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GROWTH, LEAF GAS EXCHANGE AND PRODUCTION OF BIOMASS IN COPPICED AND POLLARDED AGROFORESTRY TREE SPECIES

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THAKUR, P. S. & SEHGAL, S. 2003. Growth, leaf gas exchange and production of biomass in coppiced and pollarded agroforestry tree species. Four coppicing or pollarding treatments (stems cut at heights of 0.5, 1.0, 1.5 and 2.0 m) were applied to four tree species, aged five years old, in an agroforestry plantation. We measured growth, leaf gas exchange characteristics and foliage and branchwood biomass in four important fuel and fodder agroforestry tree species, namely, *Grewia optiva, Celtis australis, Bauhinia variegata* and *Morus alba*. Out of the four species, *B. variegata* transpired the most followed by *M. alba,* then *C. australis* and *G. optiva.* For *G. optiva* and *M. alba,* transpiration was higher from plants pollarded at 1.5 or 2.0 m compared with plants pollarded at 1.0 m or coppiced at 0.5 m. Photosynthetic rate was highest in *M. alba* and lowest in *C. australis.* In *M. alba* and *G. optiva,* higher rates of photosynthesis were observed in trees pollarded at 1.5 and 2.0 m. Water-use efficiency was higher in *M. alba* and *G. optiva* than in *B. variegata* and *C. australis.* Maximum leaf size was observed in *B. variegata,* followed by *M. alba* and *G. optiva.* Cutting height did not affect leaf size significantly. For *M. alba* and *G. optiva,* LAI was highest at cutting heights of 1.5 and 2.0 m. Coppicing and pollarding significantly affected the production of foliage and branchwood biomass. Fodder and fuelwood production from agroforestry plantations would be maximised by planting *M. alba* or *G. optiva* and pollarding annually at a height of 2.0 m.

Key words: Leaf area index - light interception - photosynthetically active radiation - water-use efficiency - foliage - branchwood

THAKUR, P. S. & SEHGAL, S. 2003. Pertumbuhan, pertukaran gas daun dan pengeluaran biojisim dalam spesies pokok agroperhutanan yang dikopis serta dicantas. Empat rawatan kopis dan cantasan (batang ditebang pada ketinggian 0.5, 1.0, 1.5 dan 2.0 m) diuji terhadap empat spesies pokok yang berusia lima tahun di sebuah ladang agroperhutanan. Kami mengukur pertumbuhan, ciri pertukaran gas daun serta biojisim dedaun dan kayu dahan dalam empat spesies pokok agroperhutanan yang penting sebagai bahan api dan makanan binatang. Pokok yang terlibat ialah *Grewia optiva, Celtis australis, Bauhinia variegata* dan *Morus alba.* Daripada empat spesies ini, *B. variegata* mengalami transpirasi tertinggi diikuti *M. alba, C. australis* dan akhirnya *G. optiva.* Transpirasi lebih tinggi bagi *G. optiva* dan *M. alba* yang dicantas pada ketinggian 1.5 atau 2.0 m berbanding pokok yang dicantas pada 1.0 m atau dikopis pada 0.5 m. Kadar fotosintesis paling tinggi bagi *M. alba* dan paling rendah bagi *C. australis.* Kadar ini lebih tinggi bagi *M. alba* dan *G. optiva* yang dicantas pada 1.5 dan 2.0 m. Kecekapan penggunaan air (WUE) lebih tinggi bagi *M. alba* serta *G. optiva* berbanding *B. variegata* dan *C. australis.* Saiz daun maksimum dicerap bagi *B. variegata* diikuti *M. alba* dan *G. optiva.* Ketinggian tebangan tidak mempengaruhi saiz daun dengan bererti. Indeks luas daun (LAI) bagi *M. alba* dan *G. optiva* paling tinggi pada ketinggian tebangan 1.5 dan 2.0 m. Tebangan kopis dan cantasan mempengaruhi pengeluaran biojisim dedaun dan kayu dahan dengan bererti. Pengeluaran makanan binatang dan bahan api daripada ladang agroperhutanan dapat dimaksimumkan dengan menanam *M. alba* atau *G. optiva* yang dicantas setiap tahun pada ketinggian 2.0 m.

Introduction

Tree management such as coppicing and pollarding are conducted to obtain foliage and branchwood biomass for fuel and fodder. The impacts of such practices can sometimes have drastic implications, as the removal of aboveground material results in enormous decrease in photosynthesis activity and the plant may die. Rising livestock population and increasing demand of trees for fuel and fodder coupled with intensive deforestation have lead to fuel and fodder crisis. The existing landuse systems with separate allocation to agriculture and forestry seem inadequate to meet the demands for food, fodder and fuel. A viable option to overcome this problem appears to be agroforestry where multipurpose tree species are grown with agricultural crops on the farmland. However, tree management under such system becomes pertinent in order to minimise below and aboveground competition for critical resources (e.g. water, nutrient, light) between the components of the system. *Grewia optiva, Celtis australis, Bauhinia variegata* and *Morus alba* are important fuel and fodder tree species for subtropical and temperate regions of Indian Western Himalayas. Farmers grow these tree species on their farmland as tall trees and undertake complete lopping once a year during the winter season. The retention of big tree with oversize canopy not only reduces productivity of understorey crops but becomes less productive during the subsequent years. The effects of coppicing and pollarding on biomass production have been outlined by Basappa (1986), Dutt & Jamwal (1987), Heering (1995), Puri & Gargya (1995), El-Fadl (1997) and Singh *et al.* (1998). Certain physiological parameters with regard to size and structure of the canopy have also been studied earlier (Leverenz & Hinckley 1990, Wang *et al.* 1990, Sequeira & Gholz 1991, Jack & Long 1992, Law *et al.* 1992). However, only at very few places have attempts been made to understand the impacts of tree management on the performance and vigour of multipurpose tree species. A comprehensive account for selecting the right species and management technique to develop compatible and viable agroforestry combination is lacking. Therefore, this study was conducted with four agroforestry tree species with the objective of selecting the best species and tree management option for maximum biomass production.

Materials and methods

Plant material

Four multipurpose agroforestry tree species with contrasting coppicing abilities, namely, *G. optiva, M. alba* (both are excellent coppicers), *C. australis* and *B. variegata* (good coppicers) were used for the present investigation. Trees were planted in January 1991 (2666 stumps ha^{-1}) at a spacing of 1.5 m (plant to plant) × 2.5 m (row to row) in randomised block design in the experimental field belonging to the Department of Silviculture and Agroforestry. The field is located at 30° 52' N latitude and 77° 11' E longitude, 14 km east of Solan Town, India. Plants were allowed to grow under subtropical to subtemperate climate at an elevation of 1200 m asl, receiving an average annual rainfall of 1150 mm and average temperature varying between 29 and 32 °C in May and June and as low as 1°C in December.

One time coppicing (to 0.5 m) and pollarding (to 1.0, 1.5, 2.0 m) treatments were imposed on five-year-old plants of these four tree species (height between 2.8 and 3.6 m) in January 1996. A total of 64 trees of each species in randomised block design, distributed in four unreplicated plots (16 trees per treatment) were used for the purpose. Stump height was maintained at the coppiced and/or pollarded level by removing regrown shoots every year. Observations were made three years after imposing treatments.

Physiological measurement

Portable photosynthesis system CI-301 (CID Inc., USA) with open system was used to measure photosynthetic rates and transpiration. Four random trees of each species at each cutting height were selected wherein photosynthetic rates and transpiration of 20 leaves, selected from upper, middle and lower (outer and inner) canopy per treatment (coppicing/pollarding), were measured at monthly interval between 10.00 a.m. and 12.30 p.m. Recorded data were downloaded into the computer. Photosynthetic rate was expressed as average photosynthetic rate ($\mu mol\ m^{-2}\ s^{-1}$) for five months, i.e. May to August, whereas, transpiration ($mmol\ m^{-2}\ s^{-1}$) was computed as g $H_2O\ m^{-2}\ hour^{-1}$ on the basis of recorded data following Thakur and Kaur (2001) and Thakur and Singh (2002).

$$\text{Transpiration} = 18 \times (T \times 3600) \times LAI/1000$$

where

18 = molecular weight of H_2O,
$(T \times 3600)/1000$ = conversion of transpiration rate ($mmol\ m^{-2}\ s^{-1}$) to $mol\ m^{-2}\ hour^{-1}$, and
LAI = Leaf area index of tree species at concerned cutting height.

Water-use efficiency (WUE) was calculated on the basis of data recorded for photosynthesis and transpiration every month according to the formula by Thakur and Kaur (2001) and Thakur and Singh (2002).

$$\text{WUE} = \frac{\text{Number of molecules of } CO_2 \text{ fixed}}{\text{Number of molecules of } H_2O \text{ transpired}}$$

Photosynthetically-active radiation was measured between 11.00 a.m. and 12.30 p.m. with the help of PAR sensor attached to the photosynthesis system.

Three readings were taken per replication, of which one was in the open, away from the tree, and two readings were under the tree canopy. Light transmission ratio (LTR) was calculated using the following formula (Thakur & Kaur 2001, Thakur & Singh 2002):

$$\text{LTR} = \frac{\text{Solar radiation beneath canopy}}{\text{Solar radiation in the open}} \times 100$$

Each value is the mean of four replicates.

Morphological measurements

The leaf size per leaf was measured in September. Twenty leaves per replication (80 leaves per treatment per tree species) were randomly selected from upper, middle and lower portions of the canopy and leaf size was determined using CI-203 leaf area meter (CID Inc., USA).

Plant canopy analyser model LAI-2000 (LI-Cor Inc., USA) was used to compute leaf area index for each treatment combination by taking one above-canopy and four below-canopy readings. A 45° view cap was used to restrict the view of the sensor. Measurements were made in shade and there were four replicates per treatment per species.

The harvesting for foliage and branchwood biomass was done in October. The regrown coppiced and pollarded shoots were removed from the main stem and leaves separated from the branches. Their fresh weight were recorded immediately after cutting. Branchwood biomass was allowed to air dry for five days before weighing. The biomass of foliage and branchwood was expressed in kg tree^{-1} year^{-1} (fresh weight basis). Each value was the mean of three replications (four trees per replications per treatment per species).

Data were subjected to analysis of variance in randomised block design (Gomez & Gomez 1984).

Results

Physiological attributes

Average amount of water transpired at each cutting height is presented in Table 1. Statistically significant differences ($p = 0.05$) in transpiration between the species were noticed and the trend observed was *B. variegata* > *M. alba* > *C. australis* > *G. optiva*. In *G. optiva* the amount of water transpired increased with increasing cutting heights from 0.5 to 2.0 m. *Morus alba* pollarded at 1.5 and 2.0 m transpired significantly ($p = 0.05$) higher amounts of water than the other tree species.

Coppiced and pollarded plants of *G. optiva* and *M. alba* recorded substantially higher average photosynthetic rates compared with *C. australis* and *B. variegata* (Table 1). Photosynthetic rate was maximum in *M. alba* where values ranged between 12.33 and 16.45 μmol m^{-2} s^{-1}, with highest value at 2.0 m cutting height.

Photosynthesis also increased with cutting height in *G. optiva*. The slight difference in photosynthesis of *G. optiva* compared with *M. alba* was not statistically significant. Minimum average photosynthesis was observed in *C. australis* at all cutting heights and the values varied between 7.01 and 8.47 μmol $m^{-2} s^{-1}$. *Bauhinia variegata* recorded photosynthesis between 7.53 and 9.92 μmol $m^{-2} s^{-1}$. *Morus alba* and *G. optiva* showed significantly ($p = 0.05$) greater rates of photosynthesis than *C. australis* and *B. variegata*.

Grewia optiva and *M. alba* when cut at 0.5 and 1.0 m heights, recorded significantly higher WUE calculated on the basis of photosynthetic rate/transpiration rate as compared with that when cut at 1.5 and 2.0 m (Table 1). Lowest WUE was observed in *B. variegata*. Differences in WUE values between species as well as between cutting heights were statistically significantly ($p = 0.05$).

Irrespective of the cutting heights, LTR was lowest in *M. alba* followed by *G. optiva*, *B. variegata* and *C. australis* (Table 1). Values of LTR ranged between 8 and 9% in *M. alba* and from 10 and 11% in *G. optiva*.

Table 1 Variation in physiological attributes in response to coppicing and pollarding. (Data average of five months, i.e. May till September)

Trees species/ cutting height	Transpiration ($g\ H_2O\ m^{-2} h^{-1}$)	Photosynthesis (μmol $m^{-2} s^{-1}$)	WUE (Photosynthetic rate/transpiration rate)	LTR (%)
Grewia optiva				
0.5 m	53.47	12.24	0.0369	11
1.0 m	55.08	12.46	0.0421	10
1.5 m	72.65	13.96	0.0173	10
2.0 m	87.97	14.89	0.0121	10
Mean	67.29	13.38	0.0271	10
Celtis australis				
0.5 m	76.39	8.47	0.0087	12
1.0 m	97.69	7.06	0.0061	11
1.5 m	85.29	8.06	0.0072	13
2.0 m	83.24	7.01	0.0231	12
Mean	85.65	7.65	0.0112	12
Bauhinia variegata				
0.5 m	155.11	9.30	0.0065	11
1.0 m	188.60	7.53	0.0048	9
1.5 m	120.68	9.72	0.0058	11
2.0 m	114.03	9.23	0.0052	12
Mean	144.60	8.94	0.0055	11
Morus alba				
0.5 m	120.22	12.33	0.0242	9
1.0 m	100.41	12.77	0.0200	9
1.5 m	162.75	14.46	0.0092	9
2.0 m	149.00	16.45	0.0117	8
Mean	133.09	14.00	0.0369	9
$LSD_{0.05}$				
Species × height	4.11	1.84	0.0009	0.56

WUE = Water-use efficiency
LTR = Light transmission ratio

Morphological parameters

Significant interspecific variations in leaf size was observed but cutting heights did not have much effect (Figure 1a). Maximum leaf size was registered by *B. variegata* where values ranged between 71.66 and 94.10 cm^2 per leaf followed by *M. alba* with leaf size ranging between 62.02 and 77.52 cm^2. Pollarding at 1.5 m in *B. variegata* and 2.0 m in *M. alba* resulted in higher leaf size over the other cutting heights. Leaf size in *G. optiva* ranged between 49.03 and 54.30 cm^2 per leaf whereas the minimum leaf size was observed in *C. australis* (11.05 to 17.65 cm^2 per leaf). The differences in leaf size were statistically significant.

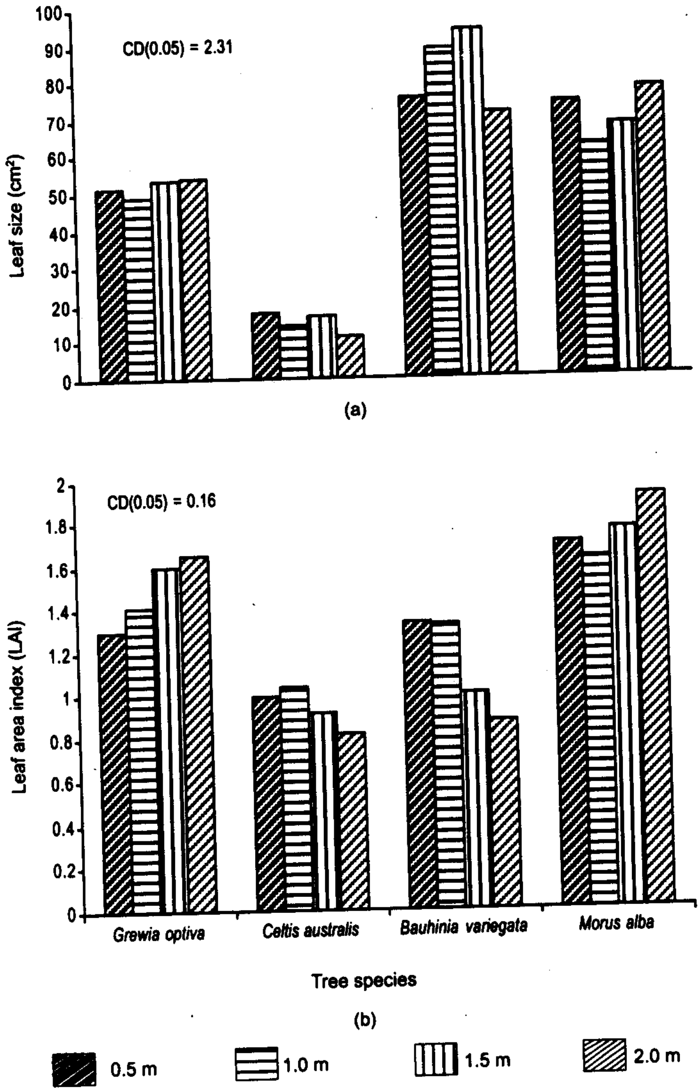

Figure 1 Effects of coppicing and pollarding on (a) leaf size and (b) leaf area index in four agroforestry tree species

Variations in LAI are shown in Figure 1(b). Irrespective of the cutting heights the maximum LAI was observed in *M. alba* and the minimum in *C. australis*. LAI was comparatively higher in pollarded plants of *G. optiva* and *M. alba* than in coppiced plants whereas in *C. australis* and *B. variegata*, the reverse was observed. LAI varied from 0.89 in pollarded *C. australis* and *B. variegata* to 1.92 in coppiced and pollarded *M. alba*. The differences were statistically significant.

Increased foliage and branchwood production with increasing pollarding heights was observed in *G. optiva* and *M. alba*, whereas *C. australis* and *B. variegata* produced higher biomass at 1.0 m cutting height (Figure 2). Maximum foliage biomass (1.40 kg tree^{-1} year^{-1}) was obtained for *M. alba* followed by *G. optiva* (1.13 kg tree^{-1} year^{-1}) at 2.0 m cutting height. For *C. australis* and *B. variegata*, the maximum foliage biomass (0.34 and 0.77 kg tree^{-1} year^{-1} respectively) was obtained at 1.0 m cutting height, whereas the minimum (0.18 and 0.45 kg tree^{-1} year^{-1} respectively) occurred at 2.0 m cutting height.

Likewise branchwood biomass production increased with increasing cutting heights particularly in *G. optiva* and *M. alba* (Figure 2(b)). *Morus alba* recorded maximum branchwood biomass (3.14 kg tree^{-1} year^{-1}). Branchwood biomass in *C. australis* and *B. variegata* was highest at 1.0 m compared with the rest of the cutting heights. The higher foliage and branchwood biomass production in *M. alba* and *G. optiva* over *B. variegata* and *C. australis* were statistically significant ($p = 0.05$). Results on the extrapolation of the above data to per hectare basis indicated that *M alba* and *G. optiva* produced maximum biomass (12.1 and 8.9 t ha^{-1} year^{-1} respectively) if pollarded at 2.0 m while *C. australis* and *B. variegata* (2.8 and 5.1 t ha^{-1} year^{-1} respectively) at 1.0 m cutting height.

Discussion

The extent of growth and biomass production under any situation and/or treatment is not only the result of cumulative effect of all vital processes in the current year, but also reflect the sharing and utilisation of various resources during the preceding years (Thakur 2000). In the present investigation, coppicing and pollarding, in addition to significantly affecting foliage and branchwood biomass production, were found to modify physiological parameters and utilisation of resources. Pollarding at 1.5 and 2.0 m heights was more effective in *G. optiva* and *M. alba*; significantly higher production of foliage and branchwood was observed. Therefore, 1.5 and 2.0 m are suitable cutting heights for any multipurpose tree species to be integrated as agroforestry tree on farmland as these heights do not affect understorey crops to a great extent. Production of significantly higher biomass in pollarded and coppiced plants of *G. optiva* and *M. alba* compared with *C. australis* and *B. variegata* appeared to be the result of higher photosynthetic rate and WUE besides intrinsic physiological ability of the individual tree species to tolerate coppicing and pollarding. The tree species with comparatively higher LAI at all the four cutting heights, namely, *M. alba* and *G. optiva* produced more biomass than *C. australis* and *B. variegata*. Leaf size and number account for total exposed photosynthetic surface besides substantial contribution to foliage biomass.

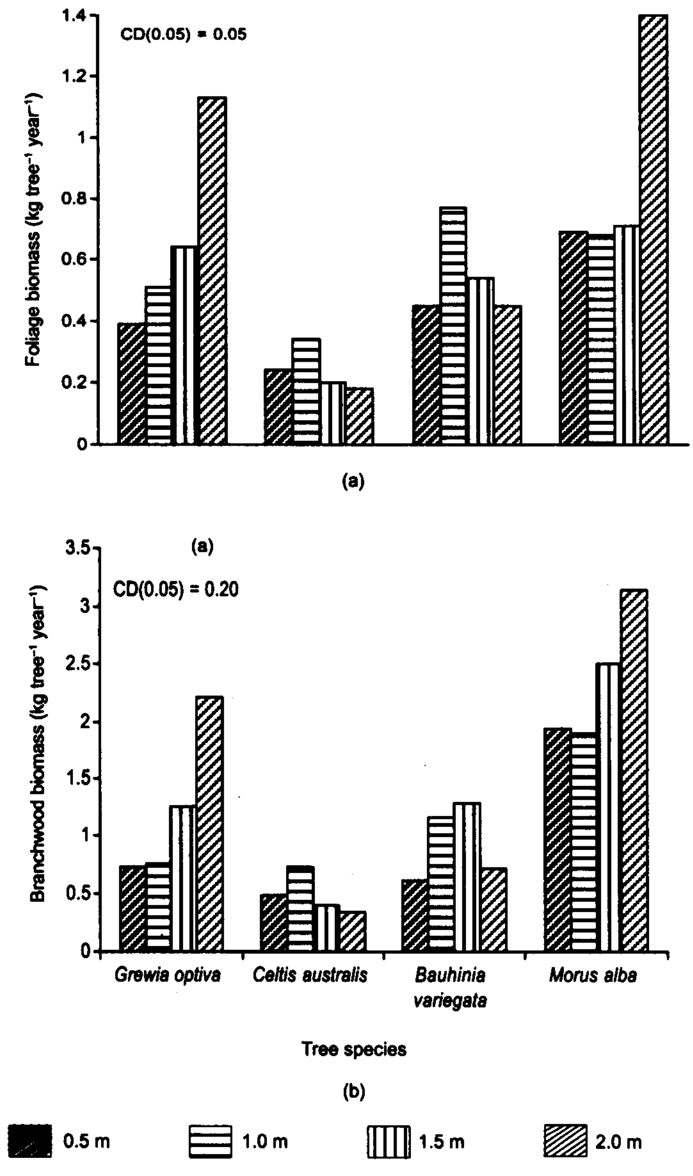

Figure 2 Effects of coppicing and pollarding on (a) foliage and (b) branchwood biomass in four agroforestry tree species

Higher transpiration potentially allows greater carbon assimilation, but may lead to development of water deficit when transpiration exceeds water availability. The higher amount of stored carbohydrates (higher photosynthetic rates) in the stump at pollarding heights may have been the reason for higher biomass production. The higher amount of water transpired from pollarded plants of *G. optiva* and *M. alba* can be ascribed to their better developed root networks fully capable of maintaining internal water status in canopies up to 2.0 m cutting height. In another study by Thakur and Sehgal (2000), coppiced and pollarded plants of *G. optiva* and *M. alba* were found to have better root growth compared with *C. australis* and *B. variegata*. It is not certain why *G. optiva* and *M. alba* cut at lower heights (0.5 and 1.0 m) have higher WUE compared with pollarding at 1.5 and 2.0 m, but the difference in transpiration at lower and higher heights may have substantially affected the WUE.

On the basis of the present study for maximum foliage and fuelwood production in this area, we, therefore, recommend cutting heights for *M. alba* and *G. optiva* at 2.0 m and *C. australis* and *B. variegata* at 1.0 m.

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