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Effect of tree plantations on biomass and primary productivity of herbaceous vegetation in eastern India

D.K. DAS*, O.P. CHATURVEDI**, M.P. MANDAL & R. KUMAR

Department of Forestry, Rajendra Agricultural University, Pusa (Samastipur) 848 125

Abstract: Seasonal variation in biomass, net primary productivity and turnover of dry matter of herbaceous layer under *Albizia lebbeck* (L.) Benth and *Populus deltoides* G_3 Marsh plantations and in an adjacent open field was studied at Pusa in Bihar, eastern India. Live shoot biomass attained peak values of 682, 665 and 512 g m^{-2}, respectively under *A. lebbeck, P. deltoides* and in open field in September. Corresponding values of net aboveground production were 749, 692 and 678 g m^{-2} $year^{-1}$. The belowground net primary production of herbaceous layer was also highest under *A. lebbeck* (89 g m^{-2} $year^{-1}$) followed by *P. deltoides* (110 g m^{-2} $year^{-1}$) and open field (67 g m^{-2} $year^{-1}$). The turnover rates of total plant biomass were maximum in the rainy season and the least in the summer season on all sites. Shoots shared 86 to 91% of annual total net primary production. Thus the herbaceous vegetation under the monsoon subtropical condition exhibited a strong seasonality in biomass production. Under the plantations, herbaceous biomass achieved higher net primary production compared to the open field.

Resumen: Se estudiaron las variaciones estacionales en la biomasa, la productividad primaria neta y el recambio de materia seca del estrato herbáceo bajo plantaciones pantanosas de *Albizia lebbeck* (L.) Benth y *Populus deltoides* G_3, y en un campo abierto adyacente en Pusa, Bihar, este de la India. La biomasa aérea viva alcanzó valores máximos de 682, 665 y 512 g m^{-2}, respectivamente, bajo *A. lebbeck, P. deltoides* y en el campo abierto en septiembre. Los valores correspondientes de producción aérea neta fueron 749, 692 y 678 g m^{-2} $año^{-1}$. La producción primaria neta subterránea de la capa herbácea también tuvo su máximo bajo *A. lebbeck* (89 g m^{-2} $año^{-1}$), seguida de *P. deltoides* (110 g m^{-2} $año^{-1}$) y del campo abierto (67 g m^{-2} $año^{-1}$). En todos los sitios las tasas de recambio de la biomasa vegetal total fueron máximas en la estación lluviosa y mínimas en la estación veraniega. Las ramillas compartieron entre 86 y 91% de la producción primaria neta total anual. La vegetación herbácea bajo la condición de monzón subtropical mostró una fuerte estacionalidad en la producción de biomasa. Bajo las plantaciones, la biomasa herbácea alcanzó una alta producción primaria neta en comparación con el campo abierto.

Resumo: A variação sazonal na biomassa, na produtividade primária líquida e na rotação da matéria seca da camada herbácea sobcoberto de plantações de *Albizia lebbeck* (L.) Benth e *Populus deltoides* G_3 Marsh, e em campos adjacentes abertos, foi estudada em Pusa, no Bihar, Índia oriental. A biomassa de rebentos vivos atingiu os valores máximos de 682,665 e 512 g m^{-2}, respectivamente sob coberto de *A. lebbeck, P. deltoides* e em campos abertos, em Setembro. Os correspondentes valores da produção aérea líquida foram de 749,692 e 678 g $m^{-2}ano^{-1}$. A produção primária líquida subterrânea da camada herbácea foi mais alta sobcoberto de *A. lebbeck* (89 g m^{-2} ano^{-1}) seguida pela de *P. deltoides* (110 g m^{-2} ano^{-1}) e a dos campos abertos (67

* *Corresponding Author*; e-mail: drdkdas@rediffmail.com; diptydaspusa@yahoo.co.in
***Present Address:* National Research Centre for Agroforestry, Jhansi 284 003

g m^{-2} ano^{-1}). As taxas de rotatividade da biomassa total foram máximas na estação das chuvas e menores no verão em todas as estações ecológicas. A rebentação participou com 86 a 91% da produção primária líquida total anual. Assim, a vegetação herbácea, sob as condições da monção subtropical, exibiu uma forte sazonalidade na produção da biomassa. Em comparação com os campos abertos, a biomassa herbácea atingiu os valores mais altos da produção primária líquida sobcoberto das plantações.

Key words: *Albizia lebbeck,* herbaceous vegetation, live shoot, net primary production, *Populus deltoides*, system transfer functions.

Introduction

Herbaceous layer is an important component of terrestrial ecosystem and plays an important role in primary production and turnover. Wilson (1990) reported that shade influence of tree canopy modifies soil conditions to promote the rate of soil mineralization and microbial activity. Thus, there are distinct soil and micro-environmental differences between a tree stand and an open field that may influence biomass production of herbaceous vegetation.

Herbaceous vegetation comprises annual and perennial herbs and grasses established by seeds, rhizomes and other vegetative parts. Most of the herbaceous vegetation that occurs naturally under plantations and in open contributes to animal feed. Relatively few studies have been made on the biomass production of grasses under tree plantations (Joshi *et al.* 1991; Maurya & Mishra 1996; Sah *et al.* 1994; Saxena *et al.* 1996). The present investigation was carried out to assess the seasonal variation in biomass, net primary productivity and turnover of dry matter of herbaceous vegetation under *Albizia lebbeck* and *Populus deltoides* plantations and in an open field.

Study area

The herbaceous vegetation was studied under 5 year old plantations of *A. lebbeck* and *P. deltoides* and in an open field at Birauli Horticultural Research Station, Rajendra Agricultural University, Bihar, Pusa (25^0 39' N, 84^0 40' E, and 52.92 m elevation). The climate is sub-tropical with a monsoon pattern of rainfall. The year is divisible into three seasons *viz*; rainy (mid June to September), winter (October to February) and summer (March to mid June). The area has an average annual rainfall of 1280 mm, of which about 80% is received during rainy season. The maximum temperature is 38^0C (May to June) and minimum is about 7^0C (December to January). Soil is classified as sandy loam illitic ustic Typic calciorthent. Some important characteristics of the soil are given in Table 1.

Density of trees in the plantations was 800 trees ha^{-1}. Average tree heights for *A. lebbeck* and *P. deltoides* were 7.25 m and 8.50 m, respectively. *Cynodon dactylon, Dactyloctenium aegyptium, Cyperus rotundus, Cannabis sativa, Sorghum halepense, Imperata cylindrica, Euphorbia hirta, Phyllanthus niruri, Gnaphalium* spp., *Trianthema portulacastrum, Digera arvensis, Commelina*

Table 1. Important characteristics of the soils of experimental fields. Values are means of three replicates ± 1SE.

Characteristics	Stands		
	A. lebbeck	*P. deltoides*	Open field
pH	7.7 ± 0.2	8.1 ± 0.3	8.4 ± 0.2
Electrical Conductivity (dS m^{-1})	0.45 ±0.06	0.60 ± 0.08	0.79 ± 0.3
Organic Carbon (%)	0.52 ± 0.10	0.46 ±0.12	0.37 ±0.03
Available N (kg ha^{-1})	260 ± 10	182 ± 8	166 ± 6
Available P_2O_5 (kg ha^{-1})	30.5 ± 2.7	26.2 ± 2.1	15.5 ± 1.5
Available K_2O (kg ha^{-1})	158.6 ±13.6	135.6 ±11.6	128.2 ± 5.8
Soil Moisture (%) (in November)	14.2 ± 3.4	10.7 ± 1.2	8.2 ± 2.7

benghalensis, Fimbristylis miliaceae, Oxalis spp., *Leanea pinnatifida, Panicum repens, Desmostachya cynosuroides, Scoparia dulcis,* and *Dichanthium annulatum* were the dominant species in both the tree stands and open field. As many as 83% of the total herbaceous species were annuals and 17% perennials. Of the perennial vegetation, 12% show vegetative growth during all seasons. Tree stands and the open field were protected from grazing.

Materials and methods

Five sample plots, each 5 x 2.5 m in size were randomly marked in each of the three sites. Aboveground biomass of herbaceous vegetation was harvested from five randomly selected 50 x 50 cm quadrats in each plot at monthly intervals starting from June 1998 to May 1999. The harvested material was sorted into standing live and dead shoots. After standing material was harvested, litter was collected. Belowground plant material was collected from 5 monoliths, each 25 x 25 x 25 cm size, from each plot on each sampling date. The monoliths were brought to the laboratory, soaked in water for 24 h, and then washed with a fine jet of water. The samples were placed in perforated paper bags and oven dried at 80^o C to constant weight.

Aboveground net primary production (ANP) was determined by summing up positive changes in biomass plus mortality (Singh & Yadava 1974). Belowground net primary production (BNP) was obtained by summation of positive increments in root biomass. The values of ANP and BNP were summed to represent total net primary production (TNP). The turnover values of above and belowground biomass were calculated by dividing ANP by maximum aboveground biomass and BNP by maximum belowground biomass, respectively (Dahlman & Kucera 1965). The turnover of total plant biomass (sum of biomass of standing live and dead shoots, litter and belowground material) was calculated as (ANP + BNP) / (Maximum total plant biomass). The inputs in to the litter compartment [L], standing dead compartment [SD] and belowground biomass compartment [BG] for the growing season were calculated by summing the positive increments in the biomass within the growing season. The disappearance from the litter compartment [LD] was calculated as: [LD] = [L] + [initial litter biomass] - [final litter biomass]. Root disappearance [RD] was calculated as: [RD] = [BG] + [initial root biomass] - [final root biomass]. Total disappearance of plant material [TD] was calculated as the sum of [LD] + [RD] (Chaturvedi & Das 2002). The ratios of input to output represented system transfer functions.

Results

Biomass

In both the tree stands and open field, live shoot biomass was minimum (204 to 345 g m^{-2}) in June and maximum (512 to 682 g m^{-2}) in September (Fig. 1). The live shoot biomass was greater in the two plantations than in the open area, and gradually declined from October to May. Standing dead biomass on all sites increased from July to January. The maximum amount of standing dead biomass was under *P. deltoides* (265 g m^{-2}) followed by open field (237 g m^{-2}) and *A. lebbeck* plantation (232 g m^{-2}) in January. Litter biomass attained peak values in May and minimum in September on all sites. In the first two months of the rainy season, production of litter biomass on all sites was higher than that in the winter season. Spontaneous increase in litter biomass in May reflects a rapid litter deposition from live and standing dead compartments. Highest belowground biomass occurred in November; it declined from December to May.

Net primary production

The maximum annual ANP occurred under *A. lebbeck* (749 g m^{-2} year^{-1}) followed by *P. deltoides* (692 g m^{-2} year^{-1}) and open field (678 g m^{-2} year^{-1}) (Table 2). On all sites, maximum ANP occurred during rainy season and minimum during summer season. The annual BNP was greatest in *P. deltoides* plantation (110 g m^{-2} year^{-1}) followed by *A. lebbeck* (89 g m^{-2} year^{-1}). BNP was also maximum in rainy season. TNP was also maximum in the rainy season and minimum in the summer season.

Biomass turnover

The turnover of aboveground and belowground biomass was maximum in the rainy season, and minimum in summer season (Table 3). During rainy season, the turnover of aboveground biomass

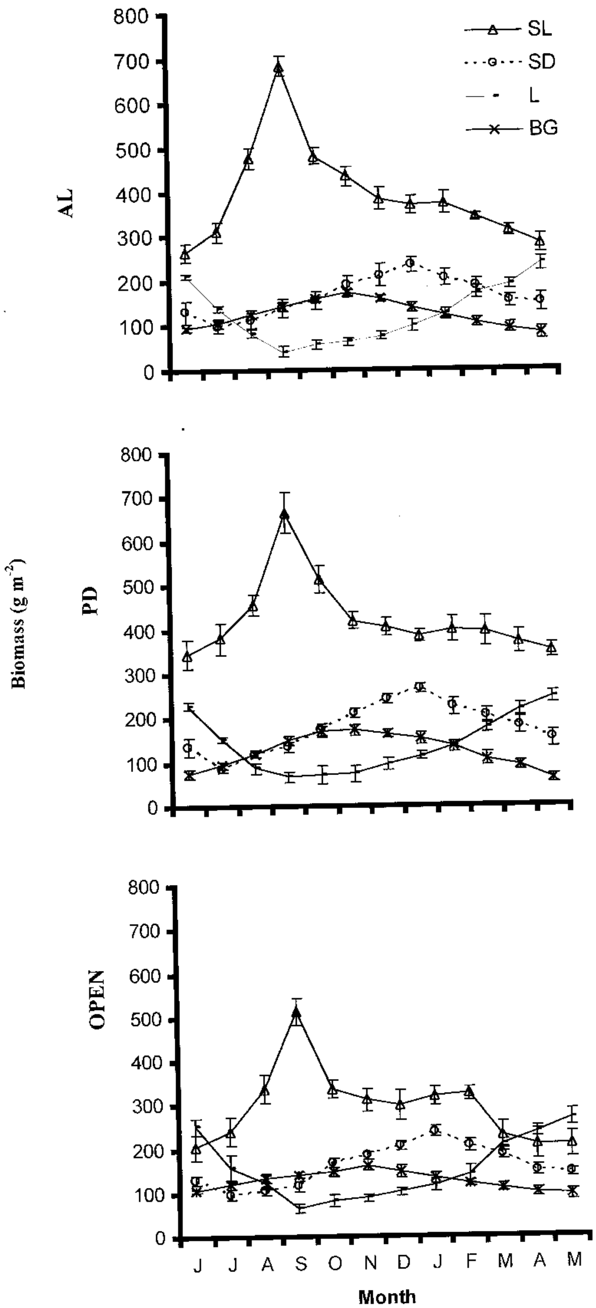

Fig 1. Monthly variation in herbaceous biomass (g m-2) under tree stands and in open field. AL - *A. lebbeck*, PD - *P. deltoides*, SL - Standing live, SD - Standing dead, L - Litter and BG - Belowground. Error bars represent ±1SE.

was greatest in *A. lebbeck* (53.1%) followed by open field (47.3%) and *P. deltoides* (42.6%). The annual

Table 2. Seasonal variation in net primary production (g m-2) of herbaceous vegetation under tree plantations and in the open field.

Stands	Season	ANP	BNP	TNP
A. lebbeck	Rainy	458	60	518
	Winter	150	29	179
	Summer	141	0	141
	Annual	749	89	838
P. deltoides	Rainy	369	88	457
	Winter	177	22	199
	Summer	146	0	146
	Annual	692	110	802
Open field	Rainy	327	45	372
	Winter	192	22	214
	Summer	159	0	159
	Annual	678	67	745
LSD ($p < 0.05$)		30.3	35.8	45.6

ANP - Aboveground net production, BNP - Belowground net production, TNP - Total net production

turnover rate of aboveground biomass was 98% in the open field, 86.9% under *A. lebbeck* and 79.8% under *P. deltoides*. For belowground biomass, it was 64% under *P. deltoides*, 52% under *A. lebbeck* and 41.4% in the open field. The turnover rate of total plant biomass was maximum during rainy season and minimum during summer season. The annual turnover rate of total plant biomass was most rapid in the open field (89.5%), intermediate under *A. lebbeck* (83.5%) and slowest under *P. deltoides* plantation (78.9%).

System transfer functions

On all sites, ANP accounted for 100% of the TNP during the summer season (Table 4). During other seasons also, the allocation of TNP to ANP was greater than the allocation to BNP. On an annual basis, the production of herbaceous vegetation on all sites was aboveground oriented with ANP accounting for 86.3 to 91% of annual TNP. The transfer of ANP to standing dead matter (SD) was maximum in winter. The ratio of litter (L) to SD was greatest in the summer season on all sites. Transfer of ANP to L was greatest in the summer followed by winter season. Litter disappearance (LD) to L ratio was maximum in the rainy season. The higher value of BNP to root disappearance (RD) compartment indicated that root dry matter did not accumulate over the annual cycle. The transfer function values for TNP

Table 3. Seasonal variation in turnover of herbaceous vegetation biomass under plantations and in the open field.

Stands	Seasons	Turnover of Aboveground biomass	Belowground biomass	Total plant biomass
Albizia lebbeck	Rainy	0.531	0.423	0.516
	Winter	0.215	0.170	0.209
	Summer	0.201	0.000	0.171
	Annual	0.869	0.520	0.835
Populus deltoides	Rainy	0.426	0.587	0.449
	Winter	0.232	0.128	0.214
	Summer	0.188	0.000	0.163
	Annual	0.798	0.640	0.789
Open field	Rainy	0.473	0.321	0.447
	Winter	0.287	0.136	0.267
	Summer	0.238	0.000	0.202
	Annual	0.980	0.414	0.895
LSD ($p < 0.05$)		0.152	0.107	0.136

to total disappearance (TD) indicated an accumulation of dry matter during rainy and winter seasons. The maximum ratio of TD to TNP was observed in summer season. On annual basis the net accumulation of dry matter was maximum in *A. lebbeck* (72%) followed by *P. deltoides* and open field (65%).

Discussion

The biomass and productivity in any ecosystem are governed by climatic conditions and edaphic characteristics. In the present study, active growth of natural herbaceous vegetation was triggered by the advent of monsoon showers, which resulted in a peak value of live aboveground biomass in September on all sites. Following the maturity of tillers and completion of life cycle of seasonal ground flora at the end of rainy season, the biomass of live shoots declined rapidly in the successive months. New seasonal ground flora were present during the beginning of winter season in November, but the growth of herbaceous vegetation was limited due to low sunlight intensity in the plantations and temperature and soil moisture stress in the open field. In the winter season, ground flora was stunted in growth and the perennial herbaceous species like, *Cynodon dactylon, Cannabis sativa, Cyperus rotundus,*

Table 4. Seasonal system transfer functions of herbaceous vegetation under plantations and in the open field. A = *A. lebbeck,* P = *P. deltoides and* O= Open field.

Compart-ment	Stands	Rainy	Winter	Summer	Annual
TNP to ANP	A	0.884	0.838	1.000	0.894
	P	0.807	0.889	1.000	0.863
	O	0.879	0.897	1.000	0.910
TNP to BNP	A	0.166	0.162	0.000	0.106
	P	0.193	0.111	0.000	0.137
	O	0.121	0.103	0.000	0.090
TNP to TD	A	0.347	0.346	0.475	0.278
	P	0.381	0.216	0.644	0.354
	O	0.530	0.248	0.314	0.354
ANP to SD	A	0.087	0.627	0.000	0.179
	P	0.187	0.734	0.000	0.288
	O	0.058	0.635	0.000	0.208
ANP to L	A	0.000	0.373	0.972	0.258
	P	0.000	0.266	0. 897	0.257
	O	0.000	0.260	0.962	0.299
SD to L	A	0.000	0.596	-	1.440
	P	0.000	0.362	-	0.894
	O	0.000	0.410	-	1.440
L to LD	A	-	0.250	0.197	0.689
	P	-	0.106	0.160	0.910
	O	-	0.320	0.163	0.921
BNP to RD	A	0.183	1.655	-	1.124
	P	0.136	1.727	-	1.109
	O	0.222	1.682	-	1.149

Sorghum halepense and *Imperata cylindrica* dominated.

With the decline of temperature during winter a large amount of live shoot biomass of perennial herbs was transferred to the standing dead compartment. A second but limited spurt of growth of a few perennial ground flora occurred in the month of February because of low precipitation during that period. An increase in ground flora biomass was recorded under tree canopies as compared to open field with full sunlight. Wilson (1990) hypothesized that the shade influence of tree canopy improves the rate of mineralization of soil nitrogen. Thus, the increased availability of nitrogen in the soil might be the possible reason for increase in the biomass of herbaceous vegetation in the plantations. According to Joshi & Bharti (2005), plants may facilitate other plants directly, by ameliorating harsh environmental conditions, altering substrate characteristics, or increasing the availability of a resource. During winter, with the decline in temperature, there was a marked accumulation of belowground biomass, perhaps due to translocation of food reserves to the belowground parts with the advent of unfavourable conditions for shoot growth.

The net primary production (NPP) on all sites was maximum in rainy season followed by winter and summer. During summer, BNP was zero. It appears that the limited amount of photosynthesizing live shoots, and high temperature accompanied by greater root respiration limited the root production in summer. The differences in ANP, BNP and TNP for herbaceous vegetation between the tree stands and in the open field under the same rainfall conditions resulted due to differences in soil and microclimatic variations. Improved fertility status (Table 1) might be associated with greater productivity of herbaceous layer under tree stands. According to Sah *et al.* (1994), soil organic carbon plays a major role in supporting the productivity of grasslands. Water use efficiency (ANP / annual rainfall) was slightly higher in plantations (0.54 to 0.59) than that in open (0.53). It could be due to lower salt concentration under tree stands.

The differences in seasonal turnover of aboveground biomass, belowground biomass and the total biomass of plant vegetation in general followed the seasonal trend of ANP, BNP and TNP, respectively. Highest turnover value for aboveground, belowground and total biomass during rainy season reflected better growth conditions. System transfer functions integrate the effects of abiotic and biotic variables and serve as indices of ecosystem functioning. In the present study, the system transfer functions indicated that most dry matter was allocated to aboveground part, which is available for harvesting. There was a greater amount of net surplus of dry matter in *A. lebbeck* (72%) than in *P. deltoides* and open stands (65%) on annual basis. On all sites, maximum transfer of litter to litter disappearance (LD : L) compartment during the rainy season indicated that with sufficient amount of soil moisture and moderate temperatures, the microbes bring about considerable litter decomposition. Of the total litter produced, about 92% in the open, 91% in the *P. deltoides* and 69% in the *A. lebbeck* plantation decomposed within the same year.

This study shows a seasonality in biomass production of herbaceous vegetation under the monsoonal subtropical condition. Further, under tree plantations, herbaceous biomass achieves higher net primary production, which can be utilized to sustain secondary production of livestock.

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