India [8]. But no such studies have been carried out in Butea plantations. Therefore, in the present study an attempt has been made to find out the biomass content and net primary productivity in three different aged Butea forest ecosystems Western India, Rajasthan. Moreover, various works have been carried out by Nirmal Kumar *et al.* [9-12] in field of fuel wood properties, seasonal changes of bio elements and assessment of carbon stock in the Teak and Butea forest ecosystem, Western India, Rajasthan.

Study Area: The study was conducted in Butea plantation forest areas (23° 03" N latitude, 69° 30" E, longitude; altitude 579.4 m above the mean sea level) from June 2007 to May 2008 at the Udaipur district in the state of Rajasthan which is 85 km away from the Udaipur city. The climate of the study area is semi-arid. There are three distinct seasons per year; winter (November to February), summer (April to mid June) and rainy season (mid-June to mid September). The climate is tropical with maximum of 45.3°C and minimum of 28.8°C during summers. Winters are little cold with the maximum temperature rising to 26.8°C and the minimum dropping to 2.5°C. Annual rainfall during the study period was 300 mm and the relative humidity ranged between 21% and 73%. The soil is alluvial, reddish brown, to deep medium black and loamy with rocky beds. The plantation system, where the sampling done, was composed of 5 to 15 years old *Butea monosperma* forest stands with a few species of *Bambusa arundinacea, Lannea coromandelica, Wrightia tinctoria and Annona squamosa.* The trees followed by shrubs like *Jatropha curcas, Lantana camara* and associated herbaceous vegetation mostly dominated by *Cassia tora* are also found in the study area. Grazing land under Butea forest was dominated by *Cassia tora*, followed by *Achyranthes aspera*, *Blepharis maderaspatensis*, *Boerhavia diffusa* and *Cassia occidentalis*. Butea forest was protected from grazing during the study period from June 2007 to May 2008.

MATERIALS AND METHODS

Estimation of Biomass: The total area planted with *B. monosperma* trees was 63 ha. Of this area, 5, 10 and 15- year old stand occupied 26, 17 and 20 ha respectively. The tree density in each Butea forest was 400 trees ha^{-1}, respectively in 5-, 10- and 15 years old forest because of similar spacing (with plant to plant and row to row distances of 5 m× 5 m in each way). A one hectare plot was sampled in each forest, which includes four replicate sub-plots of 50 m× 50 m (0.25 h). To find out the accurate results, 100 trees in each sub-plot (400 trees in each forest) were measured. The height and diameter (dbh, 1.37 m) of trees were measured by Ravi's multimeter and Tree calipers, respectively, in each forest.

For estimating density, the shrub and herb individuals were sampled in 50 quadrats of 2 m× 2 m and 1 m× 1 m, respectively. To estimate the biomass of Butea forest, the selective harvest technique was adopted [5, 13]. Two trees (*B. monosperma*) and two shrubs (*J. curcas* L.) of average dbh in each forest stand were harvested and separated into bole wood, bole bark, branches, twigs, leaves and reproductive parts, stump root, lateral roots and fine roots. The fresh weight of all components was determined in the field using a heavy weight spring balance or pan balance. Samples of approx. 500 g (fresh weight) of each tree component from each forest stand were taken separately to the laboratory and oven-dried at 60°C to constant weight. Using the fresh/dry weight factor, the dry weight was estimated. Regression equations were developed for each tree components. The data were subjected to the regression in the form $Y = a + bX$, Where, Y is the biomass of the component (kg), X is the dbh. The mean diameter in each forest stand was used in the regression equation of the different components to obtain an estimate of mean biomass.

This value was then multiplied by tree density in each forest stand to obtain the total tree biomass. Like trees, regression equations were developed for finding the shrub biomass.

For herbaceous biomass, herbs were harvested at their peak season (rainy, September, 2009) from 10, 50 m× 50 m, quadrats. The harvested material was divided into aboveground and belowground components fresh weight and dry weight was determined for each herb component. The total vegetation biomass was obtained by summing biomass values of trees, shrubs and herbs for each forest stand.

Calculation of NPP: After the selecting a permanent sample plot (area: 1 ha) in each forest stand, 50 trees and shrubs in each sub-plot were marked with white paint at breast height in June 2007 to assess diameter increments at annual intervals. The diameters of marked trees and shrubs were measured again in May 2008. The mean diameter increments for each diameter class were then calculated. The net primary productivity of the different tree components [bole wood, bole bark, branches, twigs, leaves and reproductive parts stump root, lateral roots and fine roots], shrubs [roots, stem and leaves] and herbs was calculated for each forest stand following [5, 14]. The sum of net production values of tree, shrub and herb layers yielded the total net primary production of the plantation site.

Data for forest floor litter were collected from ten, 50 × 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 litter on the forest floor was then collected carefully, avoiding contamination with soil as much as possible and categorized into: (a) fresh leaf litter; (b) partly decomposed litter; (c) wood litter; and (d) miscellaneous litter (consisting of material other than the above). The collections were brought to the laboratory separately by category and oven- dried 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 × 50 cm with 15 cm high wooden sides and fitted with a nylon net bottom. The litter was collected at monthly intervals during the study period, separated into leaf, wood, bark and reproductive parts. The samples were weighed after oven drying at 60°C to constant weight.

The biomass (above- and below-ground) and herbs on all sites was determined during their peak growth in September 2007. This value was assumed equal to net herb production. The sum of net production values of tree, shrub and herb layers yielded the total net primary production of the plantation site.

RESULTS AND DISCUSSION

Biomass: The regression coefficients for all the above ground and belowground components of trees is given in Table 1. The selection of independent variable, dbh, was occasioned by the ease and accuracy in these measurements. It is evident from r^2- values, the relations of biomass with the dbh were found to be quite satisfactory. The calculation of biomass through X^2h method (h being height) has not been used because the r^2 values from such equations did not indicate much improvement over those obtained with dbh (X). Therefore the regression model $Y=a+b$X was used for forest biomass computations. The biomass of each component and of the total tree was significantly related to the dbh.

Table 1: Relationship between the biomass of tree components (Y, kg per tree) and diameter at breast height (X, cm) for Butea forests

Components		Age of Butea forest stands (years)		
		5	10	15
Bole wood	*a*	-0.0563	-0.2284	-3.2148
	b	0.9354	1.5442	2.3544
	r^2	0.9940	0.9830	0.9850
Bole bark	*a*	-3.2456	-4.2542	-5.2141
	b	0.2432	0.4127	0.6314
	r^2	0.9950	0.9940	0.9760
Branch†	*a*	-1.5733	-1.8955	-2.4985
	b	0.4605	0.5983	0.7256
	r^2	0.9930	0.9860	0.9890
Twig‡	*a*	-2.0961	-4.5143	-5.3565
	b	0.1069	0.2347	0.3754
	r^2	0.9950	0.9950	0.9790
Leaf	*a*	-2.1761	-2.8647	-3.2548
	b	0.3133	0.3984	0.3766
	r^2	0.9950	0.9940	0.9680
Reproductive parts§	*a*	-0.1258	-1.6472	-2.6542
	b	0.0562	0.0697	0.1842
	r^2	0.9940	0.9950	0.9850
Stump root¶	*a*	-0.2543	-1.6214	-1.0355
	b	0.5354	0.7354	0.9875
	r^2	0.9950	0.9960	0.9860
Lateral roots‖	*a*	-0.2291	- 2.3561	-2.0457
	b	0.1684	0.3197	0.4021
	r^2	0.9940	0.9940	0.9440
Fine roots**	*a*	-2.5487	-2.9854	-4.2549
	b	0.0681	0.1436	0.1649
	r^2	0.9940	0.9940	0.9470

All equations were significant at $P< 0.01$

† Shoots of larger dimension without leaves

‡ Current shoots bearing leaves

§ Includes flowers and fruits

¶ Main root bearing 30 cm above- ground stem part

‖ Lateral branches of stump root (Main root) with a diameter > 5mm

** Roots originate from lateral roots with a diameter < 5mm and associated mycorrhizae

Table 2: Biomass of different components ($t\ ha^{-1}$) in tree, shrub and herb layers at different ages of Butea forests in Udaipur, Rajasthan

Components	Age of Butea forest stands (years)		
	5	10	15
Tree layer	183.7±3.21	246.1±3.38	298.3±3.57
% of allocation in			
Bole*	63.6	67.3	67.8
Branch†	12.3	11.9	12.8
Leaf	6.5	5.1	4.3
Reproductive parts	0.7	1.3	1.9
Coarse roots‡	15.5	13.1	11.6
Fine roots	1.4	1.3	1.6
Shrub layer	4.9±1.61	5.5±1.57	6.3±1.38
% of allocation in			
Above ground parts§	69.4	75.2	71.8
Below ground parts	30.6	24.8	28.2
Herb layer	2.1±1.81	1.9±1.79	1.7±1.64
% of allocation in			
Above ground parts	78.6	76.5	73.1
Below ground parts	21.4	23.5	26.9
Total vegetation	190.7±2.21	253.5±2.24	306.3±2.19

*Bole wood + bole bark, which accounted for 10.0-10.2 % of the values

†Branch + twig, which accounted for 3.7-4.8 % of the values

‡Stump root (main root) + lateral roots (lateral branches of main root), which accounted for 3.8-4.2 % of the values

§ Stem + foliage, which accounted for 13.1- 16.1 % of the values

Total biomass of trees increased with age from 183.7 ± 3.21 in 5-year- old stand to 298.3 ± 3.57 t ha^{-1} in 15-year-old stand, of which above- and below-ground parts represented percent values of 83-87 and 13-17, respectively (Table 2). Shrub biomass ranged from 4.9 ± 1.61 in 5-year-old stands to 6.3 ± 1.38 t ha^{-1} in 15-year-old stand, of which stem, foliage and roots accounted for about 53-62, 13-15 and 25-31%, respectively. The herb biomass ranged from 1.7 ± 1.64 in 15-year-old stand to 2.1 ± 1.81 in 5-year-old stands. Of this, the above ground component accounted for 73-79%. Herb biomass decreased with increasing age of the forest stand (Table 2). This could have been probably due to decrease in light penetration because of increase in forest canopy.

The total vegetation biomass ranges from 190.7 ± 2.21(5-year-old stand) to 306.3 ± 2.19 t ha^{-1} (15-year-old stand). The moderate amount of biomass has been observed in 10-year-old stands. Of this, the tree layer accounted for 96 to 98%, shrubs for 2-3% and herbs for 0.5-1% (Table 2). The present values fall with in the range reported for *Eucalyptus* stands (54-319 t ha^{-1}; by [15]), 100 plus year old oak forest (263-301 t ha^{-1}; by [16]), *Eucalyptus* plantation (319 t ha^{-1}, by [17, 18]).

Analysis of variance showed significant ($P < 0.01$) variations in total tree biomass and its components among plantations of different ages. The contribution of bole wood, branches, twigs, reproductive parts, lateral roots and fine roots increased with age while that of the remaining parts (Herb layer) decreased (Table 2). The contribution of root biomass to the total biomass generally decreased with age [5].

According to Harris *et al.* [19], although the importance of roots as structural, storage and physiologically active organs has been known, they have been neglected in most of the 'ecosystem studies' today because of difficulties surrounding investigation. For example, the root parts left in the soil of a mature Douglas fir accounted for only 11-18% of the weight of the total root system [20].

Forest Floor Biomass: The quantity of forest floor depends on canopy closure and climate. The biomass of litter on the forest floor increased with age of the forest stand. The seasonal mean total forest floor biomass (including herbaceous litter) increased from 4.04 t ha^{-1} in 5-year-old to 5.1 ha^{-1} in the 15-year-old stands (Table 3). The herbaceous biomass, both live and dead, however, showed a reverse trend. The same trend and the range were observed for *Populus deltoides* plantations (4.6-6.1) by [21] and *Eucalyptus* hybrid plantations (4.0-6.7 t ha^{-1}) by [22]. Frederick *et al.* [18] studied an age series of *Eucalyptus regnans* and stated that the native wood species and ferns generally increased with stand age, while herbaceous species declined.

Table 3: The average forest floor biomass (t ha^{-1}, across seasons) and turnover of litter (rate and time) in Butea forests of Udaipur, Rajasthan

	Age of Butea forest stands (years)		
Components	5	10	15
Forest floor biomass (t ha^{-1})	4.04±2.11	4.92±2.36	5.1±3.02
% Allocation in			
Fresh leaf litter	9.1	9.6	10.1
Partially and more decomposed litter	24.6	28.4	32.3
Wood litter	5.3	11.9	18.5
Miscellaneous litter*	24.4	20.1	18.8
Herbaceous litter†	36.6	30.0	20.3
Turnover rate (kg year)	0.94	0.93	0.92
Turnover time (t, year)	1.06	1.08	1.09

*Includes reproductive parts of trees and litter parts of shrubs

†Includes living and dead herbaceous material

Table 4: Litter production (t ha^{-1} year^{-1}) in Butea forests of Udaipur, Rajasthan

	Age of Butea forest stands (years)		
Litter components	5	10	15
Leaf litter	2.38 (80.1)	2.91 (75.0)	3.27 (70.9)
Wood litter*	0.13 (4.4)	0.23 (5.9)	0.40 (8.7)
Reproductive litter†	0.04 (1.3)	0.10 (2.6)	0.19 4.1)
Miscellaneous litter‡	0.42 (14.2)	0.64 (16.5)	0.75 (16.3)
Total	2.97 (100)	3.88 (100)	4.61 (100)

*Includes barks, twigs and branches

†Includes inflorescences, pods and fruits of trees and shrubs

‡Includes the leaf litter of shrubs and herbs

The accumulated forest floor in the present study (Table 3) was lower than those reported for Pinus stands (13-110 t ha^{-1}; [23]), oak forests (9.6-12.6 t ha^{-1}; [24, 25]), *Eucalyptus saligna* (12.4 t ha^{-1}; [26]), *Eucalyptus obliqua* (18.3 t ha^{-1}; [27]), *Eucalyptus regnans* (47.5 t ha^{-1}; [28]) and *Pinus roxburghii* forests (9.6-13.6 t ha^{-1}; [29]) but is with in the range reported for eucalyptus plantations [18, 30] and close to the values reported for *Eucalyptus* hybrid plantations (4.0-6.7 t ha^{-1}; [22]) and oak forest [14]. The smaller biomass on the forest floor indicates a high rate of decomposition under the warm and humid conditions.

Litter Fall: Seasonal fluctuations like climatic variables, latitude, exposure, altitude, soil moisture and wind velocity etc., affect variation in litter fall [29]. Leaves are a major component of the total litter input. Total litter fall ranged from 2.97 in 5-year-old-stand to 4.61 t ha^{-1} year^{-1}

Table 5: Component wise net primary productivity (t ha^{-1} year^{-1}) in trees, shrubs and herbs of Butea forests of Udaipur, Rajasthan

	Age of Butea forest stands (years)		
Vegetation	5	10	15
Tree layer	17.2±2.31	23.8±2.66	29.3±2.98
% of allocation in			
Bole	58.4	58.9	57.1
Branch	12.1	12.6	13.4
Leaf	6.7	6.9	7.1
Reproductive parts	1.2	1.4	1.7
Coarse roots	15.9	13.5	13.3
Fine roots	5.7	6.7	7.4
Shrub layer	0.8±0.78	1.4±0.89	1.6±0.95
% of allocation in			
Above ground parts	70.9	71.2	69.5
Below ground parts	29.1	28.8	30.5
Herb layer	3.1±1.53	2.8±1.65	2.3±1.82
% of allocation in			
Above ground parts	78.2	76.1	72.7
Below ground parts	21.8	23.9	27.3
Total vegetation	21.1±1.54	28.0±1.73	33.2±1.92

in 15-year-old-stand (Table 4). Of this, leaf litter accounted for 71-80%, with in the range reported for natural sal forests of Central Himalaya (60-80%; [31]) and for temperate forest (40-84%; [32]). However, wood litter represented 4-9%, which lower than the value reported for various forests around the world (10-36%; [31, 33, 34]).

Net Primary Productivity (NPP): The reliability of estimates of production for a site depends mainly on the accuracy in determinations of the annual biomass increment of trees. By using the same Vernier Calipers at exactly the same location on the tree, systematic errors in successive measurements of dbh of marked trees were reduced in the present work.

Total NPP (t ha^{-1} year^{-1}) of Butea forests at different ages is given in Table 5. NPP in the tree layer ranged from 17.2 (5-year-old stand) to 29.3 t ha^{-1} year^{-1} (15-year-old stand). Above-ground parts account for 78 (5-year-old stand) to 79% (15-year-old stand) and below-ground parts for 20 (10-year-old stand) to 22% (15-year-old stand). The NPP of the shrub layer was 0.88 (5-year-old stand) to 1.6 t ha^{-1} year^{-1} (15-year-old stand). Of this, above-ground and below-ground parts accounted for 70-71% and 30-31%, respectively. The productivity of the herb layer was 2.3 (15-year-old stand) to 3.1 t ha^{-1} year^{-1} (5-year-old stand). Above –ground parts accounted for 73 (15-year-old stand) to 78% (5-year-old stand) and below- ground parts for 22 (5-year-old stand) to 27% (15-year-old stand).

The total NPP in vegetation ranged from 21.1 (5-year-old stand) to 33.2 t ha^{-1} year^{-1} (15-year-old stand), of which the tree layer accounted for 88.2 (5-year-old stand) to 91.4% (15-year-old stand), the shrub layer for 2.4 (5-year-old stand) to 3.5% (15-year-old stand) and the herb layer for 5.1 (15-year-old stand) to 9.4 % (5-year-old stand) (Table 5). The NPP of 10-year-old-stands was found moderate between 5-year and 15-year-old stands.

Comparisons with other forests and plantations around the world show that the NPP of the present Butea forests (21-33 t ha^{-1} year^{-1}) was much higher than the values reported for Shisham forests (13-20 t ha^{-1} year^{-1}; [35]), for *Gmelina arborea* forest (10 t ha^{-1} year^{-1}; [8]). The difference in average net production among different forests may be partly caused by climate, especially the length of the growing season when both thermal and moisture conditions are favourable. The high productivity in the present study is probably caused by greater leaf surface and larger duration of photosynthetic activity [5].

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