Journal of Tropical Forest Science 10(4): 478 - 493 (1998)

PRODUCTIVITY DYNAMICS OF *POPULUS DELTOIDES* CLONES ON A DEGRADED GANGETIC-ALLUVIUM IN NORTH INDIA

Bajrang Singh

National Botanical Research Institute, Lucknow-226001, India

Received July 1996

SINGH, B. 1998. Productivity dynamics of *Populus deltoides* clones on a degraded Gangetic-alluvium in north India. Dry matter dynamics of 6-y-old *Populus deltoides* clones (G3, G48 and D121) were studied in a degraded site of the Gangetic plains in north India. Whilst absolute biomass increased with tree growth, there was a big reduction (95-27%) in corresponding increase in proportional biomass. Biomass profile and crown architecture were developed along the vertical axis of the trees with increasing tree size. Stand structure consisted of 3.03 (D121) to 8.25 (G3) m^2 ha^{-1} basal area. Leaf area index of 2.8 m^2 m^{-2} was greatest in clone G3 which had maximum stand biomass of 29.18 t ha^{-1}, though net production (6.91 t ha^{-1} y^{-1}) was slightly greater in clone G48. Production efficiency varied from 2.64 to 3.46 kg kg^{-1} of leaf biomass in decreasing order of G48, G3 and D121 clones. Litterfall was 0.8 (D121) to 1.92 (G48) t $ha^{-1} y^{-1}$, of which 80% decomposed within a year. Among the interrelationship derived with girth, height and girth increment relations were best fitted by a logarithmic curve. Stand density and biomass were simulated by a polynomial curve of different shape, with increasing tree size. The dependence of stand biomass on the collective effects of basal area and leaf area index was deduced through a multiple regression model. A linear increase in production efficiency was associated with the positive effect of net production and negative effect of leaf production. The study revealed a marginal potential for commercial production unless the long term benefit of soil conservation/land rehabilitation is taken into account.

Key words: Biomass profile - tree girth - leaf area - production - litter decomposition - simulation - modeling

SINGH, B. 1998. Dinamik pengeluaran klon *Populus deltoides* terhadap aluvium - Gangetik usang di utara India. Dinamik bahan kering klon *Populus deltoides* berumur 6 tahun (G3, G48 dan D121) dikaji di tapak usang dataran Gangetik di utara India. Sementara biojisim mutlak bertambah dengan pertumbuhan pokok, terdapat pengurangan yang besar (95-27%) dengan tambahan yang sama dalam biojisim seimbang. Bentuk biojisim dan binaan silara dikembangkan di sepanjang paksi tegak pokok-pokok tersebut dengan saiz pokok yang bertambah. Struktur dirian mengandungi 3.03 (D121) hingga 8.25 (G3) m^2 ha^{-1} luas pangkal. Indeks luas daun iaitu 2.8 m^2 m^{-2} didapati terbesar dalam klon G3 yang mempunyai biojisim dirian maksimum sebanyak 29.18 t ha^{-1} walaupun pengeluaran bersih (6.91 t ha^{-1} y^{-1}) didapati lebih banyak dalam klon G48. Kecekapan pengeluaran berubah-ubah daripada 2.64 hingga 3.46 kg kg^{-1} biojisim pokok daripada biojisim daun dalam turutan

Corresponding address: Tree Biology, National Botanical Research Institute, Lucknow-226001, India.

menurun iaitu klon G48, G3 dan D121. Jatuhan sarap adalah 0.8 (D121) hingga 1.92 (G48) t ha^{-1} y^{-1} yang mana 80% reput dalam masa setahun. Di antara perkaitan yang diperoleh daripada kaitan lilitan, ketinggian dan kaitan pertambahan lilitan paling baik dipadankan dengan keluk logaritma. Kepadatan dan biojisim dirian dirangsang oleh keluk polinomial dengan bentuk yang berbeza, dengan saiz pokok yang bertambah. Pergantungan biojisim dirian ke atas himpunan kesan-kesan luas pangkal dan indeks luas daun dibuat melalui model regresi berganda. Pertambahan lurus dalam kecekapan pengeluaran adalah berasosiasi dengan kesan positif pengeluaran bersih dan kesan negatif pengeluaran daun. Kajian menunjukkan potensi marginal bagi pengeluaran komersial melainkan jika faedah jangka panjang pemuliharaan tanah/pemulihan tanah diambil kira.

Introduction

Indian forests are decreasing at a rate of 1.3 million ha y^{-1} reducing the forest cover to 19% of the country's geographical area by 1991. Consequently, wood production from natural forests and plantations of indigenous species is insufficient to meet the growing demand of the country. In consequence, most of the forest-based industries are suffering because of diminishing supplies of raw materials. To mitigate the crisis, a large number of fast-growing exotic species are being grown in various parts of the country. Of these exotics, *Populus deltoides* has been widely adopted in the north Indian plains due to its fast growth and multiple uses.

Though some preliminary studies have been made to quantify the biomass potential of *P. deltoides* in the Tarai region of Uttar Pradesh (Kaul & Sharma 1983, Kaul *et al.* 1983, Singh & Mittal 1983, Tandon *et al.* 1991), the detailed productivity analysis to determine the status and flux of biological material of assorted clones is still unknown in general, and particularly on the Gangetic-alluvium. Indeed, it is imperative to identify the scope of the poplar plantations on a large tract of such marginal lands which spread widely over the Gangetic plains. The present paper evaluates the biomass status and dry-matter dynamics in three clones of *Populus deltoides*. The objectives were to determine a) the biomass status and its accumulation rate with chronological tree size, b) the biomass profiles and development of crown architecture along the vertical tree axis and growth of tree size, c) the stand structure and production of clones and the contribution of their biomass components, and d) the interrelationships of the demographic characters that control biomass accumulation and production efficiency.

Materials and methods

Study site

Three clones of *Populus deltoides* (G3, G48 and D121) were established in four replicated plots each of size 33 × 33 m in February-March 1985, on degraded sodic soils at the Banthra Research Station, Lucknow (26° 48' N, 80° 53' E) in a subtropical semi-arid climate. Clones G3 and G48 were of Australian origin and clone D121 was received from Stoneville, Mississippi, U.S.A. The ETPs (entire transplants) were planted in pits of 1 m^3 filled with a ratio of 3:1:1 soil : cowdung manure: sand, at a distance of 3 m apart, accomodating 121 trees in each plot. Mortalities were replaced only in the first two consecutive years (1986-1987). The plantations were not fertilised subsequently and were only irrigated as and when required during their growth period of six years. The active growing period of poplars in this semi-arid climate extends from April to September after which the trees start shedding their leaves which is completed by December. Thus the trees remain almost in a dormant condition during winter (November-February).

The average annual rainfall during the study was 988 mm, 82% of which occurred in the rainy season from mid-June to September. The summer and winter seasons were quite distinct with mean maximum and minimum monthly temperatures of 39.6 and 8.1°C respectively. Average annual maximum and minimum temperatures were recorded as 32.1 and 18.6 °C. Average relative humidity was 63%. Lucknow receives 18.99 MJ m^{-2} day^{1} solar radiation and 7.5 h day^{1} of sunshine on an average basis.

The soil of the site is characterised as silty clay loam inseptisol developed on a deep alluvium which constitutes a compact layer 30-40 cm thick of calcium carbonate gravels located between 50 and 100 cm depths. This layer impedes root penetration and water permeability. Soils are very hard and develop deep cracks at the surface and remain cloddy during the dry-hot summer, becoming sticky in the rainy season. Soils are alkaline with pH ranging from 8.3 to 8.7 and have low electrical conductivity (0.27 - 0.41 dS m^{-1}), organic carbon of 0.31- 0.58% and moisture contents of 11-15%. The bulk density of the soil (1.38 g cm^{-3}) was slightly less in the plots of G3 clone. As a results of litter decomposition, surface soil (0.15 cm) was slightly less dense than soil at 0.60 cm depth.

Methods

After an initial census of tree populations, trees were allocated to seven girth classes of 10 cm interval at DBH level (diameter at breast height, 1.37 m) up to 70 cm in each clone except for D121 where trees were limited to six classes. Three trees from each girth class were selected for sampling constituting a total of 60 trees, 21 from each of G3 and G48, and 18 from the D121 clone. Before leaf fall, all sample trees were harvested, separated into different components then weighed. Roots were also excavated in 1 m^3 soil and weighed as stump root, lateral roots and fine roots. Replicate sub-samples (*c.* 500 g) were oven dried at 65 °C to constant weight to convert the fresh weight of the sample trees into dry biomass. Leaves from the sample plants were classified into three sizes, i.e. small, medium and large, and four replicates of 50 leaves of each size were assessed for leaf area (one side). The group of leaves of known leaf area of each size was then oven dried and weighed to enable estimation of ratio of leaf area per unit dry weight of leaf for each clone. The ratio was applied to determine the total leaf area of the sample trees for a clone. As with leaf area, stand biomass of different plant components was determined by allometric regression equations of the form $\ln y = a + b \ln x$, where x is tree size (DBH) and y is biomass or leaf area (Table 3).

The mean DBH of the individuals in a girth class was used in the above regression equations to obtain an estimate of mean biomass of a particular plant component for that girth class. This value was than multiplied by the population density in that girth class, followed by summation of values in each GBH class in a given plot of a particular clone. Such estimates were averaged for four plots to provide a mean estimate and standard error for the different plant components in each clone. Total leaf area of the plots of different clones was similarly calculated and which on dividing by the respective plot area gave estimates of leaf area index (LAI).

Litterfall, collected in 12 porous trays of 1 m^2, placed in each plot, occurred from September to December. The trees were completely defoliated by the end of December. Because the plantations were young, and lower branches up to 2 m height were prunned for straight boles, litter constituted only leaf material. Litter samples were oven dried to ascertain the flux of dry matter returned per unit area per year. Samples of fresh leaf litter (50 g) were packed in 20 × 15 cm nylon net bag (1 mm size) and placed in the plots to observe the weight loss during the year by decomposition processes.

To estimate net production, three marked trees from each size class of a clone measured in December 1990 were remeasured after one year. Thus a mean value of each size class was used to solve the allometric regression equations to obtain stand biomass for both years. The net change in biomass of tree components (except leaf) between the two consecutive years provided an estimate of net production. The second year's leaf biomass represented foliage production during a year.

Results

Tree biomass

Whereas tree biomass increased in all clones with the growth in plant size, the rate of increase dropped in clone G3 for trees bigger than 55 cm girth. Biomass increase appeared slower in clone D121 than in other clones. There was a great reduction in the proportional increase per unit biomass with the advancement in tree size, particularly in the G3 clone (95-27%). Such characteristic patterns of tree biomass indicate that the bigger trees of G3 clone are stagnating on this site after attaining a size of about 55 cm girth while those of G48 are growing at a relatively faster rate.

Biomass profile and crown architecture

Stratified biomass along the vertical axis of the tree height is of importance to understand the physiognomy of the forest stand. Since the dry matter distribution among the plant components along the vertical axis of the trees varies considerably within individuals of the same clone, different crown shapes are organised according to the growth of the trees and have a potential impact on energy fixation and nutrient transfer efficiency of the trees. Mean stratified biomass of the three sampled trees from each of the three girth classes (10-20, 30-40, 50-60 cm) is presented diagramatically in Figure 1. Adjusting the scale of leaf biomass and leaf area, an elliptical shape of the canopy was developed. The tree initiates the formation of a spindle shaped crown in the early stage of growth and then shows a tendency to become flatter at later growth stages in general, particularly for G48. Since G48 was shorter than the others and all were pruned to 2 m height, it was therefore bound to be flatter. The proportion of fine root biomass decreased with increasing tree size. The biomass of lateral roots was larger than the stump root in trees of greatest circumference. Branch twig and leaf components of biomass were concentrated in the middle portion of the crown and diminished towards both ends.

Regression equations

The form of equation was $\ln y = a+b \ln x$. All allometric equations between plant size as x and component biomass or leaf area as y were statistically significant at $p < 0.001$ and $p < 0.05$ probability levels (Table 1).

Table 1. Coefficients and errors of allometric regression equations ($\ln y = a+b \ln x$) between plant DBH as x and component biomass or leaf area as y of *Populus deltoides*

Plant component	b	a	r	sr	sb	syx
Stem	2.48	3.85	0.95*	0.028	0.071	0.444
Branch	3.67	- 0.78	0.94**	0.308	0.116	0.726
Twig	2.49	1.58	0.90***	0.410	0.108	0.595
Leaf	2.20	2.48	0.95*	0.029	0.065	0.403
SR	2.16	2.71	0.94*	0.031	0.069	0.431
LR	3.69	- 1.24	0.95*	0.030	0.114	0.710
FR	1.14	2.43	0.71*	0.071	0.096	0.601
Total	2.46	4.50	0.99*	0.012	0.030	0.185
Leaf area	2.24	7.28	0.85*	0.051	0.124	0.777

n = 60, consisting of 21 trees of each of G3 and G48 clones and 18 trees of D121 clone representing the entire size variation from 1.6 to 20.7 cm DBH.

*$p < 0.001$, ** $p < 0.01$, *** $p < 0.05$
SR = stump root, LR = lateral root, FR = fine root
sr = error of correlation coefficient r
sb = error of regression coefficient b
syx=error of regression line of y on x

Stand structure and frequency distribution

Mean diameter and height were greatest in clone G3 followed by G48 and D121 clones (Table 2). The growth pattern of tree height and stem diameter directly

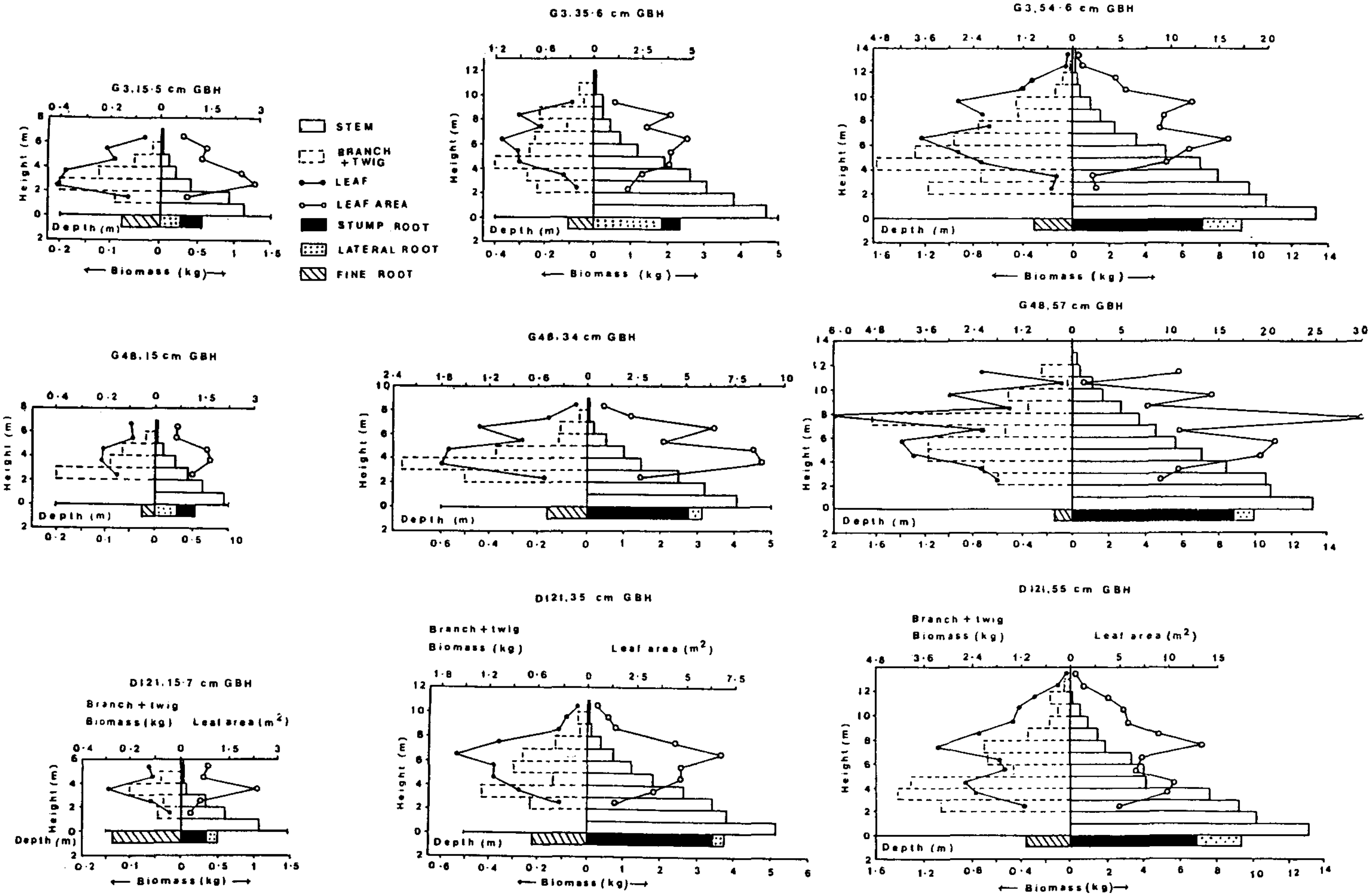

Figure 1. Biomass profiles and crown architectures along the vertical axes of trees in three girth classes in three clones, G3, G48 and D121 of *Populus deltoides* stands at Lucknow, India

influenced the magnitude of stand biomass and productivity. The girth-height relation in young poplar plantations was best fitted ($p<0.001$) by a logarithmic curvilinear model, i.e. y (height) = a + b log x (girth) derived from 21 trees of the seven girth classes in a clone (Figure 2). Height growth did not follow a rectilinear pattern according to girth size, which increased logarithmically (curvilinearly) for these clones with minor variations in their slopes (10.34-11.45) and intercepts (-5.48 to -6.38).

Table 2. Stand structure of 6-y-old *Populus deltoides* clones raised on degraded soils in India (mean ± se)

Character	Clone G3	Clone G48	Clone D121
Survival (%)	83 ± 2.83	83 ± 5.15	75 ± 6.72
Mean diameter (cm)	9.72 ± 0.92	8.67 ± 0.58	6.10 ± 0.54
Mean height (m)	9.57 ± 0.64	7.96 ± 0.19	5.95 ± 0.45
Stand density (No. ha^{-1})	923 ± 30	923 ± 57	843 ± 75
Basal area (m^2 ha^{-1})	8.25 ± 1.52	6.86 ± 0.74	3.03 ± 0.60
*Leaf area (m^2 kg^{-1})	12.95 ± 0.52	14.68 ± 1.92	12.41 ± 3.00
Site index (m)	13.95 ± 0.64	13.28 ± 0.45	12.55 ± 0.53
Stand density index (No. ha^{-1})	895 ± 104	777 ± 55	490 ± 54
Leaf area index (m^2 m^{-2})	2.80 ± 0.56	2.31 ± 0.28	0.93 ± 0.21

*m^2 per kg of leaf biomass.

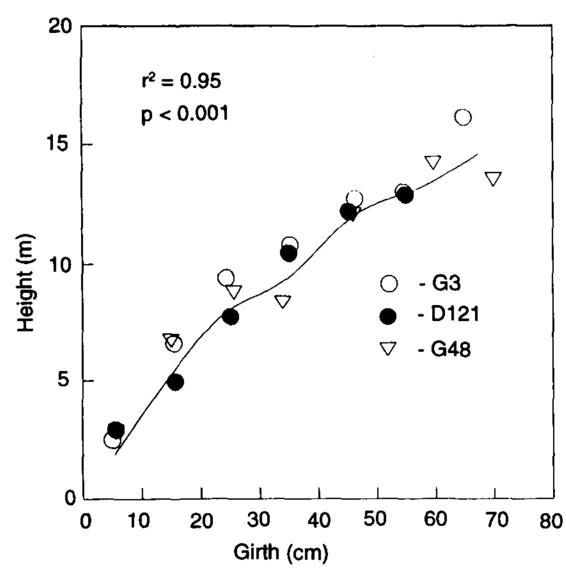

Figure 2. Girth-height relations for three clones of *Populus deltoides* at 7 y of age

Whilst mean stand density remained the same in G3 and G48 clones, their basal area varied, i.e. 8.25 and 6.86 m^2 ha^{-1} respectively. Clone D121 did not perform well; it had fewer survivors and smaller basal area (3.03 m^2 ha^{-1}). Trees of G48 had the largest specific leaf area, 14.68 m^2 kg^{-1} of leaf dry weight. Site index (average height of the dominant and codominant trees) ranged from 12.55 m (D121) to 13.95 m (G3) at 6 y age. The stand density index formulated by Reineke (1933) is an additional valuable parameter describing the status of stand biomass corresponding to basal area as both are a function of tree size and number in a stand (Table 5). The relation between log of the number of trees (log N) and log of their mean size (log D) among the plots of the clones can be described as $N = 1.08 \log D + 0.67$. Using the technique of translation of axis, stand density index (SDI) may be computed from the formula $\log SDI = \log N - a(\log D - \log 10)$ in the descending order of G3 < G48 < D121 clones. The leaf area index was also more for clone G3 (2.8 ± 0.56) as expected by their demography.

All trees do not grow at the same rate, especially where a considerable size heterogenity occurs in even-aged stands. Frequency distribution of trees which entails the shape of population growth, illustrates the levels of standing crop and also helps to reveal the factors that control the changes in size distribution within a stand. When the number of trees according to their girth size was classified, the frequency distribution curve had the intra-clonal variability of 32- 55% in D121 and G48 clones, and a tendency to have a small number of individuals in large size classes. The frequency distribution over the size classes showed an asymmetrical clumped distribution of the individuals as their variance/mean ratios were significantly greater than one (6.8 and 8.1 in G3 and G48 clones respectively).

Stand biomass

As a result of superior indices of basal area and tree height, G3 clone contained the greatest biomass, i.e. 29.18 ± 6.55 t ha^{-1} at 6 y, much greater than the 8.5 ± 2.39 t ha^{-1} produced by D121 clone (Table 3). Of the total standing crop, more than 50% was contained in tree stems, about 15 - 20% in branches including twigs, 7- 8% in leaves and 15-16% in roots. There was no difference between the biomass of stump and lateral roots. Fine root biomass was about 3-5% of the total root mass.

Table 3. Biomass production to age 6 y by *Populus deltoides* clones on degraded soils in India (t ha^{-1})

Plant component	G3	%	G48	%	D121	%
Stem	16.79 ± 3.62	57.5	13.68 ± 1.78	58.4	5.12 ± 1.33	60.2
Branch	3.78 ± 1.08	13.0	2.56 ± 0.45	11.0	0.72 ± 0.35	8.5
Twig	1.78 ± 0.38	6.1	1.45 ± 0.19	6.2	0.54 ± 0.14	6.4
Leaf	2.08 ± 0.41	7.1	1.71 ± 0.20	7.3	0.71 ± 0.16	8.4
Stump root	2.09 ± 0.32	7.2	1.95 ± 0.22	8.3	0.82 ± 0.18	9.6
Lateral root	2.52 ± 0.72	8.6	1.95 ± 0.35	8.3	0.52 ± 0.22	6.1
Fine root	0.14 ± 0.02	0.5	0.12 ± 0.01	0.5	0.07 ± 0.01	0.8
Total	29.18 ± 6.55	-	23.42 ± 3.20	-	8.50 ± 2.39	-

Net production

Net production by the clones, varying from 2.02± 0.48 (D121) to 6.91± 0.63 (G48) t ha^{-1} y^{1}, did not essentially coincide with the biomass values due to greater basal area increment of 1.09 m^2 y^1 in G48 clone in comparison with G3 clone (0.68 m^2 ha^{-1}) indicating the growth stagnation of G3 clone (Table 4). Stem and leaf were the major contributors to net production constituting about 29 - 40% and 66-77% of annual dry matter production after year six. Foliage production was greater in G3 than for G48 with a reversed trend that prevailed for the branch production, indicating the vigorous branching nature of G48 and confirming the crown architecture discussed earlier.

Litterfall ranged from 0.8 (D121) to 1.92 (G48) t ha^{-1} y^1, and constituted about 26 (G3) to 40% (D121) of total dry matter production. However, litterfall was less than foliage production during that year due to wind losses and pest infestation of the senescent leaves (Table 4). Of the total litterfall, 80% decomposed in the first year. The rate of decomposition remained fairly constant among the replicates as well as the clones. Thus, 21 (G3) to 31% (D121) of biomass production is ultimately transferred to humus matter and energy through an organic detritus cycle.

Table 4. Net production by *Populus deltoides* clones between ages 6 and 7 y on degraded soils in India (t ha^{-1} y^1)

Flux	G3	%	G48	%	D121	%
Stem	1.90 ± 0.33	37.4	2.55 ± 0.14	36.9	0.74 ± 0.21	36.6
Branch	0.60 ± 0.12	9.0	1.20 ± 0.11	17.4	0.20 ± 0.05	9.0
Twig	0.36 ± 0.04	5.4	0.27 ± 0.01	3.9	0.08 ± 0.02	4.0
Leaf	2.29 ± 0.44	34.3	2.00 ± 0.21	28.9	0.80 ± 0.17	39.6
Stump root	0.28 ± 0.18	7.6	0.32 ± 0.04	4.6	0.10 ± 0.01	4.9
Lateral root	0.41 ± 0.11	6.1	0.55 ± 0.09	8.0	0.09 ± 0.02	4.4
Fine root	0.01 ± 0.00	0.2	0.02 ± 0.00	0.3	0.01 ± 0.00	0.5
Total	5.85 ± 1.22	-	6.91 ± 0.63	-	2.02 ± 0.48	-
Litterfall	1.78 ± 0.48	26.6	1.92 ± 0.20	27.8	0.80 ± 0.20	39.6
Liter decomposition	1.41 ± 0.20	21.1	1.53 ± 0.03	22.1	0.63 ± 0.01	31.2

Girth increment

All the measured trees registered some increment in girth each year with an increasing trend with tree size, but increases were not rectilinear in nature. The relative growth rate as girth increment (GI) of three mean trees of each girth class when correleted with tree girth (log G) in the form y (GI) = a- b log G showed a curvilinear decrease in girth increment (Figure 3). This relation was statistically significant in each clone: D121, $r^2 = 0.93$, $p < 0.001$; G48, $r^2 = -0.82$, $p < 0.01$; and G3, $r^2 = -0.75$, $p < 0.05$. The average girth increments (cm y^1) of the marked trees in each clone were 2.79 (G48), 1.74 (G3) and 1.39 (D121).

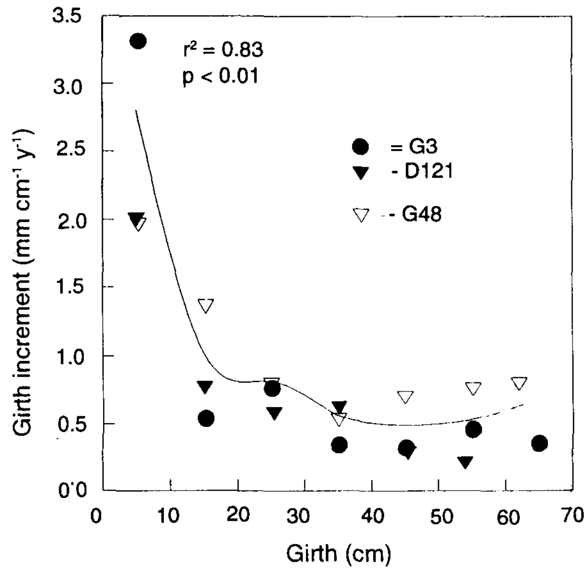

Figure 3. Annual girth increment with tree size for three clones of *Populus deltoides* between 6 and 7 y of age

Discussion

Field productivity of *P. deltoides* clones in a degraded habitat determines the selection of the site-specific clones, as the individual tree biomass did not display significant differences between clones. However, the crown architecture of the three sizes provides some information on the growth habits of the clones (Figure 1), although the net result of individuals interaction in the population still remains unknown. It is therefore required to measure the stand productivity in which size hierarchy differentiates the growth response among the clones (Tables 2-4). The synthesis and distribution of biomass in tree components are influenced by the component distribution along the tree height, particularly foliage (Ovington & Madgwick 1959, Hall 1965) which also varies with tree size (Gillespie *et al.* 1994.). Kira *et al.* (1969) reported that integration of the leaf mass and the degree of inclination of the leaves affect light interception by the canopy. There is a higher coefficient of light extinction in planophile than erectophile canopies because horizontal leaves intercept light more efficiently than erect leaves (Monsi & Saeki 1953). One of the reasons for faster growth of *P. deltoides* may be attributed to its planophile canopy.

Growth pattern of the tree can be examined through the appropriate mathematical model (relationship) between the tree size and time (Hara *et al.* 1991). A clone better in early growth may prove inferior in later growth stages as in the case of G3. Therefore, the size dependent growth curves illustrate a better pattern

(Figure 3). The leaf area index of this study was inferior to that of broad-leaved forests (Tadaki 1996). However, considering the estimate of LAI of 3 cm^2 cm^{-2} in beech and poplar plantations (Kira & Shidei 1967) and of 1.8 cm^2 cm^{-2} in a mature stand of *Populus tremuloides* (Peterson *et al.* 1970), the values found in this study are within the same order of magnitude.

The structural development of a stand depends on the size and growth rate of individuals and fluctuates greatly in response to both biotic and abiotic factors (Kohyama & Hara 1989). By comparison with estimates obtained in the Tarai regions of Uttar Pradesh, India (Kaul *et al.* 1983, Tandon *et al.* 1991), results obtained here indicate how soil constraints associated with climatic factors may limit the production of a species by more than half despite its capacity for fast growth. However, estimate for clone G3 was not too disappointing in the light of other measurements. For instance, above-ground biomass of 41.7 t ha^{-1} was estimated for a 5-y-old hybrid poplar plantation in USA (Wittwer & Stringer 1985) and 35 t ha^{-1} in a 8-y-old *Eucalyptus diversicolor* stand in Australia (Grove & Malajcku 1985). In contrast, the net production of the promising poplar clone was only one third to that of a 6-y-old *Eucalyptus* plantation growing in central Himalaya (Bargali *et al.* 1992).

Thus it is now evident that rate of production is largely influenced by environmental factors associated with the species' intrinsic potential. Similar is the case for biodegradation of organic residues which indicated that litter decomposition of G3 clone increased by 10% from the dry semi-arid to a dry sub-humid region of north India where Lekha and Gupta (1989) reported relatively faster decomposition.

Besides the climatic and edaphic factors, the biological productivity of the plantations depends to some extent on the interaction of individuals in a population. Exploration of such inter-relationships reasonably explains the yield potential of a species or a forest community (Whittakerr 1966, Whittaker & Woodwell 1968, 1969). The relationship between stand-age and the population density has been observed for a few species to interpret the coherent theory of the growth trajectories (McFadden & Oliver 1988, O'Hara & Oliver 1988). Stand biomass depends largely on the size distribution of individuals in a population and therefore the composition of population density and standing crop biomass in these plantations (clones pooled) were assessed with the increasing tree sizes (Figure 4). Their polynomial coefficients for density, $y = 156.53 + 3.84x - 0.1x^2$ ($\eta^2 = 0.77$, $p < 0.01$) and biomass, $y = -2.15 + 0.35x - 0.004x^2$ ($\eta^2 = 0.88$, $p < 0.01$) form two different types of curve with tree sizes.

While mean annual increment of biomass was greatest in clone G3, its current annual increment was less than that of clone G48, thus illustrating the growth limitation of clone G3 (Table 5). The greater amount of net production of clone G48 was associated with its more specific leaf area (leaf area per unit leaf dry weight) despite having a lower leaf area index than G3. Root shoot ratio did not vary much for biomass (0.19-0.21) and production (0.11-0.16 t ha^{-1} y^{-1}) among the clones. Various soil constraints (compact, heavy, alkaline, poor organic matter and N contents) have inhibited proper root growth resulting in a relatively low root/shoot ratio of biomass in comparison to the other estimates (0.30 to 0.31) of *P. deltoides* at the same age on better sites (Tandon *et al.* 1991, Toky & Bisht 1992). However, root/shoot ratios of 0.2 to 0.22 have also been reported in *P. deltoides* (Kaul *et al.* 1983, Raizada & Srivastava 1989). Leaf/wood ratio of 0.091 and production of 0.41 - 0.65 t $ha^{-1}y^{1}$ entail greater foliage production per unit wood weight by D121 clone and the efficient ability of wood production by G48 clone. Biomass turnover, the ratio of net production to stand biomass, indicated maximum turnover rate (0.29 t $ha^{-1}y^{1}$) for G48. Its turnover time being reciprocal to rate fraction was lowest (3.4 y) among the clones. Organic matter density and biomass accumulation ratio are measured for the assessment of wood quantity in a forest. As such the G3 clone was superior in spatial organic matter density (0.21 kg m^{-3}), as also in the biomass accumulation ratio (4.37), the amount of biomass accumulated per unit of net production. This latter ratio agrees fairly well with those from young *Alnus nepalensis* (4.2) and *Eucalyptus tereticornis* (4.83) plantations of comparable age (Sharma & Ambasht 1991, Bargali *et al.* 1992). Stem wood production per unit of leaf production was greater by 14% in G48 clone than that of clone G3. In contrast, the leaf biomass per unit of basal area did not change between these clones (Table 5).

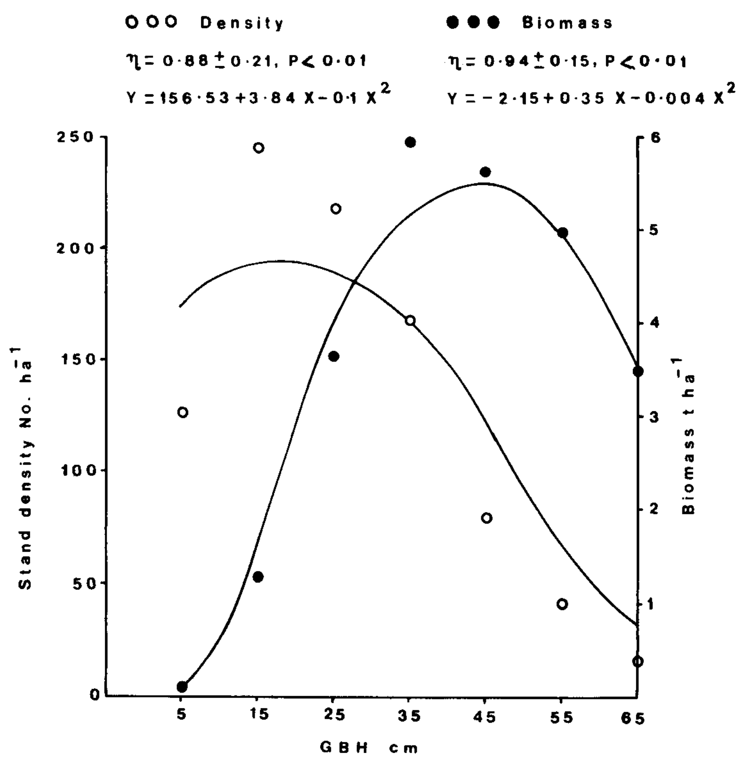

Figure 4. Simulation of stand density and biomass with tree size in 7-y-old *Populus deltoides* plantations

Table 5. Biomass and production interrelations in *Populus deltoides* plantations of 6 -7 y of age

Interrelation	Clone G3	G48	D121
Mean annual increment in biomass (t ha^{-1})	4.86	3.90	1.42
Current annual increment in biomass (t ha^{-1})	4.60	5.20	1.31
Root/shoot ratio for biomass	0.19	0..21	0.20
Root/shoot ratio for net production	0.16	0.15	0.11
Leaf/wood ratio for biomass	0.076	0.079	0.091
Leaf/wood ratio for net production	0.52	0.41	0.65
Biomass turnover rate (t ha^{-1})	0.23	0.29	0.24
Biomass turnover time (y)	4.37	3.39	4.21
Organic matter density (kg m^{-3})	0.21	0.18	0.07
Biomass accumulation ratio (t ha^{-1})	4.37	3.39	4.21
Stem wood production/leaf production ratio	1.09	1.27	0.92
Leaf biomass/basal area ratio (t m^{-2})	0.25	0.25	0.23
Production efficiency (kg kg^{-1} leaf biomass)	2.92	3.46	2.64
Production efficiency (kg m^{-2} leaf area)	0.216	0.256	0.190

Dependence of stand biomass on the collective effect of basal area and leaf area index has been shown through the interaction of a multiple regression model in which clones were pooled in the order of G3 > G48 > D121 (Figure 5). The surface of the regression plane reveals the ascending effect of two variables jointly by a mathemathical function of y (biomass) = -2.02+0.64 x (basal area) + 9.26 z (LAI) based on the empirical observations of 12 plots (R^2 = 0.95, p < 0.01).

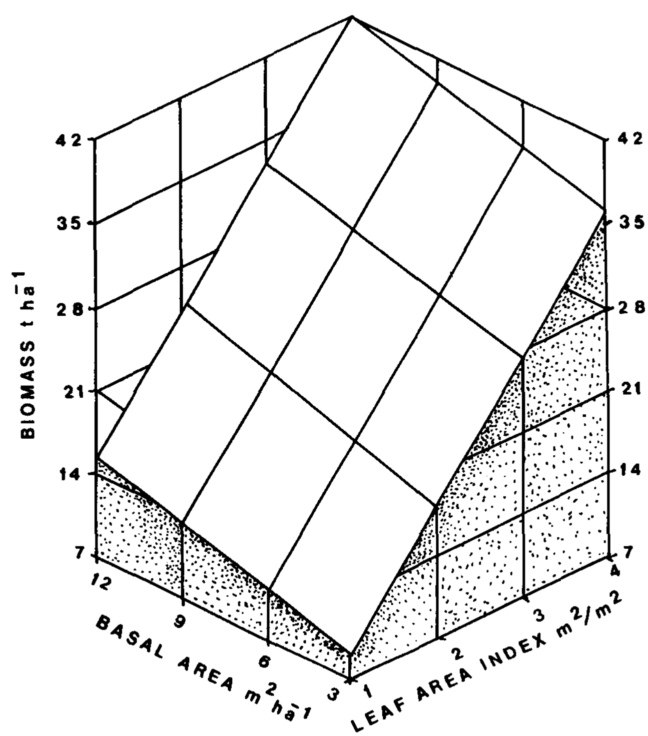

Figure 5. Dependence of biomass on collective effect of basal area and leaf area index (regression plane, y = -2.02+0.64x + 9.26z ; R = 0.977 ± 0.07, p<0.01, n = 12)

Production efficiency is a measure of net production per unit leaf biomass (Johnson & Risser 1974) or per unit leaf area. In both these terms, the G48 clone had the highest level of 3.46 kg kg^{-1} and 0.26 kg m^{-2} respectively (Table 5). Production efficiency followed a 'saucer' shaped hyperbolic curve with tree sizes in G3 and G48 clones, whereas the same decreased linearly in D121 clone due to the greater reduction of the number of individuals in later size classes of this clone.

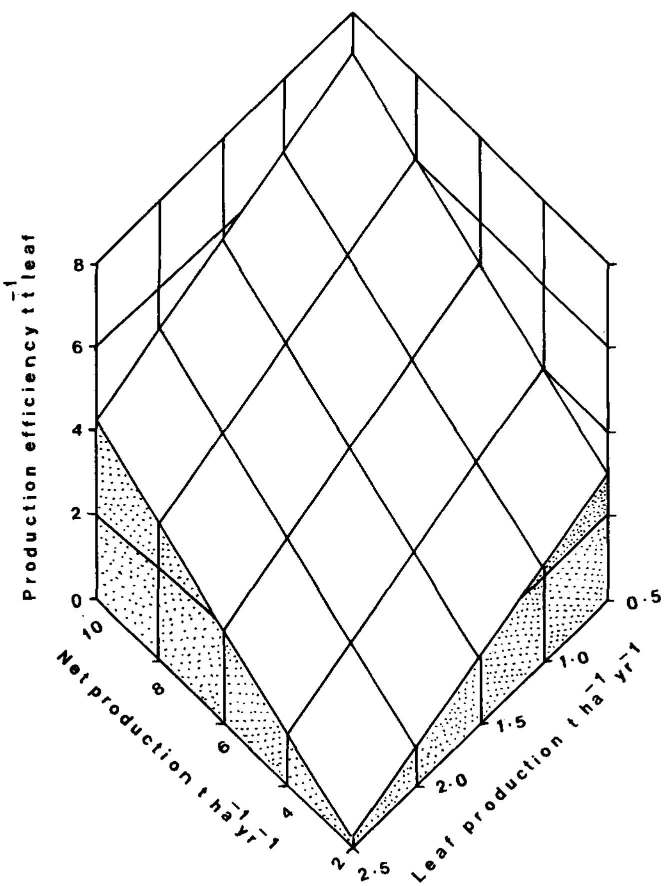

Figure 6. Simulation of production efficiency on the collective effect of net production and leaf production (regression plane $y = 2.7 + 0.5x - 1.4z$; $R = 0.991 \pm 0.04$; $p < 0.01$, $n=12$)

The interacting effect of leaf production (LP) and net production (Pn) on the production efficiency (PE), illustrated through the form of a multiple regression plane, y (PE) = 2.7+ 0.5x(Pn) -1.4z (LP), did not exactly match the previous model of biomass (Figure 6). Here, the negative effect of leaf production combines with the positive effect of net production to produce a linear increase in production efficiency. This relationship was well correlated (R^2 = 0.98, $p<0.01$) with the empirical observations among the clones.

Conclusion

Despite the fast-growing nature of *P. deltoides*, its production was limited on the degraded sites. However, some clones grew reasonably well in this habitat, and while there is only marginal potential for commercial production, other long term benefits of soil conservation/land rehabilitation must be taken into account. As a quarter of the net production flows through the detritus circuit, the erratic carbon cycle did not appear to replenish soil fertility in an already impoverished soil and may have led to the stagnation of growth of G3 clone. An intensive management of the silvicultural practices is therefore required to ensure the climate based yield on these sites. Clone G3 may be harvested on short rotation cycling of 5-6 y, whereas clone G48 would be better for 10-12 y cycle.

Acknowledgements

I am grateful to P.V. Sane, the former Director, and P.N. Misra, former Scientist, of the National Botanical Research Institute, Lucknow, for conceiving the project on poplars to make possible this work. I thank R.S. Katiyar for the management of the poplar plantations at Banthra Research Station. Financial support from the Ministry of Non-Conventional Energy Sources (MNES), Government of India, New Delhi, is duly acknowledged.

References

BARGALI, S.S., SINGH, S.P. & SINGH, R.P. 1992. Structure and function of an age series of eucalypt plantations in Central Himalaya. *Annals of Botany* 69 : 405 - 411.

GROVE, T.S. & MALAJCZUK, N. 1985. Nutrient accumulation by trees and understory shrubs in an age series of *Eucalyptus diversicolor* F. Muell. stands. *Forest Ecology and Management* 11: 75 - 95.

GILLESPIE, A.R., ALLEN, H.L. & VOSE, J.M. 1994. Amount and vertical distribution of foliage of young loblolly pine trees as effected by canopy position and silvicultural treatment. *Canadian Journal of Forest Research* 24 : 1337 - 1344.

HALL, G.S. 1965. Wood increment and crown distribution relationships in red pine. *Forest Science* 11: 438 - 448.

HARA, T., KIMURA, M. & KIKUZAWA, K. 1991. Growth patterns of tree height and stem diameter in populations of *Abies veithii, A. mariesii* and *Betula framanii*. *Journal of Ecology* 79 : 1085 - 1098.

JOHNSON, F.L. & RISSER, P.G. 1974. Biomass annual net primary production, and dynamics of six mineral elements in a post oak-blackjack oak forest. *Ecology* 55 : 1246 - 1258.

KAUL, O.N., SHARMA, D.C. & TANDON, V.N. 1983. Biomass distribution and productivity in a poplar plantation. *Indian Forester* 109 : 822 - 828.

KAUL, O.N. & SHARMA, K.K. 1983. Biomass production system of poplars and willows in India. *Indian Forester* 109 : 699 - 705.

KIRA, T. & SHIDEI, T. 1967. Primary production and turnover of organic matter in different forest ecosystems of the Western Pacific. *Japanese Journal of Ecology* 17 : 70 - 87.

KIRA, T., SHINOZAKI, K. & HOZUMI, K. 1969. Structure of forest canopies as related to their primary productivity. *Plant and Cell Physiology* 10 : 129 - 142.

KOHYAMA, T. & HARA, T. 1989. Frequency distribution of tree growth in natural forest stands. *Annals of Botany* 64 : 47 - 57.

LEKHA, A. & GUPTA, S.R. 1989. Decomposition of *Populus* and *Leucaena* leaf litter in agroforestry system. *International Journal of Ecology and Environmental Sciences* 15 : 97 - 108.

MCFADDEN, G. & OLIVER, C.D. 1988. Three-dimensional forest growth model relating tree size, tree number and stand age: relation to previous growth models and self-thinning. *Forest Science* 34 : 662 - 676.

MONSI, M. & SAEKI, T. 1953. Über den Lichtfaktor in den Pflanzengesellschaften und seine Bedeutung für die Stoffproduktion. *Japanese Journal of Botany* 14 : 22 - 52.

O'HARA, K. & OLIVER, C.D. 1988. Three-dimensional representation of Douglas-fir volume growth: comparison of growth and yield models with stand data. *Forest Science* 34 : 724 - 743.

OVINGTON, J.D. & MADGWICK, H.A.I. 1959. Distribution of organic matter and plant nutrients in a plantation of Scots pine. *Forest Science* 5 : 344 - 355.

PETERSON, E.B., CHAN, Y.H. & CRAGG, J.B. 1970. Aboveground standing crop, leaf area and caloric value in an aspen clone near Calgary, Alberta. *Canadian Journal of Botany* 48 : 1459 - 1469.

RAIZADA, A. & SRIVASTAVA, M.M. 1989. Biomass yield and biomass equations for *Populus deltoides*. *Indian Journal of Forestry* 12 : 56 - 61.

REINEKE, L.H. 1933. Perfecting a stand density index for even-aged forests. *Journal of Agriculture Research* 46 : 627 - 638.

SHARMA, E. & AMBASHT, R.S. 1991. Biomass, productivity and energetics in Himalayan alder plantations. *Annals of Botany* 67 : 285 - 293.

SINGH, S.P. & MITTAL, M.C. 1983. Growth of poplar plantations in Tarai regions of Uttar Pradesh. *Indian Forester* 109 : 755 - 761.

TADAKI, Y. 1966. Some discussions on the leaf biomass of forest stands and trees. *Bulletin of the Government Forest Experimental Station* 184: 135-161.

TANDON, V.N., PANDEY, M.C., RAWAT, H.S. & SHARMA, D.C. 1991. Organic productivity and mineral cycling in plantations of *Populus deltoides* in Tarai region of Uttar Pradesh. *Indian Forester* 117 : 596 - 608.

TOKY, O.P. & BISHT, R.P. 1992. Observations on the rooting pattern of some agroforestry trees in arid region of north-western India. *Agroforestry Systems* 18 : 245 - 263.

WITTWER, R.F. & STRINGER, J.W. 1985. Biomass production and nutrient accumulation in seedling and coppice hardwood plantations. *Forest Ecology and Management* 13 : 223 - 233.

WHITTAKER, R.H. 1966. Forest dimensions and production in the Great Smoky Mountains. *Ecology* 47 : 103 - 121.

WHITTAKER, R.H. & WOODWELL, G.M. 1968. Dimension and production relations of trees and shrubs in the Brookhaven forest, New York. *Journal of Ecology* 56 : 1 - 25.

WHITTAKER, R.H. & WOODWELL, G.M. 1969. Structure, production and diversity of the oak-pine forest at Brookhaven, New York. *Journal of Ecology* 57 : 155 - 174.