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Biomass production in 7 year old plantations of *Casuarina equisetifolia* on sodic soil

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Abstract: This paper deals with biomass and net primary productivity of three 7-year old *Casuarina equisetifolia* (Forst) stands raised on sodic wasteland. Two regression models (dbh based and d^2H based models) were used to estimate tree biomass. Biomass ranged from 137 to 199 t ha^{-1} in case of first model; and 135 to 205 t ha^{-1}, in case of second model. There was an insignificant difference in average stand biomass (170.5-172 t ha^{-1}) by using two different models. Coefficient of variation showed that component biomass was more variable (CV = 8.5-23%) in case of d^2H based model than that of dbh based model (CV = 5-21%). It, therefore, appears that use of dbh as an independent variable instead of d^2H is an easier and precise method for biomass estimation. Litterfall in three stands ranged from 5.2 to 7.2 t ha^{-1} yr^{-1} (average 6.1 t ha^{-1} yr^{-1}) of which leaf litter accounted for 79%. Net primary productivity ranged from 17.9-19.3 t ha^{-1} yr^{-1}. The bole wood shared maximum productivity (35%), followed by leaf (27.4%) and root (15.5%).

Resumen: Este trabajo analiza la biomasa y la productividad primaria neta en tres rodales de *Casuarina equisetifolia* (Forst) con siete años de edad cultivados en suelos deteriorados sódicos. Se utilizaron dos modelos de regresión (uno basado en dap y otro en d^2H) para estimar la biomasa arbórea. La biomasa fluctuó entre 137 y 199 t ha^{-1} en el caso del primero modelo, y entre 135 y 205 t ha^{-1} en el caso del segundo. El uso de los dos modelos produjo una diferencia no significativa en la biomasa promedio del rodal (170.5 - 172 t ha^{-1}). El coeficiente de variación mostró que el componente biomasa fue más variable (CV = 8.5-23%) para el caso del modelo basado en d^2H que para el del modelo basado en el dap (CV = 5-21%). Por lo tanto, parece que el uso del dap como variable independiente, en lugar de d^2H, constituye un método más sencillo y preciso para la estimación de la biomasa. La caída de hojarasca en los tres rodales fluctuó entre 5.2 y 7.2 t ha^{-1} $año^{-1}$, (con un promedio de 6.1 t ha^{-1} $año^{-1}$), de la cual la hojarasca foliar representó el 79%. La productividad primaria neta fluctuó entre 17.9 y 19.3 t ha^{-1} $año^{-1}$. La madera del tronco tuvo la máxima productividad (35%), seguida por las hojas (27.4%) y la raíz (15.5%).

Resumo: Este artigo trata da biomassa e da produtividade líquida de 3 parcelas de *Casuarina equisetifolia* (Forst) implantadas num solo sódico inculto. Foram utilizados dois modelos regressionais (baseados no dap e d^2H) para estimar a biomassa arbórea. A biomassa oscilou entre as 137 e as 199 $t.ha^{-1}$ no caso do primeiro modelo e 135 a 205 $t.ha^{-1}$ no caso do segundo modelo. Constatou-se uma diferença insignificante na biomassa média da parcela (170,5-172 $t.ha^{-1}$) quando eram usados os dois modelos. O coeficiente de variação mostrou que as componentes de biomassa eram mais variáveis (CV = 8,5-23%) no caso do modelo baseado na variável combinada d^2H quando comparadas com o modelo baseado no dap (CV5-21%). Parece, portanto, que o uso do dap como variável independente é mais fácil, e preciso, do que o uso do d^2H para estimar a biomassa. A queda de folhada nas três parcelas variou entre os 5,2 e os 7,2 $t.ha^{-1}.ano^{-1}$, com um valor (médio de 6,1 $t.ha^{-1}.ano^{-1}$) e, no qual, as folhas foram responsáveis

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por 79% daquele valor. A produtividade média líquida variou entre 17,9-19,3 t.ha^{-1}.ano^{-1}. A madeira do tronco contribuiu para a produtividade máxima (35%), seguida pelas folhas (27,4%) e raízes (15,5%).

Key words: Biomass, *Casuarina equisetifolia*, NPP, plantations, sodic soil.

Introduction

Nearly 80 per cent of wood in developing countries is consumed for fuel, whereas developed countries use approximately the same proportion for industrial uses (Goodman 1986). *Casuarina equisetifolia* is a very good source of fuel wood in the Phillipines (Halos 1983). The merit of planting *Casuarina* for fuel wood lies in its high tolerance to salinity and nutrient poor sodic land conditions. Apart from a fuel wood species, it is an efficient N-fixer and also allows tremendous nutrient return to soil through litter input. Relying on its tolerance to unusually high pH range (8.5-9.5), it has been introduced in agroforestry systems on problem sodic soil (Parihar & Rana 1999).

Comprehensive reports on biomass and productivity of man-made plantations are available (Lodhiyal *et al.* 1992; Rana *et al.* 1989; Rana *et al.* 1993). However, information on productive potential of *C. equisetifolia* outside its natural zone is quite meagre. The present study was designed to estimate biomass and productivity of three 7-year old stands of *C. equisetifolia* raised on sodic wasteland in a part of the Indo-Gangetic Plain. The major objective of the study was to investigate the dry matter dynamics of *C. equisetifolia* in nutrient poor sodic land with a view to understanding the structure and function of this short rotation tree species outside its natural zone. The other objectives were: (i) to use two different regression models from the stand point of finding an easier and accurate method for quantification of biomass; and (ii) to compare the biomass and productivity, with certain similar aged man made plantations of various other species.

Materials and methods

The study area lies (26^{o}47' N lat. and 82^{o}12' E long.) at Kumarganj (113 m elevation) located about 42 km south west of Faizabad town. The year is broadly divisible into three seasons: summer (April to mid June); rainy season mid June to mid September); and winter (November to February). The months of October (autumn) and March (spring) are transitional periods between the rainy and winter; and the winter and summer seasons, respectively. Of the total annual rainfall (1012 mm; 10 years average), the rainy season accounts for about 89%. Mean monthly maximum and minimum temperature ranges are 23-39^{o}C and 7.5-25.8^{o}C, respectively.

The soil is sodic (usar) with silt clay loam texture characterized by unusually high pH (8.5-9.5) indicating poor permeability. Due to high soil bulk density and compaction of soil the mechanical impedance is also high. The soil is very poor in organic carbon and nutrient status. A hard kankar pan of 20-30 cm thickness is commonly found within 1 m depth in the soil profile. The plantation of *C. equisetifolia* under present investigation, was established in 1989 at 2 x 2 m spacing on sodic wasteland.

Tree vegetation was analysed in September 1995. Within measurement sample plot area (1/4 ha area) in each stand the trees were marked for recording tree height and dbh growth. Condition of trees in measurement area and its outside buffer area was similar. The trees were selectively filled for biomass estimation by stratified clip method (Newbould 1967). For biomass estimation, three trees each class viz., 7.5-10, 12.5-15.0, 15.0-17.5, 17.5-20.0 cm were harvested and fresh weight for components of tree (i.e., bole wood, bark, branch, twig, leaf and root) were taken in the field. Roots were excavated from 1 m^{3} soil volume for one randomly chosen harvested tree in each of the dbh classes. Fresh samples (about 0.5 kg) for different components were brought to the laboratory and oven dried at 80^{o}C to constant weight. Using fresh: dry weight ratio for different samples, the dry weight of trees was obtained. The data were subjected to regression analysis. Following two regression models were tried:

(i) $\ln y = a + b \ln (d)$

(ii) $\ln y = a + b \ln (d^2H)$

where, y = biomass or dry weight (kg tree^{-1}) of the component; d = diameter at breast height (dbh) in cm; H = tree height in m; a = intercept; b = slope or regression coefficient.

The mean diameter or squared height for each diameter class was used in the regression equation of different components to get an estimate of mean biomass. This value was then multiplied by tree density determined in that diameter class. Totalling across dbh classes, stand biomass was obtained.

For the litterfall study, nine litter traps (50 x 50 cm size) in September 1995 were randomly placed on the forest floor of each of the three stands. At monthly intervals the litter was collected and dried at 80^{o}C to constant weight and litter fall per ha was calculated.

Three trees of each dbh class were marked in September 1995, and dbh was observed using Vernier calliper and in September 1996 (after one year) the increment in dbh was recorded. Net annual productivity was determined by using only the dbh based regression model ($\ln Y = a + b \ln D$). The use of this equation gives a reasonably reliable estimate (Rana *et al.* 1993). Net changes in biomass ($\Delta B = B_2 - B_1$) over the year yielded biomass accumulation. The sum of biomass accumulation in different components of trees yielded net biomass accretion in the trees. Net productivity was estimated using biomass accumulation and litter fall following Newbould (1967).

Results and discussion

Fig. 1 represents certain attributes of trees across dbh classes in three 7 year old stands of *C. equisetifolia* (hereafter denoted as S_1, S_2 and S_3 stands) raised on sodic soil. Despite similar tree density (2500 trees ha^{-1}) in each stand, S_2 had the lowest basal area (21 m^2 ha^{-1}). A comparison of h/d ratio (tree height in cm: dbh in cm) across dbh classes in three stands indicated the order: S_2 (98.1-126) >S_1 (91.2-105.5) >S_3 (89.90-102.9). The relationship of tree dbh as well as of height with h/d ratio indicated invariably negative correlation ($r = -0.95$; $P < 0.01$). However, d^2H vs h/d ratio had a positive correlation ($r = 0.85$; $P < 0.01$) in the present study.

The relationships between independent variable (dbh or d^2H) and component dry weight for trees showed a positive correlation ($P<0.01$) (Table 1). Correlation was stronger (r^2 = 0.93 to 0.99) in case of perennial components (bole wood, branch, root) than (r^2 = 0.87 to 0.91) components of short durability (twig, leaf and bark).

Biomass estimated using the first regression model (with dbh as independent variable) ranged from 137 to 199 t ha^{-1}, whereas in the case of the second model (with d^2H as independent variable) it ranged from 135 to 205 t ha^{-1} (average 172 t ha^{-1}) (Table 2). Coefficient of variation indicated that component biomass was more variable in case of using d^2H based regression model than that of dbh based model (Table 2). Thus it appears that the use of dbh instead of d^2H is an easier, precise and accurate method for biomass estimation.

Present estimates are comparable with reports for similar aged stands of *Leucaena leuecocephala* (159 t ha^{-1}) and *Eucalyptus* hybrid (153 t ha^{-1}) on sodic land (Rana *et al.* 1998). Our estimates are also consistent with reports for short rotation *Populus deltoides* plantations (84-189 t ha^{-1}; Kaul & Sharma 1983; Lodhiyal *et al.* 1992). Our range approaches higher than range of values (54-129 t ha^{-1}: Kaul *et al.* 1983; Raizada & Srivastava 1989)

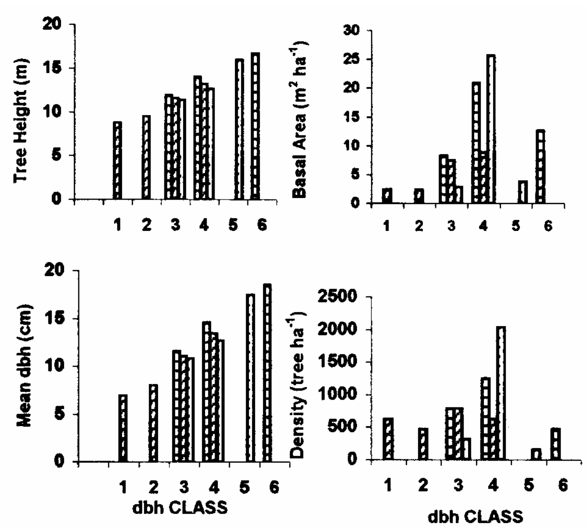

Fig. 1. Certain attributes of trees across dbh classes in 7-year old *C. equisetifolia* plantation, Parallel bars = Stand I (S_1); diagonal bars = Stand II (S_2); and dotted bars = Stand III (S_3 dbh classes (cm): 1 = 7.5-10; 2 = 10.0-12.5; 3 = 12.5-15.0; 4 = 15.0-17.5; 5 = 17.5-20.0.

Table 1. Allometric relationship and related statistics for various component weights (kg $tree^{-1}$ weights) of *Casuarina equisetifolia* trees.

Biomass (kg $tree^{-1}$)	Intercept (a)	Slope (b)	S.E.	r^2	t
		$\ln Y = a + b \ln (d)$			
Bole wood	0.437	1.232	0.102	0.93	12.08
Bole bark	-1.092	0.808	0.796	0.90	10.15
Branch	-0.264	1.077	0.031	0.99	35.05
Twig	0.310	0.441	0.042	0.91	10.51
Leaf	0.171	0.390	0.045	0.87	8.58
Root	-0.359	1.120	0.083	0.94	13.55
Total	1.527	1.072	0.064	0.96	16.80
		$\ln Y = a + b \ln (d^2H)$			
Bole wood	-0.253	0.503	0.043	0.93	11.78
Bole bark	-1.566	0.332	0.031	0.91	10.60
Branch	-0.886	0.442	0.012	0.99	36.06
Twig	0.052	0.181	0.016	0.92	11.31
Leaf	-0.056	0.160	0.018	0.88	8.97
Root	-0.989	0.459	0.034	0.94	13.41
Total	-0.914	0.439	0.026	0.96	16.64

d = dbh (cm), y = biomass or dry weight (kg $tree^{-1}$), all equations significant at P>0.001.

Table 2. Biomass (t ha^{-1}) using two regression models for 7 year old stands of *C. equisetifolia* on sodic soil.

Components	Stand			Average	CV (%)
	S^1	S^2	S^3		
Estimates based on equation $\ln y = a + b \ln (d)$					
Bole wood	103.9	68.0	89.3	87.1 ± 10.42	20.70
Bole bark	7.2	5.4	6.5	6.4 ± 0.52	14.25
Branch	33.9	23.3	29.7	29.0 ± 3.08	18.43
Twig	11.0	9.4	10.5	10.3 ± 0.50	7.97
Leaf	8.4	7.6	8.0	8.0 ± 0.20	5.00
Root	35.0	23.7	30.5	29.7 ± 3.30	19.13
Total	199.4	137.4	174.5	170.5 ± 18.00	18.30
Estimates based on equation $\ln y = a + b \ln (d^2H)$					
Bole wood	107.3	66.8	90.5	88.2 ± 11.75	23.07
Bole bark	7.4	5.3	6.6	6.4 ± 0.61	16.47
Branch	34.9	22.9	30.1	29.3 ± 3.49	20.61
Twig	11.1	9.3	10.5	10.3 ± 0.53	8.90
Leaf	8.4	7.1	8.0	7.8 ± 0.38	8.50
Root	36.0	23.3	30.9	30.1 ± 3.69	21.26
Total	205.1	134.7	176.6	172.1 ± 20.44	20.57

of *P. deltoides*.

A comparison of above-ground biomass showed that there was an insignificant difference in estimates (stand average) using dbh based regression model (141 t ha^{-1}) and d^2H based model (142 t ha^{-1}). Belowground shared about 17.5% of the total biomass. Of the aboveground biomass, bole wood accounted for 61.9%; bark 4.5%; branch 20.6%; twig 7.3%; and leaf 5.7%.

The biomass allocation to leaf was greater (7.6-11.5%) in 5-9 yrs old *P. deltoides* (Lodhiyal *et al.* 1992) than in the present estimation. The difference in percent biomass allocation in leaf perhaps corresponds primarily to the genetic setup of the species followed by climatic and edaphic limitations of the area under present investigation.

Table 3 indicates litter fall in three stands of present study. Total litter fall averaged at 6.1 t ha^{-1} yr^{-1} (5.2-7.2 t ha^{-1} yr^{-1}; S^1 vs S^3 stand), of which leaf litter shared 78.8%; wood 14.6%; and miscellaneous 6.6%. According to Kondas (1985) a 12 yr old plantation yields total litter and humus of 27 t ha^{-1}. The wood litter was a more variable component among stands (CV = 45.36%) than that of leaf litter (CV = 12.4%). Although, among stand differ-

Table 3. Litter fall (t ha^{-1} ± S.E.) in 7 year old stands of *C. equisetifolia*.

Stand	Litter			
	Leaf	Wood	Miscellaneous	Total
S^1	4.20 ± 0.384	0.63 ± 0.029	0.38 ± 0.042	5.21 ± 0.334
S^2	4.80 ± 0.321	0.69 ± 0.072	0.40 ± 0.055	5.89 ± 0.419
S^3	5.39 ± 0.150	1.36 ± 0.140	0.42 ± 0.035	7.17 ± 0.262
Average	4.80 ± 0.343	0.89 ± 0.234	0.40 ± 0.011	6.09 ± 0.575
CV (%)	12.4	45.3	3.7	16.3

ences in quantity of leaf as well as wood litters were not sizeable, however, relatively smaller contribution of wood compared to leaf litter increased coefficient of variation in the present study.

Our estimates of leaf litter values (4.2-5.4 t ha^{-1}) fall in the range of values (4.2-7.8 t ha^{-1} yr^{-1}) reported for 5-9 year old plantations of *P. deltoides* by certain workers (Zavitkovski & Newton 1971; Lodhiyal *et al.* 1995). The leaf litter values (2-2.5 t ha^{-1} yr^{-1}) for certain similar aged plantations raised on sodic land (*Leucaena leucocephala, Eucalyptus* hybrid and *Dalbergia sissoo*; Rana *et al.* 1998) are lower than the present estimates. The wood litter fall values (0.6-1.4 ha^{-1} yr^{-1}) in present study are in the higher side of the reported range (0.4-0.5 t ha^{-1} yr^{-1}) for *P. deltoides* stands of Central Himalayan region (Lodhiyal *et al.* 1992).

The net primary productivity of *C. equisetifolia* stands is shown in Table 4. The productivity in present study averaged 18.6 t ha^{-1} yr^{-1}, indicating that the stand range (17.9-19.3 t ha^{-1} yr^{-1}, S^1 vs S^3 stand) was greater than similar aged sodic land stands of *L. leucocephala* (15.2 t ha^{-1} yr^{-1} and *Eucalyptus* hybrid (13.9 t ha^{-1} yr^{-1}) as reported by Rana *et al.* 1998). Interestingly, our estimates are comparable with the range of productivity (17-21 t ha^{-1} yr^{-1}) reported for similar aged man made plantations (Bargali 1990; Lodhiyal *et al.* 1992).

On the whole, bole wood shared maximum productivity (35%) followed by leaf (27.4%) and root (15.5%). Productivity estimates for leaf in these stands are in good agreement with those of leaf litter fall in present study. Leaf efficiencies for production of aboveground portions (aboveground net production divided by total leaf biomass) were 1.8, 2.0 and 2.1 t ha^{-1} yr^{-1} for S^1, S^2 and S^3 stands, respectively. In general, leaf efficiency showed an inverse relationship with that of leaf biomass. Leaf efficiencies reported for similar aged stands of *P. deltoides* (1.49-1.79 t ha^{-1} yr^{-1}; Lodhiyal *et al.* 1992) are in the lower side of present estimates.

Table 4. Net primary productivity (t $ha^{-1}yr^{-1}$) of 7 year old stands of *C. equisetifolia* on sodic soil.

Components	Stand			Average
	S^1	S^2	S^3	
Bole wood	6.58	6.77	6.15	6.50
Bole bark	0.30	0.32	0.39	0.34
Branch	1.88	1.97	1.66	1.84
Twig	1.99	1.37	2.45	1.94
Leaf	4.37	4.99	5.90	5.09
Root	2.82	3.06	2.76	2.88
Total	17.94	18.48	19.31	18.58

The biomass accumulation ratio (biomass/net productivity) has been used to characterize production conditions of forests by Whittaker (1966) and Whittaker & Woodwell (1969). It expresses the quantum of biomass retained per unit of net production. The ratio is largely governed by the disappearance and accumulation rates of perennial biomass. In short rotation forestry crops biomass accumulation ratio is generally lower than natural forests, mainly due to similar contribution of tree size and rate of wood increment as affected by younger stand age. Our estimates for biomass accumulation ratio (7.43-11.11) are comparable with estimates (from 7 to 8; Bargali 1990; Lodhiyal *et al.* 1992; Singh *et al.* 1990) of similar aged plantations of *P. deltoides* and *Eucalyptus* hybrid of Central Himalayan region.

Plantations under present investigation were raised on sodic soil (unfit for agriculture production) with high pH and poor organic carbon and nutrients status. No amelioration was done except for using pit mixture (good soil, sand and FYM in 1:2:1 ratio). The irrigation in plantation area was done in summer months as and when required during first year. Only 20% plant mortality was noticed during summer season in first year, which was immediately compensated by gap filling from our nursery stock. Under adverse soil and different climatic conditions *C. equisetifolia* (a species of coastal origin) reflected indifference and assumed greater potential of biomass and productivity than other species (Rana *et al.* 1998). By inclusion of *C. equisetifolia* in agroforestry, satisfactory improvement in wheat and paddy crop yields on sodic soil occurred within 5 year of intensive cultivation in the same locality (Parihar & Rana 1999).

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