BIOMASS AND PRODUCTIVITY OF AN AGE SERIES OF THREE COTTONWOOD CLONES (*POPULUS DELTOIDES*) IN CENTRAL HIMALAYAN TARAI REGION, INDIA

K. Singh*, B. S. Rana

Department of Forestry, Narender Dav University of Agriculture and Technology, Kumarganj, Faizabad (Uttar Pradesh), India

&

R. P. Singh

Department of Forestry, D.S.B. College, Kumaun University, Mallital, Nainital (Uttranchal) 263102, India

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SINGH, K., RANA, B. S. & SINGH, R. P. 2004. Biomass and productivity of an age series of three cottonwood clones (*Populus deltoides*) in central Himalayan tarai region, India. This paper deals with estimates of biomass and net primary productivity of three clones of *Populus deltoides*, namely, IC, D-121 and G-3. Each of the three clones had one young (four years old), one middle age (six years old) and one mature (eight to 10 years) stand. All stands had similar stocking (667 trees ha^{-1}) at the time of plantation, but mature stands developed into stands with the lowest stocking (400–505 trees ha^{-1}) due to stem mortality with progressing stand age. Highest basal area (22.8–24.1 $m^2 ha^{-1}$) was attained by mature stands. Parabolic volume did not vary markedly from that of wood volume for young and middle age stands but showed wide variation in mature stands. Total tree biomass in investigated clones increased from young (32–42 t ha^{-1}) to mature stands (120–170 t ha^{-1}), the lowest and highest biomass being in IC and G-3 clones respectively. Net primary productivity also revealed similar pattern. At maturity, net productivity was in the order: D-121 (23 t ha^{-1} $year^{-1}$) > G-3 (21 t ha^{-1} $year^{-1}$) > IC (14 t ha^{-1} $year^{-1}$). The ratio of stem to leaf production generally decreased with age from around 2.0 in young stands (D-121 and G-3 clones) to less than 1.0 in mature stands. The relationship between biomass and net primary production was very weak. However, if biomass estimates for IC clone were excluded, a significant positive correlation ($r = 0.956$, $p < 0.01$) was achieved. Weighted mean height and aboveground net production were also significantly related ($r = 0.973$, $p < 0.01$).

Key words: Clonal stocking – parabolic volume – net primary productivity

SINGH, K., RANA, B. S. & SINGH, R. P. 2004. Biojisim dan produktiviti tiga klon poplar (*Populus deltoides*) berlainan usia di kawasan tarai Himalaya tengah, India. Kertas kerja ini membincangkan anggaran biojisim dan produktiviti primer bersih tiga klon *Populus deltoides* iaitu IC, D-121 dan G-3. Ketiga-tiga klon itu mempunyai satu dirian muda (empat tahun), satu dirian sederhana (enam tahun) dan satu dirian matang (lapan hingga 10 tahun). Semua dirian mempunyai stok awal yang sama (667 pokok ha^{-1}) tetapi dirian matang akhirnya mempunyai stok paling rendah (400–505 pokok ha^{-1})

**Present address: Department of Forestry, Indian Council of Agriculture and Research Complex for Northeastern Region, Umiam, Meghalaya - 793103, India. E-mail: kundansingh33@yahoo.com*

akibat kematian batang semakin pokok meningkat usia. Luas pangkal yang tertinggi (22.8–24.1 m^2 ha^{-1}) dicapai oleh dirian matang. Isi padu parabolik pada dirian muda serta sederhana tidak berbeza dengan ketara berbanding isi padu kayu tetapi menunjukkan variasi yang besar dalam dirian matang. Jumlah keseluruhan biojisim dalam klon yang diselidik meningkat daripada dirian muda (32–42 t ha^{-1}) ke dirian matang (120–270 t ha^{-1}). Biojisim yang terendah dan tertinggi adalah masing-masing dalam klon IC dan G-3. Produktiviti primer bersih juga menunjukkan corak yang serupa. Apabila matang, produktiviti bersih adalah mengikut urutan berikut: D-121 (23 t ha^{-1} $tahun^{-1}$) > G-3 (21 t ha^{-1} $tahun^{-1}$) > IC (14 t ha^{-1} $tahun^{-1}$). Pada dasarnya, nisbah penghasilan batang kepada daun berkurangan apabila umur meningkat iaitu daripada lebih kurang 2.0 dalam dirian muda (klon D-121 dan G-3) kepada kurang daripada 1.0 dalam dirian matang. Hubungan antara biojisim dan produktiviti primer bersih adalah sangat lemah. Bagaimanapun, jika anggaran biojisim untuk klon IC diabaikan, korelasi positif yang signifikan didapati ($r = 0.956$, $p < 0.01$). Hubungan antara ketinggian min berpemberat dan produktiviti bersih atas tanah adalah juga signifikan ($r = 0.973$, $p < 0.01$).

Introduction

Cottonwood (*Populus deltoides*) was introduced to India as early as 1950, and since then, over 415 clones have been tried under different agroclimatic regions (Kaul & Sharma 1983). High water table and soil fertility status in central Himalayan tarai has been considered extremely favourable for fast-growing cottonwood clones. There are now about 12 clones planted in the region.

The present study dealt with estimates of biomass and net primary productivity of three clones of *P. deltoides*, namely, IC, D-121 and G-3 planted in central Himalayan tarai region. These clones account for about 72% of the total area of 536 ha plantations in the region. IC and D-121 originates from America whereas G-3 is an Australian clone. Each of the three clones had young (four years old), middle age (six years old) and mature (eight to ten years old) stands.

The aim of the present investigation was to suggest potential clones from the management point of view by comparing interclonal estimates of biomass along an age series of central Himalayan tarai region.

Materials and methods

The study site lies at 79° 22'–79° 26' E longitude and 29° 3'–29° 5' N latitude at 230 m average elevation in central tarai forest division of Uttar Pradesh. The area extends over submontane tarai tract of Indo-Gangetic plains, south of the outer Siwalik ranges of the central Himalayan mountains. The tarai is a belt of gently sloping plains with an average slope of 2.5 m per km (i.e. 0.025%) and is composed of moist/alluvial/loam and free from gravel and boulders and overlain with beds of clay. Water seepage from higher elevations results in high water table (3 m) and high soil moisture content. Soil texture is mainly silt loam to silt clay loam. Organic matter (wet oxidation method) ranges between 1 and 3% and soil pH is 7.5. Original natural vegetation of the region is mainly alluvial savannah woodland, with some pockets of moist sal (*Shorea robusta*) forest.

The climate of the study site is subtropical monsoon with dry spell usually occurring from October till mid June. Rainy season starts from mid June till mid September. Winter extends from November till February and severe frost has been recorded during these months. Mean daily maximum temperature (38.4 °C) is recorded in May and mean daily minimum (4.3 °C) in January. Of the total annual rainfall (1400 mm from 20 years average), about 80% occurs in the rainy season.

Young (four years old), middle age (six years old), and mature (eight to 10 years old) stands of each clone were selected for detailed study. All stands had similar stocking (667 trees ha^{-1}) at the time of plantation. However, mature stands eventually had the lowest stocking (400–505 trees ha^{-1}) due to stem mortality with progressing stand age. A sample plot (1 ha) was established in each of the stands in March 1996. Tree diameter at breast height (dbh) and tree height were measured for all trees in a centrally located 0.25 ha area of each sample plot. The data obtained on tree dbh were used to select sample trees to be felled for developing regression equations relating dbh to dry weight of the different tree parts. Diameter range in each stand was divided into 5 cm dbh classes.

In late summer, before the leaves turned colour, three sample trees from each dbh class were randomly selected for harvest outside the sample plots. Using spades and shovels, roots were excavated around the base of sample trees (60 cm and 150 cm depth were used for 4- and > 5-year-old plant of poplar clones respectively). The individual trees were then pulled out with ropes and guided to fall in spaces between adjoining trees. Immediately, the tree dbh and height were measured and the tree was then separated into four components, namely, root, bole, branch and foliage. The bole of each harvested tree was cut into one-meter long sections and a 4- to 6-cm disc was cut from each end of the sections for determination of bark thickness, volume and moisture content. All samples were oven dried at 60 °C to constant weight and weighed. Fresh weights of other components were taken in the field and their subsamples (each about 500 g) were used for converting green weight taken in the field to dry weight.

The dry weight of each of the components was subjected to regression analysis. The regression equations were used in the form of

$$Y = a + bD$$

where

Y = dry weight of the component (kg $tree^{-1}$)
D = dbh (cm $tree^{-1}$)
a = intercept and
b = slope

The litter input was measured by placing 10 litter traps on the forest floor in all stands. Each trap was 50 × 50 cm, with 15 cm high wooden sides and fitted with a nylon net bottom. Litter from the trap was collected at monthly intervals during the study period. Litter samples were brought to the laboratory, dried and weighed.

In each sample plot, the annual increments in dbh of marked trees (three trees per dbh class) were measured in the field. The net changes in biomass yielded annual biomass accumulation. The sum of the biomass accumulation of the different tree components yielded net biomass accretion in the tree. To this, litter fall values were added and root mortality was regarded as one-fifth of leaf litterfall (Ogino 1977).

Results

Tree characteristics by clone and age stocking (stem ha^{-1}) varied considerably within and among the clonal stands (Table 1). Among the ages, mature stands (eight to 10 years old) had the lowest stocking, largely due to stem mortality during stand development. Though the stocking (667 stems ha^{-1}) was the same in all three clones at the time of planting the shoot cuttings, mature stand of IC clone had lower stem mortality (24%) than did the other two clones (about 40% each).

Dbh of the three clones under combined ages ranged from 15–26 cm. Mean tree height ranged from 14–22, 13–25 and 15–28 m respectively for IC, D-121 and G-3. A linear relationship between dbh and tree height was discernible and showed a positive correlation ($r = 0.94$ to 0.96, $p < 0.01$) for each of the three clones.

Stem basal area was highest in mature stands; 23.8, 22.8 and 24.1 m^2 ha^{-1} in IC, D-121 and G-3 clones respectively (Table 1). The ratio of bark to stem basal area is an index of relative bark thickness in trees. Among mature stands, D-121 had the lowest bark to stem basal area (12.7%), indicating its lower bark thickness compared with the other two clones (Table 1).

The stem (wood + bark) and wood of current basal area increments and MAI (mean annual increment) for mature D-121 stands were greater than G-3 and IC clones (Table 1). The ratio of basal area increment to wood basal area was lowest in mature stands ranging between 4.1 and 9.0%.

Table 1 Tree characteristics among different cottonwood clones

Stand dimension	Clone								
	IC			D-121			G-3		
Age (year)	4	6	10	4	6	8	4	6	9
Nos. of plant studied (N)	25	25	25	25	25	25	25	25	25
Mean tree height (m)	13.8	16.2	22.2	12.9	18.9	25.0	15.0	21.2	27.7
Mean dbh range (cm)	14.8	19.4	22.1	14.9	19.8	25.2	14.9	19.7	25.6
Stocking (stem ha^{-1})	540.0	520.0	505.0	460.0	431.0	410.0	465.0	424.0	400.0
Stem basal area (m^2 ha^{-1})	9.1	16.1	23.8	6.8	14.8	22.8	7.7	14.9	24.1
Volume basal area (m^3 ha^{-1})	7.7	12.1	19.7	5.5	9.9	19.9	6.4	12.9	20.4
Bark:stem basal area (%)	16.2	25.2	17.2	19.1	38.0	12.7	7.2	13.4	15.4
Stem basal area increment (m^2 ha^{-1} $year^{-1}$)	0.9	2.1	1.0	2.2	2.0	2.1	2.9	2.2	1.3
Wood basal area increment/wood basal area ratio (%)	10.4	13.2	4.1	32.7	14.1	9.0	37.5	14.7	5.4
Stem MAI (m^2 ha^{-1} $year^{-1}$)	2.3	2.7	2.4	1.7	2.5	2.8	1.9	2.5	2.7
Stem volume (m^3 ha^{-1})	26.5	110.4	212.1	45.3	125.9	229.8	55.5	149.6	252.7
Wood volume (m^3 ha^{-1})	47.4	93.7	175.3	36.9	85.1	199.2	46.2	130.9	213.6
Parabolic volume (m^3 ha^{-1})	53.1	98.1	218.8	35.4	93.7	248.5	47.9	130.0	283.0
Estimated volume increment (m^3 ha^{-1} $year^{-1}$)	4.4	12.7	9.3	11.6	12.9	22.9	18.1	20.4	15.8

MAI = Mean annual increment

Stem and wood volume estimates of some clones revealed wider variation among similar aged stands of the clones. Stem volume estimated in mature stands was between 212 (IC) and 253 m^3 ha^{-1} (G-3) and wood volume values were between 175 (IC) and 214 m^3 ha^{-1} (G-3). Parabolic volume did not markedly vary from that of wood volume for young and middle age stands but revealed wider variations in mature stands (Table 1).

The relationships between several stem dimensions are shown in Figure 1. The coefficient of determination values were generally satisfactory for stand biomass and annual dry matter production.

Linear equations relating biomass of different components to dbh for the three cottonwood clones are given in Table 2. It is evident from the r^2 values that the relationships are satisfactory.

Total tree biomass (aboveground + belowground) in all clones increased from 35–42 t ha^{-1} (aboveground 30–37 t ha^{-1}) in young stands to 120–170 t ha^{-1}

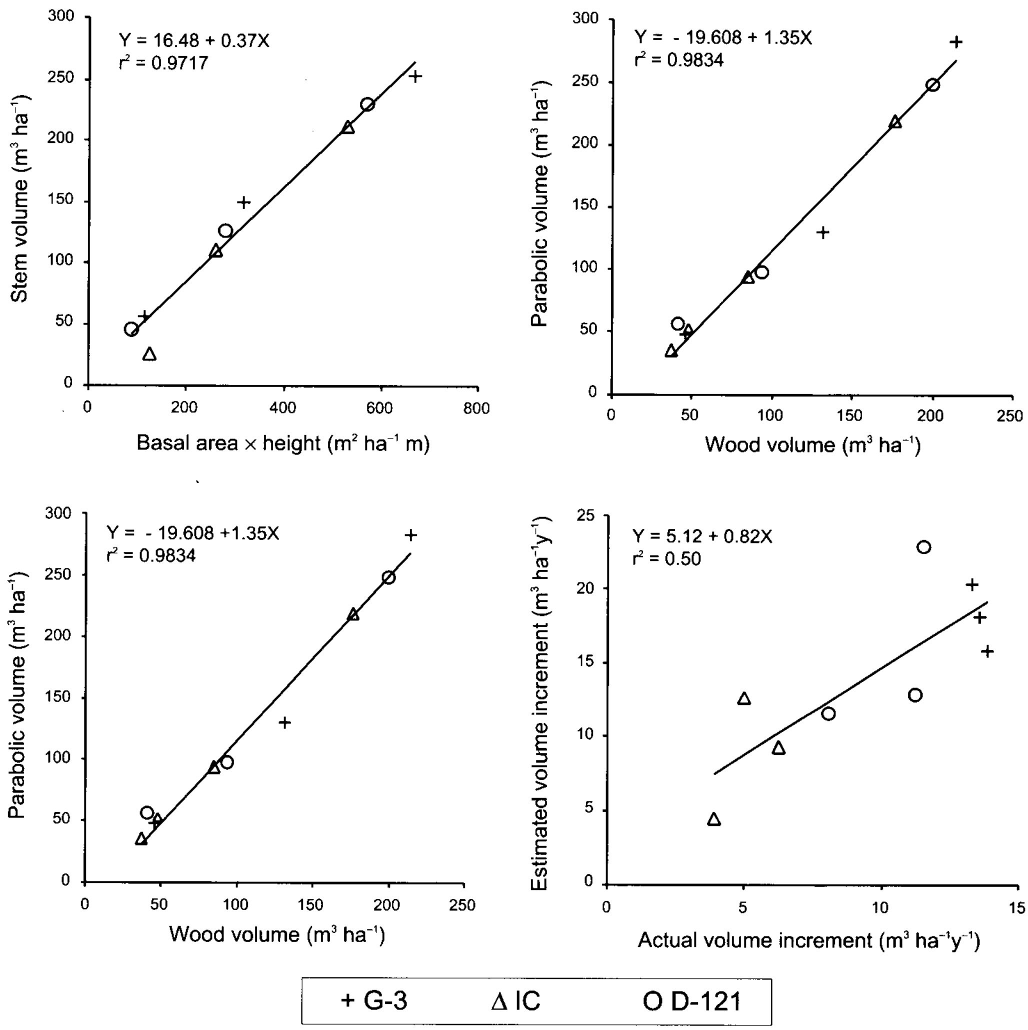

Figure 1 Regression lines and equations showing relationship between volumes and growth of different stem dimensions of poplar clones

Table 2 Linear equations between biomass of different tree components (*Y*, kg tree^{-1}) and diameter at breast height (*D*, cm) for various clones

Clone	Age (year)	Nos. of plant studied	Bole biomass (under bark)	Bole bark biomass	Branch biomass	Leaf biomass	Root biomass
IC	4	25	Y= 0.0269+0.00475 D (r^2=0.96; Syx=0.00037)	Y= -0.0267+0.00124 D (r^2=0.91; Syx=0.00013)	Y= -0.0109+0.00209 D (r^2=0.83; Syx=0.00049)	Y= -0.00427+0.00135 D (r^2=0.93; Syx=0.00014)	Y= -0.00412+0.00125 D (r^2=0.89; Syx=0.00016)
	6	25	Y=0.0521+0.00674 D (r^2=0.93; Syx=0.00067)	Y= 0.00468+0.00121 D (r^2=0.96; Syx=0.00007)	Y= -0.0109+0.00195 D (r^2=0.88; Syx=0.00036)	Y= -0.00908+0.00105 D (r^2=0.95; Syx=0.00008)	Y= -0.00612+0.00119 D (r^2=0.76; Syx=0.00025)
	10	25	Y=0.1080+0.01040 D (r^2=0.96; Syx=0.00739)	Y= 0.00867+0.00133 D (r^2=0.96; Syx=0.00007)	Y= -0.0224+0.00239 D (r^2=0.70; Syx=0.00071)	Y= -0.0145+0.00228 D (r^2=0.95; Syx=0.00015)	Y= -0.00654+0.00133 D (r^2=0.93; Syx=0.00010)
D-121	4	25	Y= -0.0647+0.00179 D (r^2=0.92; Syx=0.00080)	Y= -0.0129+0.00127 D (r^2=0.53; Syx=0.00055)	Y= -0.0123+0.00148 D (r^2=0.68; Syx=0.00077)	Y= -0.0105+0.00984 D (r^2=0.94; Syx=0.00010)	Y= -0.0120+0.00167 D (r^2=0.96; Syx=0.00015)
	6	25	Y= -0.0892+0.00103 D (r^2=0.97; Syx=0.00066)	Y= -0.00712+0.00113 D (r^2=0.97; Syx=0.00007)	Y= -0.0424+0.00355 D (r^2=0.75; Syx=0.00095)	Y= -0.0152+0.00153 D (r^2=0.95; Syx=0.00016)	Y= -0.00766+0.00227 D (r^2=0.61; Syx=0.00081)
	8	25	Y= -0.0116+0.00126 D (r^2=0.95; Syx=0.00101)	Y= -0.0173+0.00121 D (r^2=0.98; Syx=0.00012)	Y= -0.0286+0.00328 D (r^2=0.89; Syx=0.00340)	Y= -0.0190+0.00236 D (r^2=0.95;Syx=0.00016)	Y= -0.0274+0.00333 D (r^2=0.73; Syx=0.00900)
G-3	4	25	Y= -0.0368+0.00462 D (r^2=0.98; Syx=0.00030)	Y= -0.00614+0.00129 D (r^2=0.96; Syx=0.00007)	Y= -0.0170+0.00176 D (r^2=0.93; Syx=0.00019)	Y= -0.00802+0.00133 D (r^2=0.98; Syx=0.00006)	Y= -0.0120+0.00234 D (r^2=0.89; Syx=0.00039)
	6	25	Y= -0.1080+0.01670 D (r^2=0.97; Syx=0.00079)	Y= -0.00769+0.00133 D (r^2=0.95; Syx=0.00008)	Y= -0.0406+0.00439 D (r^2=0.87; Syx=0.00035)	Y= -0.0154+0.00237 D (r^2=0.97; Syx=0.00013)	Y= -0.0244+0.00197 D (r^2=0.95; Syx=0.00013)
	9	25	Y= -0.1470+0.01580 D (r^2=0.94; Syx=0.00133)	Y= -0.0110+0.00109 D (r^2=0.82; Syx=0.00019)	Y= -0.0411+0.00355 D (r^2=0.82; Syx=0.00079)	Y= -0.0271+0.00302D (r^2=0.94; Syx=0.00029)	Y= -0.0350+0.00323 D (r^2=0.92; Syx=0.00030)

(aboveground 106–151 t ha^{-1}) in mature stands, the lowest being in IC clones and highest in G-3 clones (Table 3). Stocking level (stem ha^{-1}) did not show marked influence on biomass, except in young stands. The distribution pattern of biomass among different components was bole wood > branch > root > leaf > bark (Table 3). In the total aboveground biomass, percentage of bole wood generally increased while that of crown (branch + leaf) decreased with stand development. In the middle age and mature stands, root biomass was highest in D-121.

Figure 2 shows linear increase in aboveground biomass with regard to increase in several stem dimensions, namely, basal area, basal area × height, parabolic volume, stem volume, weighted mean height and leaf area index (LAI). LAI peaked in mature stands (6 in IC and 8.8 in D-121). LAI increased with stand age, largely paralleling the changes in foliage biomass ($r = 0.90$, $p > 0.01$).

In clones D-121 and G-3, net primary production (NPP) increased with increase in stand age (Table 4). However, in the case of clone IC, NPP declined from about 16 t ha^{-1} $year^{-1}$ in middle age stands to 14 t ha^{-1} $year^{-1}$ in mature stands. At maturity, the NPP was 23 t ha^{-1} $year^{-1}$ for clone D-121 and about 21 t ha^{-1} $year^{-1}$ for G-3.

NPP among different components of trees varied with stand age. NPP of leaves increased from 26 to 49% in young stands and from 44 to 57% in mature stands (Table 4). Contrarily, proportional allocation of production of bole wood and bole bark decreased with age. Branch and root production did not indicate appreciable difference in NPP among stands.

The ratio of stem to leaf production generally decreased with age from around 2 in young stands (D-121 and G-3 clones) to less than 1 in mature stands (Figure 3). The ratio from branch to leaf production also decreased with age in all three clones. Pattern similar to aforementioned ratio was also evident by stem production to leaf weight ratio.

Biomass accumulation ratios (biomass/net primary production) were 2 to 7.1 for young stands, 1.6 to 5.1 for middle age stands and 7.1 to 8.6 for mature stands and indicated some correlation with stand age (Figure 4). In general, the lowest biomass accumulation ratio occurred in D-121 clone and the highest in IC clones. Differences in biomass accumulation ratio were due to differential growth rates of

Table 3 Total stand biomass (± SE) and per cent allocation of different tree components

Clone	Age (year)	Total biomass (t ha^{-1})	Allocation of biomass (%)				
			Bole	Bark	Branch	Foliage	Root
IC	4	41.9 ± 6.5	52.0	7.2	20.3	9.0	11.5
D-121	4	34.7 ± 4.0	54.1	9.0	14.3	9.2	13.4
G-3	4	34.9 ± 4.1	48.1	8.5	19.8	10.1	13.5
IC	6	73.6 ± 10.2	53.1	7.7	15.2	10.8	13.2
D-121	6	98.9 ± 16.3	51.2	6.4	17.9	8.3	16.2
G-3	6	97.1 ± 16.5	60.6	6.9	11.8	8.5	12.2
IC	10	119.6 ± 12.0	57.5	8.0	11.5	11.1	11.9
D-121	9	161.2 ± 17.8	58.8	8.5	11.7	8.7	12.3
G-3	8	171.4 ± 20.1	57.5	6.2	14.1	10.8	11.4

trees in the three clones of this study. D-121 with the lowest ratio at maturity (7.1) appeared to have greater production potential than the other two clones of this study.

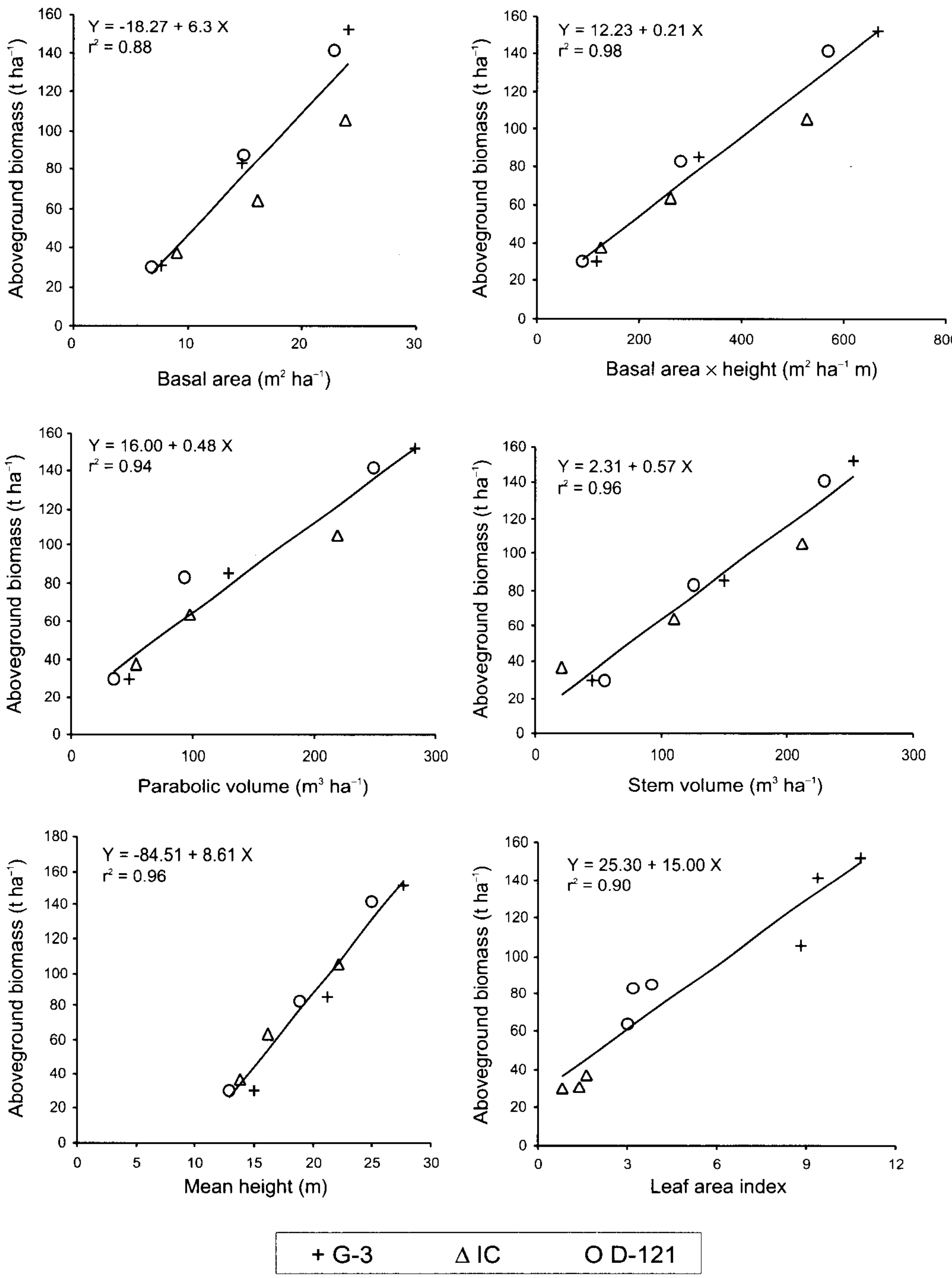

Figure 2 Regression lines and equations showing relationship between aboveground biomass with regard to increases in certain stem dimensions of poplar clones

Table 4 Total net primary production and per cent allocation of different components

Clone	Age (year)	Net primary production (NPP) (t $ha^{-1}y^{-1}$)	Percentage allocation of net primary production (%)				
			Bole	Bark	Branch	Foliage	Root
IC	4	5.9	21.7	3.9	11.8	49.1	13.5
D-121	4	17.3	42.7	8.1	10.0	27.6	11.6
G-3	4	16.6	42.0	6.0	12.3	26.1	14.6
IC	6	15.9	39.9	3.3	2.9	39.1	11.8
D-121	6	19.2	32.3	8.4	10.2	36.1	11.8
G-3	6	20.2	37.4	3.6	10.2	34.8	14.0
IC	10	13.9	18.1	1.7	9.9	56.7	13.6
D-121	9	22.7	28.4	4.1	10.0	43.6	13.9
G-3	8	21.4	19.4	1.9	10.3	54.1	14.3

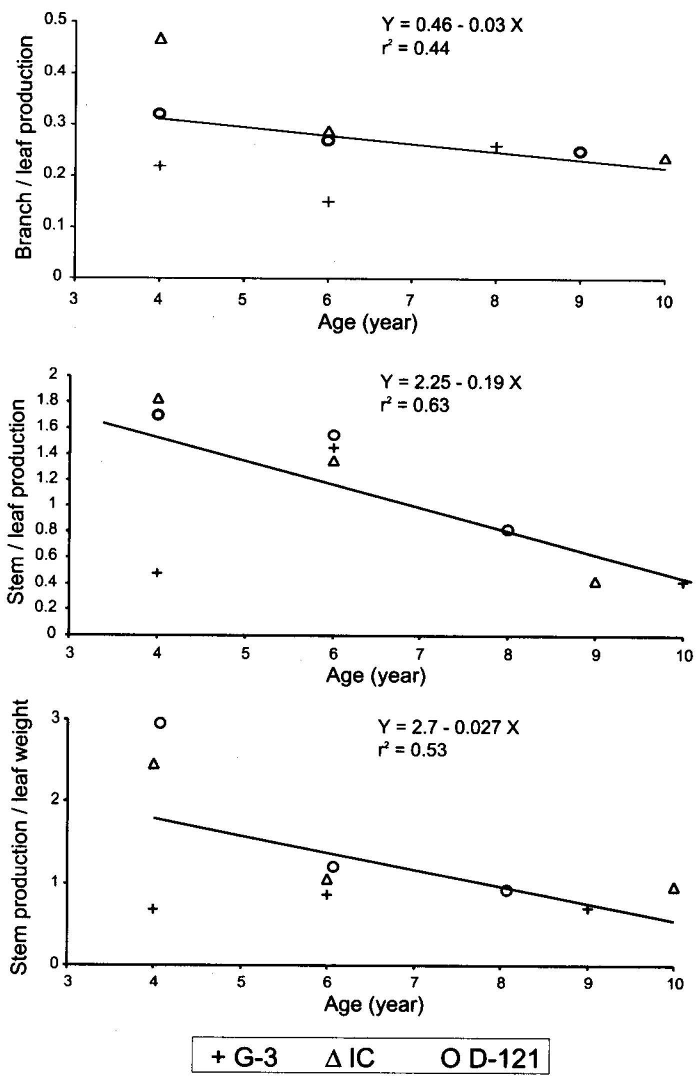

Figure 3 Regression lines and equations showing relationship between production of different components and different age group of three poplar clones

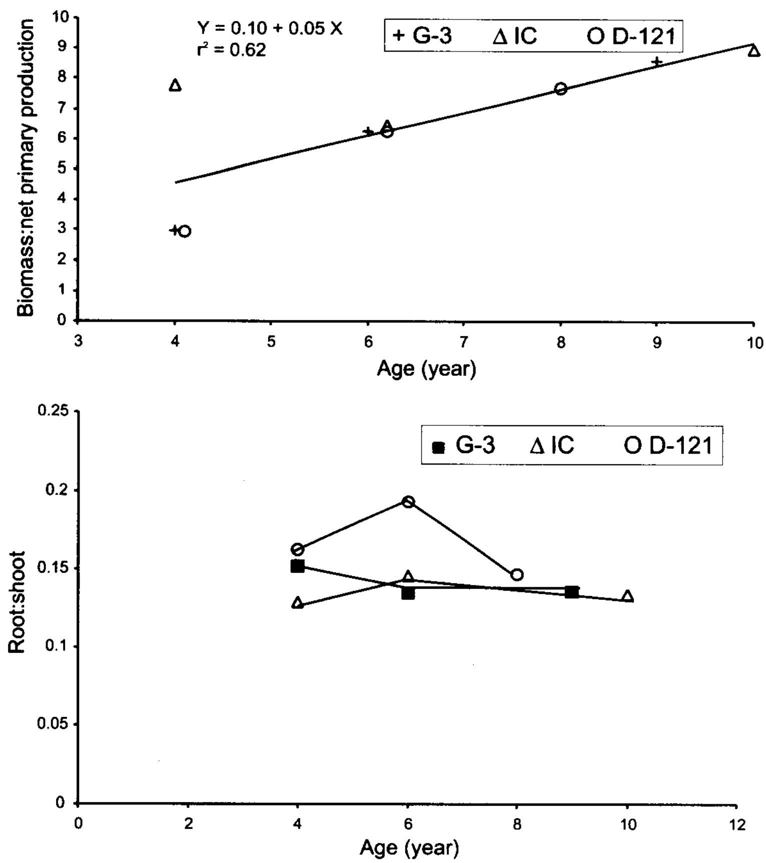

Figure 4 Regression lines and equations showing relationship between accumulation ratio of component of three poplar clones and different age groups

Discussion

Density of plantations for different clones were comparable and ranged between 400–520 trees ha^{-1} across the clones of different ages. Tree height also showed an increasing trend for all clones. The height of trees for a given diameter class was greater for older trees than for younger trees of that class. With increase in age, trees of lower diameter classes were suppressed (due to lower height) and development of their crowns hampered. With increase in age, there was a steady decline in total number of stems per ha for all clones.

With increase in age, stand biomass of all clones showed an increasing trend but rates varied with age from one clone to another. In all the three clones, the stand biomass increased rapidly up to six years. Thereafter, IC showed the least increase in biomass. The range of total biomass for the mature cottonwood stands in this study (120–171 t ha^{-1}) is comparable with those of 16–20 years old *P. deltoides* (141–171 t ha^{-1}) and 40–45 years old *P. tremuloides* (167–171 t ha^{-1}) stands in the USA as reported by Shelton *et al.* 1982 and Alban *et al.* 1978 respectively. In the central Himalayan tarai, the total biomass value (127 t ha^{-1}) of eight-year-old *Eucalyptus* plantation (Bargali & Singh 1991) is lower than these studies. However, present estimates are greater than those of a 12-year-old plantation (69 t ha^{-1}) in Italy and of a 10-year-old plantation of *P. euramericana* (64 t ha^{-1}) in Canada as reported by Switzer *et al.* (1976) and Carlistle and Mathven (1979).

Greater root:shoot ratio for D-121 clones (Figure 4) indicated a more developed root system than IC and G-3 clones. This would enable D-121 clone to have better access to soil nutrients.

Photosynthesis is a function of foliar characteristics. It is apparent that mean leaf area decreased significantly with increase in stand age ($r = -0.941$, $p < 0.01$) and towards maturity, IC clones had smaller leaves than the other two clones of this study. Since individual leaf weight also decreased significantly ($r = 0.95$, $p < 0.01$) this showed that weight per leaf was partly area dependent. Average weight per leaf of the three clones was in order D-121 > G-3 > IC. This indicated that dry matter accumulation pattern varied at the intraclonal level.

The net primary production of mature cottonwood clones ranged from 14 to 23 t ha^{-1} $year^{-1}$. Clone D-121, having the highest yield in terms of productivity at maturity, had 6% greater net production than that of G-3 clone and about 65% from IC clone. Net primary production in mature stands of D-121 and G-3 clones closely agrees with estimates reported for eight-year-old *Eucalyptus* plantation (23 t ha^{-1} $year^{-1}$) and natural forests (22 t ha^{-1} $year^{-1}$) occurring in the region (Bargali & Singh 1991). Net production of sal new growth forest (19 t ha^{-1} $year^{-1}$) and other central forests (about 20 t ha^{-1} $year^{-1}$) in adjacent areas are also comparable (Singh & Singh 1987, Rana *et al.* 1988, 1989). Thus, it appears that despite a short rotation (8–10 years), poplar clones assume similar productive potential as attained by relatively undisturbed forests of adjacent area.

Compared with evergreen habit, the deciduous habit of trees (as in the case of poplars) is a drawback for dry matter production, inspite of higher photosynthetic efficiency of leaves. This is because low productivity can prevent trees from fully utilising climatically favourable periods. Tadaki (1966) observed that low productivity of deciduous broad-leaved forests is probably caused by their short leaf period and partly by their small LAI. From this study, it appeared that net primary production of cottonwood clones is directly proportional to leaf biomass of the stands at different stages of growth. Clones D-121 and G-3 retain leaves up to December (but start shedding leaves in November) and set buds early in the growing season in March (compared with leaf renewal by IC clone in April) (Singh 1989). Thus greater productivity in D-121 and G-3 clones is favoured by their long growth period than in IC clone. The phenological aspect concerning leaf period should be given due weight while selecting clone for afforestation programmes.

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