INFLUENCE OF COPPICING AND POLLARDING ON WATER USE EFFICIENCY, LIGHT TRANSMISSION AND ROOT CHARACTERISTICS IN AGROFORESTRY TREE SPECIES

Thesis

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Affectionately
dedicated
to
my
Grandparents

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CERTIFICATE-I

This is to certify that the thesis entitled **"Influence of coppicing and pollarding on water use efficiency, light transmission and root characteristics in agroforestry tree species"**, submitted in partial fulfilment of the requirements for the award of degree of **MASTER OF SCIENCE** in **AGROFORESTRY** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan (H.P.) is a bonafide research work carried out by **Mr. Sandeep Sehgal (F-96-8-M)** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of investigations have been fully acknowledged.

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CERTIFICATE-II

This is to certify that the thesis entitled **"Influence of coppicing and pollarding on water use efficiency, light transmission and root characteristics in agroforestry tree species"** submitted by **Mr. Sandeep Sehgal (F-96-8-M)** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan (HP), in partial fulfilment of the requirements for the award of degree of **MASTER OF SCIENCE** in **AGROFORESTRY** has been approved by the Student's Advisory Committee after an oral examination of the same in collaboration with the external examiner.

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CONTENTS

Chapter	Title	Page(s)
1.	INTRODUCTION	1 - 3
2.	REVIEW OF LITERATURE	4 - 13
3.	MATERIALS AND METHODS	14- 24
4.	EXPERIMENTAL RESULTS	25- 64
5.	DISCUSSION	65- 79
6.	SUMMARY AND CONCLUSIONS	80- 84
	BIBLIOGRAPHY	(i) - (viii)
	APPENDIX	I

LIST OF TABLES

Table	*Title*	*Page(s)*
1.	Monthly variation in transpiration rate (m mol $m^{-2} s^{-1}$) in four coppiced and pollarded agroforestry tree species	32
2.	Monthly variation in total amount of water transpired (g H_2O $tree^{-1} hr^{-1}$) in four coppiced and pollarded agroforestry tree species	34
3.	Monthly variation in stomatal conductance (m mol $m^{-2} s^{-1}$) in four coppiced and pollarded agroforestry tree species	37
4.	Monthly variation in photosynthetic rate (μ mol $m^{-2} s^{-1}$) in four coppiced and pollarded agroforestry tree species	40
5.	Monthly variation in light transmission ratio (%) in four coppiced and pollarded agroforestry tree species	43
6.	Difference in above and beneath canopy air temperature (°C) at monthly intervals in four coppiced and pollarded agroforestry tree species	46
7.	Monthly variation in water use efficiency (WUE) in four coppiced and pollarded agroforestry tree species	49
8.	Monthly variation in soil moisture (%) at two depths in four coppiced and pollarded agroforestry tree species	51
9.	Monthly variation in leaf area index (LAI) at different cutting heights in four agroforestry tree species	58
10.	Effect of coppicing and pollarding on total biomass (fresh weight basis) in t ha^{-1} in four agroforestry tree species	64

LIST OF FIGURES

Figure	*Title*	*Between page(s)*
1.	Effect of coppicing and pollarding on number of proximal roots in four agroforestry tree species	25-26
2.	Effect of coppicing and pollarding on number of lateral roots in four agroforestry tree species.	26-27
3.	Effect of coppicing and pollarding on diameter (mm) of proximal roots in four agroforestry tree species	27-28
4.	Effect of coppicing and pollarding on diameter (mm) of lateral roots in four agroforestry tree species	27-28
5.	Effect of coppicing and pollarding on root angles (degree) of proximal roots in four agroforestry tree species	28-29
6.	Effect of coppicing and pollarding on root distribution in four agroforestry tree species	29-30
7.	Effect of coppicing and pollarding on number of shoots stump^{-1} in four agroforestry tree species.	53-54
8.	Effect of coppicing and pollarding on number of nodes in longest shoot in four agroforestry tree species.	54-55
9.	Effect of coppicing and pollarding on shoot angle (degree) in four agroforestry tree species	55-56
10.	Effect of coppicing and pollarding on leaf area in four agroforestry tree species.	56-57
11.	Effect of coppicing and pollarding on foliage biomass in four agroforestry tree species.	60-61
12.	Effect of coppicing and pollarding on branchwood biomass in four agroforestry tree species.	61-62
13.	Effect of coppicing and pollarding on leaf to shoot ratio in four agroforestry tree species.	62-63
14.	Effect of coppicing and pollarding on total biomass in four agroforestry tree species.	63-64

INTRODUCTION

1

INTRODUCTION

Agroforestry is not new and has been practiced by farmers in many parts of the world. But in the recent years, there has been substantial increase in research and development in agroforestry. It is due to the recognition of the fact that agroforestry has the potential to contribute significantly to sustainable land use. Agroforestry is much more than simple amalgamation of farming and forestry. In principle, there could be as many ways to combine woody perennials with agricultural crops and/or livestock as there are sites in different parts of the world and farmers with different ways of working, resources and production goals.

Agroforestry requires new management practices and technologies which take into consideration the intricate interactions of the various components of the system. Trees are grown in close proximity to crops and pastures and as a result, a number of desired and/or undesired interactions take place between the tree and the crop. Trees and crops compete with each other for the critical resources like nutrients, light, moisture and space. So, before integrating trees with crops, it is very important to understand the nature as well as the management practices of the tree species. The reasons why certain trees and crops are compatible, while others are not, need to be underlined before short and long term strategies for improving the production potential of any agroforestry system can be worked out. Nevertheless, it is of paramount importance to further bring about the refinement in the technology package based on the past experiences and/or failures to make agroforestry more productive, viable, environmentally sound and widely acceptable option during 21st century.

Trees comprise of an integral part in any agroforestry system because trees are able to produce more fodder per unit area than agricultural crops. Trees are better adapted to drought conditions and can sustain biomass production even under severe water stress conditions. The leaf fodder production from trees offers another advantage as fuelwood is obtained as by-product when the trees are lopped. This helps to meet the energy requirements of the rural population. This is especially true in hills, where timber production is of minor importance. The products most required by local communities are fuelwood and foliage for fodder, bedding material and fertilizer which are mostly obtained by tree managing systems involving coppicing, lopping and pollarding (Mohns and Thompson, 1984). Nevertheless, the choice of species has to be careful and need based otherwise many problems can arise. These include increased erosion, high soil moisture removal from the soil, adverse chemical and biological effects and the problems caused to other species due to shading. In order to overcome these adverse effects, tree management becomes inevitable. The aim of the management practices is to manipulate the currently existing stands. Trees react to these manipulations according to their inbuilt physiological characteristics. The tree management practices have a direct bearing on the performance and vigour of the tree and are controlled by various vital processes like the source - sink relationship, reallocation of photosynthates, water use efficiency etc. Management of trees plays an important role and results in the overall yield advantage of agroforestry system by modifying the intensity of temporal and spatial competition with the agricultural crops.

The major management options for manipulating trees in agroforestry are based on the alteration of light (radiation) profile and moisture distribution. This is, especially true when trees grow large as in upper storey in the taungya system or homegardens or when they are scattered in cropland or planted on boundaries. There is also competition for light between hedgerows of smaller trees and crops before pruning is done. If this competition is compounded by competition for water or nutrients, trees will have deleterious effects on the arable crops.

The options for managing the trees are numerous, but the time, intensity and their effects need to be studied carefully because these can result in the success or failure of any agroforestry system. The impacts of such practices can sometimes have drastic implications, as the removal of upper ground parts result in enormous decrease in photosynthesis and the plant may die. In addition, the management of trees have direct bearing on the root characteristics which in turn regulates the above ground interactions for various resources. The reliable information on the influence of coppicing and pollarding in agroforestry trees with regard to various aspects related to vigour and biomass productivity is lacking. Therefore, the present study was conducted with four agroforestry tree species i.e. *Grewia optiva*, *Celtis australis*, *Bauhinia variegata* and *Morus* M-5 to test the hypothesis, if the management of these tree species influences vigour, biomass production, root architecture and resource capturing under rainfed conditions.

Objectives

i) To study coppicing and pollarding effects on growth parameters and biomass productivity of agroforestry tree species

ii) To study coppicing and pollarding effects on root characteristics

iii) To study coppicing and pollarding effects on water use efficiency, light transmission, photosynthesis and water relations.

REVIEW OF LITERATURE

2

REVIEW OF LITERATURE

The literature on multipurpose tree species with regard to their ability for resource capturing, growth and biomass production and the economics of managed and unmanaged agroforestry systems has been reviewed under the following heads:

2.1 Resource capturing by trees and the effect of management

2.2 Biomass production and management of trees

2.1 Resource capturing by trees and the effect of management

Productivity in plants can be viewed as a system of conversion of solar energy into chemical form of energy that can be transported and stored. This conversion occurs through the reaction known as photosynthesis. Forest productivity has been related to canopy light interception (Anderson, 1970; Jarvis and Leverenz, 1983). Numerous investigations have demonstrated a strong linear relationship between the intercepted photosynthetically active radiations (PAR) and above ground dry matter production (Monteith, 1977; Linder, 1985; Cannell *et al.*, 1987; Grace *et al.*, 1987; Dalla-Tea and Jokela, 1991). Research conducted over a range of environments and species has laid stress on the studies determining the relationships between forest production, light interception and organization of foliage and shoots within the crowns and canopies (Carter and Smith, 1985; Kellomaki *et al.*, 1985; Cannell *et al.*, 1987, Linder *et al.*, 1987; Smith and Long, 1989; Leverenz and Hinckley, 1990; Whitehead *et al.*, 1990; Jack and Long, 1992 and Law *et al.*, 1992).

Light directly influences tree growth by its intensity, quality as well as duration. Of these characteristics, light intensity is perhaps more important to the forester, because it is most readily manipulated. Light transmission through a tree canopy is dependent on the type of canopy; whether it is composed of hardwoods or conifers i.e., the manner in which the leaves are displayed, the density of leaves and the homogenity of the canopy. The yield of crops, whether tree or ground crops,is dependent on the radiant energy which they intercept. Low light intensity is one of the most important constraints for higher yield. Tanaka *et al.* (1964) reported lower dry matter accumulation and decreased photosynthesis in shaded crops. In order to estimate the potential productivity of crops, whether growing alone or in mixtures, it is first necessary to know, how much PAR is intercepted. Wang *et al.*(1990) in sitka spruce(*Picea sitchensis*) plantations studied four structural properties viz., crown shape, total area of leaves, spatial distribution of leaves within the tree crown, and leaf inclination angle in relation to radiation absorption, photosynthesis, transpiration and concluded that the total area of leaves and their spatial distribution within the tree crown were far more important than the other two properties for radiation absorption, photosynthesis and transpiration. El-Fadl (1997) investigated the silvicultural management, yield components and general suitability of *Prosopis juliflora* for use in agroforestry systems. The coppicing ability of *P. juliflora* was investigated and it was found that cutting to the height of 30 cm in December (winter season) produced the maximum average number of coppiced shoots per stump. Pruning effects were also studied in the same species, which indicated that untreated trees cast more shade than pruned *P. juliflora* trees.

Investigations on light interception and competition in agroforestry systems are generally scarce. An additional problem is the difficulty to compare the available results because of the differences in methodologies used in the investigations. However, some insights originate from few available studies, including some on intercropping of herbaceous species. Shading was found to be more important than below-ground competition in an intercropping study with pearlmillet and groundnut in India (Willey and Reddy, 1981). Similarly, Verinumbe and Okali (1985) showed that competition for light was a more critical factor than root competition for intercropped maize between teak trees (*Tectona grandis*) in Nigeria. In another study, Kang *et al.* (1981) attributed low yields from maize rows adjacent to *Leucaena leucocephala* hedgerows to shade. Neuman and Pietrowicz (1989), who studied competition in an agroforestry combination of *Grevillea robusta*, maize and beans reported that the shade cast by *Grevillea* appeared more important than other effects of the trees. Another study examining the resource sharing ability of multipurpose trees in an intercropping system, crop yield was found to be depressed by competition with the trees for light (Srinivasan *et al.*, 1990). Light penetration or transmission through tree crown influences the yield of the understorey crops. Hazra and Tripathi (1986) reported that *Leucaena leucocephala* and *Acacia tortalis* severely reduced the barseem yield as compared to *Hardwickia binnata*, which allowed 80 per cent of the light available in the open. Similarly, a study by Ramakrishna (1984) revealed that under a silvi-pastoral system, in a thirteen year old *Acacia tortalis* plantation, the total incident radiation just beneath the tree canopy was only 14 to 30 per cent of that in the open. A significantly higher decrease in incident light was also observed by Miah *et al.* (1995) under unpruned *Acacia auriculiformis* and *A. mangium* trees than the pruned trees. The decrease in incident light also reduced the rice and mung bean yields growing as the understorey crops. Bhatt *et al.* (1994) studied transpiration and stomatal conductance of grass species under *Leucaena* based silvi-pastoral system. The PAR transmission through 10 year old *Leucaena leucocephala* tree canopy was 20-25 per cent. Sequeira and Gholz (1991) proved that tree crown area is the most important crown related parameter determining the light penetration and tree growth. It was observed that light penetration decreased as crown area increased. Thus,in agroforestry, when trees are grown together with the agriculture crops, the understorey crops are bound to be affected by the decreased light penetration or increased shade.

Black and Kelliher (1989) advocated that solar radiation not only influences the production of understorey crops, but also the below canopy climate. Ramakrishna and Sastri (1977) observed a seven per cent increase in the mean daily relative humidity values beneath the tree canopy of seven year old *Acacia tortalis* during the active cropping season. In another study, carried out by Hazra and Patil (1986) on the micrometeorological conditions under a silvi-pastoral system, 36.8 to 37.8°C air temperature was recorded under the tree cover as compared to 38.4°C in the open. Similarly, the leaf temperature of the grasses under different tree covers were 31.5°C to 32.2°C compared to 33.8°C in the open. In areas where evaporation exceeds precipitation, soil water deficit develops and competition for water between trees and weeds or between trees and pasture or crops in agroforestry systems can be immediate and severe. This is particularly so when the trees are small and compete with species having high rooting densities. Water is often a limiting factor and unavoidable constraints, so water stress at any phenophase may be deleterious and result in intense competition between trees and crops. Reports are available investigating the deterimental effects of water deficits on various vital processes affecting biomass production (Kozlowski, 1985). Soil moisture levels also affect photosynthesis. Drought is believed to reduce photosynthesis by increased resistance to diffusion of CO_2 to chloroplasts and through reduced photosynthetic capacity. A study carried out by Broshilova *et al.* (1988) on young trees of ten species regarding seasonal dynamics of photosynthetic and transpiration rate with an infra-red gas analyzer observed that the photosynthetic rate was greatest in *Tilia tomentosa* and *Betula alba* and lowest in *Alnus glutinosa* and *Platanus intermedia*. In all the species, the photosynthetic rate was greatest at the start of growing season and decreased with decreasing soil moisture. Stomatal conductance plays a very important role in maintaining internal water status of an individual tree. Natarajan and Paliwal (1995) studied the potted seedling of 5 month old *Leucaena leucocephala* cv. K8. The seedlings were subjected to water stress by imposing six levels of irrigation incorporating drying periods of seven days. Rate of photosynthesis, transpiration and stomatal conductance decreased with increasing water stress. Thakur *et al.* (1998) have earlier reported that the establishment and growth potential of *Grewia optiva* seedlings at water stress sites can be improved significantly through preconditioning treatments.

Plants under stress produce less leaf area and therefore intercept less radiation and produce less stemwood. A number of authors have related morphological and phenological attributes such as leaf morphology, leaf area and allometric relationships in trees to the presence of interfering vegetation (Brand, 1986; Zutter *et al.*, 1986). In *Eucalyptus globulus*, productivity was related to leaf area, irrespective of whether changes in leaf area were caused by competition from weeds or defoliation by insects (Nambiar, 1990). Thus, leaf area may be one of the most sensitive and integrated measures of the degree of stress experienced by a tree, irrespective of whether the stress is abiotic (light, water or nutrient) biotic (defoliation by insects, disease), caused by deficiencies in the soil and/or competition.

Leaf area index on the other hand can be defined as the leaf area per unit of soil surface (Daughtry, 1990) and is a dimensionless value. Many physiological processes such as photosynthesis, transpiration and evapotranspiration are related to LAI (Mc Naughton and Jarvis, 1983; Pierce and Running, 1988). LAI is also highly correlated with productivity (Gholz, 1982). Gratini (1997) while studying the canopy structure, vertical radiation profile and photosynthetic function in a *Quercus ilex* evergreen forest observed that high LAI drastically modified the quality and quantity of solar radiation on the forest understorey/ ground vegetation. The spectral distribution of the radiation under the forest was highly deficient in blue and green wavelengths. The maximum absorption in these spectral bands was found in spring, when net photosynthetic rate was at its maximum and in summer when new leaves reached 90 per cent of their definitive structure. Clear differences in leaf size and specific leaf area were also observed.

Water use efficiency (WUE) refers to the amount of plant material produced per unit of water used (Kramer, 1983). Physiologists often define it as net CO_2 uptake per unit of transpiration. Czarnowski (1964) pointed out that inspite of the large literature available on transpiration from both single tree and canopies, there is still lack of information about the relationships between transpiration and growth parameters of different species. Field *et al.* (1983) estimated WUE for five California evergreen tree species and shrubs grown under controlled conditions.

They found that species common in xerophytic habitats were more efficient than those from mesophytic sites. Within species, differences in WUE have been reported among clones of Hevea (Samsuddin and Impens, 1978), Populus (Drew and Bazzaz, 1978; Blake *et al*, 1984). Most of these studies were performed with trees not grown under field conditions.

Steven *et al.* (1992) determined the water use efficiencies for sprouts of three broad-leaved species grown in a short rotation coppice system. During the 95 day study period, *Liquidambar styraciflua* and *Platanus occidentalis* produced an average of 132.2 g and 105.1 g woody biomass m^{-2} land area respectively, and transpired about 3.6 Kg water g^{-1} biomass produced. *Robinia pseudoacacia*, however, grew much less (14.0 g m^{2}) and transpired more than six times as much as 22.2 Kg water g^{-1} dry matter produced. Thus, transpiration is the dominant factor in plant water relations because it produces the energy gradient, which causes.the movement of water into and throughout the plants. Bhatt (1990) while studying the seasonal variation in light absorption and transpiration in *Prunus*, *Celtis* and *Grewia* to predict their suitability in agroforestry system, observed that the transpiration rate was highest in *Prunus cerasoides* but almost equal in *Celtis australis* and *Grewia oppositifolia*. The rate of transpiration increased with increasing air temperature and light intensity in the summer months in all the three species. Similar results were also reported by Haseba *et al.* (1967) in *Citrus* leaves. Dunin and Mackay (1982) reported WUE's of 1.0 Kg m^{-3} in *Eucalyptus* forests and 2.5 Kg m^{-3} in coniferous forests. The movement of water from the soil to the above ground parts of the tree occurs through roots. Thus, the roots of trees are obviously of fundamental importance in tree growth and development. Not do they only provide mechanical fastening to maintain the tree's upright structure, but nevertheless are essential for water uptake and mineral absorption per se. In fact, the health and vigour of root systems are so fundamental to the health and vigour of the tree as a whole that, ideally, silvicultural treatments should be equally based on root as well as crown characteristics. Unfortunately, relatively little is known regarding root systems because of the inherent difficulties encountered in generating adequate and reliable information, especially under agroforestry systems.

Farmers often suspect that trees in agroforestry systems will compete strongly with the crops for nutrients and water. The effective root systems of woody perennials tend to be deeper than non-woody perennials, with annual crop components having the shallowest root system (Buck, 1986). Reports on tree root distribution, especially those suitable for agroforestry are scanty. Jonson *et al.* (1988) studied the vertical distribution of fine roots of five species and maize. The vertical distribution of fine roots (<2 mm) in diameter of five tree species in pure two year old stands was compared to that of mature maize. They found that *Cassia siamea, Eucalyptus tereticomis, Leucaena leucocephala* and *Prosopis chilensis* had a rooting pattern similar to that of maize, i.e., a slow decline in fine root mass from 0-100 cm soil depth. *Eucalyptus camaldulensis* had its roots evenly distributed down to 100 cm. Dhyani *et al.* (1990) studied the root distribution of five multipurpose tree species viz. *Bauhinia purpurea, Grewia optiva, Eucalyptus tereticomis, Leucaena leucocephala* and *Ougenia oojeinensis* and found that major part of the root system was confined within 90-120 cm soil depth in case of *Bauhinia purpurea, Grewia optiva* and *Leucaena leucocephala,* whereas, *Eucalyptus tereticomis* and *Ougenia oojeinensis* strike their roots to deeper depths. Huck (1983) proposed that the distribution of root system through space and time is usually influenced by both genetic characters of the plants and localized soil conditions. Savill (1976) observed that root systems were typically wide and deep in freely draining soils and usually flat when developed in surface soil underlain by dense substrata. Soil moisture also influences the root systems to a large extent. Kozlowski (1949) observed superficial root systems in soil with high moisture level and in areas subjected to drought, deep root systems were found. A similar result was observed by Liffers and Rothwell (1987), who reported a positive correlation between root penetration and depth of water table. Rooting patterns of some agroforestry trees were studied by Toky and Bisht (1992) in an arid region of north-western India. They observed highest root density in the top 30 cm of the soil layer, which declined sharply with the increase of depth in *Morus alba, Melia azedarach* and *Eucalyptus tereticomis*. However, *Prosopis cineraria* and *Acacia catechu* showed a uniform root distribution through the soil column. As far as root architecture is concerned, the root branch angles are a key component of it, but almost no information is available on this, except for the general observation that the primary roots tend to be positively geotropic, secondaries diageotropies and further branches to be ageotropic (Fitter, 1987). Dickman *et al.* (1996) studied the effects of irrigation and coppicing on above ground growth, physiology and fine root dynamics of two field grown hybrid poplar clones established in May, 1984. Supplimental water in the form of drip irrigation was applied to half of the trees beginning the first growing season. All the trees were cut down in March, 1998 and the stumps allowed to coppice. Post-coppice rates of photosynthesis were not affected by irrigation in either clone. Both the clones also showed substantial fine root production in the spring, immediately following coppicing with no evidence of a shock induced dieback of roots.

2.2 Biomass production and management of trees

Managing trees in agroforestry systems is of utmost importance. Trees in agroforestry require individual management otherwise they may become too large or uneconomical. Trees in fodder lots or in hedgerow- intercropping systems are mostly lopped for producing fodder and mulch and also to reduce shade on adjacent crop. Muthna and Arora (1979) reported more grain yield of *Vigna mungo* and *Cyamopsis tetragonoloba* under lopped 8 years old *Holoptelia integrifolia* trees as compared to unlopped trees. Coppicing and pollarding are also integral part of tree management practices. Ssekabembe *et al.* (1997) studied the effect of hedgerow orientation on maize light interception and yield in black locust (*Robinia pseudoacacia*) alleys. It was observed that as compared with unpruned black locust hedges, pruning improved light availability to maize at ear height by 36 per cent and allowed 52 per cent more light to penetrate to the 15 cm height of the maize plants and increased maize yield. Management of trees in agroforestry system by coppicing has been studied by many workers (Bhimaya *et al.*, 1965 and Basappa, 1986). Dutt and Jamwal (1987) studied the effects of coppicing at different heights on wood production in *Leucaena leucocephala* and observed that when trees are coppiced at ground level, 25, 50, 75 and 100 cm, more sprouts per stump were produced at coppicing heights of 25 to 100 cm than at ground level.

The height, diameter and volume increments were significantly greater in coppicing heights of 50 to 100 cm.

The leaves and biomass production may be obtained by one or more management practices viz., coppicing, pollarding, lopping, pricking, pruning etc. For example, in case of *Morus alba*, all these practices are used (Singh, 1983; Gupta, 1993). Not all the species have the same power of coppicing. It varies from one species to another. Singh *et al.* (1998) studied 15 local multipurpose tree species for identifying maximum yield of fuelwood, fodder, pole timber etc. during 1988 to 1991. About 15 years old tree species were coppiced at 15 cm above the ground level at ICAR Research Complex in Imphal. Maximum number of branches and green fodder yield were recorded in *Grewia optiva*. Khybri *et al.* (1992) studied the tree biomass and tree crop interactions under rainfed conditions in Dehradoon valley for 13 years during 1977 to 1990 and reported that the average biomass production by the trees were 30.6 t ha^{-1} from *Eucalyptus*, 9.5 t ha^{-1} from *Grewia optiva* and 11.6 t ha^{-1} from *Morus alba*.

Puri and Gargya (1995) in another study regarding the establishment and management of the multipurpose trees like *Morus alba* and *Grewia optiva* at a degraded site in Uttar Pradesh with a plant population of 25,000 ha^{-1}, recorded a leaf fodder of 16.5 t ha^{-1} and 12.38 t ha^{-1} of fuelwood from *Morus* after 15 years of planting. *Grewia optiva* produced 45.35 t ha^{-1} leaf fodder and 26 t ha^{-1} fuelwood after 8 years. They reported pollarding as the best management practice for *Morus* trees to obtain more leaf fodder. Similar result was put forth by Singh *et al.*, 1988 while studying the biomass production of *Morus alba* under different management practices on degraded bouldery riverbed lands of Doon valley. They reported coppicing as the best management practice for better branchwood yield. An increase in leaf (dry matter) production was observed with the increase in cutting height from 75 to 150 cm by Heering (1995) while studying the effect of cutting height and frequency on forage, wood and seed production of six *Sesbania sesban*. Yadava (1997) while studying biomass productivity and nutrient content of *Morus alba* and *Leucaena leucocephala* based silvi-pastoral system also recorded an increase in both leaf and branchwood biomass with increase in pollarding hight from 1.0, 1.5 to 2.0 m. Not only leaf and branchwood biomass, but Athya *et al.* (1983) reported an increase in the leaf size as a result of coppicing, while studying the effects of pollarding and coppicing on the leaves of *Diospyros melanoxylon*.

From the proceeding review it is inferred that at various levels efforts have been done to understand the various aspects of growth and development of multipurpose tree species. References are available wherein effect of coppicing and pollarding on biomass production has been underlined. The responses of various multipurpose trees, in general, regarding resource capturing are also available. However, at very few places attempt has been made to understand the effect of tree management practices on the growth and vigour of multipurpose trees, especially when trees are grown along with the agricultural crops in an agroforestry system. Almost negligible information is available on the root architecture of multipurpose trees, especially when extensive tree management practices are undertaken. There are many vital areas wherein quantum of data is not adequate to hypothesise suitable tree crop management practices to develop suitable, viable and compatible agroforestry systems. Therefore it is indispensable and need of the day to understand extensive experimentation to have a deep insight into the various aspects of tree management practices and their implications on the productivity potential of agroforestry systems, especially under rainfed conditions.

MATERIALS AND METHODS

3

MATERIALS AND METHODS

The present study entitled, "Influence of coppicing and pollarding on water use efficiency, light transmission and root characteristics in agroforestry tree species" was conducted at the experimental field of the Department of Silviculture and Agroforestry, Nauni, Solan (H.P.) during the year 1998. The details about the experimental site, materials and methodology adopted for carrying out this investigation are given below:

3.1 Experimental site

3.1.1 Location

The experimental site is located at Nauni, at 30°51'N latitude and 76°11'E longitude, with an elevation of 1200 m a.m.s.l., 15 km south-east of Solan and represents the transitional zone between sub-tropical and sub-temperate region of the state.

3.1.2 Climate

The climate of the study area is sub-tropical to sub-temperate. The area receives an average annual rainfall of 1150 mm, most of which is received during the months of July and August. There is considerable variation in the temperature. May and June are the hottest months with temperature varying between 29-32°C whereas December and January are the coldest months recording temperature as low as 1°C. The details of meteorological information collected for the year 1998 are given in Appendix I.

3.2 Experimental methodology

The present study comprised of the following three experiments:

3.2.1 Experiment I

Studies on growth and biomass production in coppiced and pollarded agroforestry tree species.

3.2.2 Experiment II

Root characteristics of coppiced and pollarded agroforestry tree species.

3.2.3 Experiment III

Studies on the effect of coppicing and pollarding on attributes related to resource capturing.

3.3 Treatments

Four agroforestry tree species viz. *Grewia optiva, Celtis australis, Bauhinia variegata and Morus* M-5, were selected for the present investigation.

T_1 - *Grewia optiva*

T_2 - *Celtis australis*

T_3 - *Bauhinia variegata*

T_4 - *Morus alba* var. M-5

These four agroforestry tree species were subjected to coppicing and pollarding, consisting of following cutting heights :

H_1 - 0.5 m

H_2 - 1.0 m

H_3 - 1.5 m

H_4 - 2.0 m

The cutting height at 0.5 m in the entire text represents the coppicing treatment whereas the remaining cutting heights reffer to pollarding.

Various treatment combinations so obtained were:

T_1H_1	T_2H_1	T_3H_1	T_4H_1
T_1H_2	T_2H_2	T_3H_2	T_4H_2
T_1H_3	T_2H_3	T_3H_3	T_4H_3
T_1H_4	T_2H_4	T_3H_4	T_4H_4

3.3.1 Spacings

Plant to plant	- 1.5 m
Row to row	- 2.5 m
Geometry	- Line planting
Date of planting	- March 1991
Year of imposing coppicing and pollarding treatments	- 1996
Replications	- 4
Design	- R.B.D.

3.4 Observations recorded

3.4.1 Growth attributes

i) Shoot angle (orientation)
ii) Number of nodes and internodes
iii) Number of shoots (sprouts) per stump
iv) Green leaf and branchwood biomass
v) Leaf to shoot ratio
vi) Leaf area
vii) Leaf Area Index (LAI)

3.4.2 Root characteristics

i) Number of roots
ii) Diameter of proximal roots
iii) Root orientation
iv) Root distribution

3.4.3 Resource capturing

i) Water use efficiency (WUE)
ii) Light transmission
iii) Photosynthesis
iv) Transpirational losses
v) Stomatal conductance
vi) Variation in below canopy temperature
vii) Variation in soil moisture content

3.5 Observational procedure

3.5.1 Growth attributes

3.5.1.1 Shoot angle (orientation)

The shoot angle was determined for the coppiced and pollarded shoots arising from the tree trunk. For this purpose, the shoots were divided into two categories, one arising from near the cut end, forming the top portion whereas the rest arising from the stem and forming the middle and lower middle portion of the stem. The shoot angle was determined using trignometric ratios.

3.5.1.2 Number of nodes and internodes

The number of nodes and internodes for the longest shoot were counted in the month of September, 1998 in order to determine interspecific and interaspecific variations in the longest shoot.

3.5.1.3 Number of shoots (sprouts) per stump

The total number of sprouts per stump were counted. The observations were made in September, 1998 before harveting the biomass.

3.5.1.4 Green leaf and branchwood biomass

The harvesting for foliage and branchwood biomass was done in the first week of October, 1998. The regrown coppiced or pollarded shoots were removed from the main stem. The leaves were separated from the branches and their fresh weight was recorded. Similarly the fresh weight of branches without leaves was also recorded. The fresh weight has been expressed in kg tree^{-1} and t ha^{-1}.

3.5.1.5 Leaf to shoot ratio

This parameter was determined for all the four agroforestry tree species by estimating the leaf biomass and branchwood biomass by using the following formula :

$$\frac{\text{Leaf biomass}}{\text{Branchwood biomass}} \times 100$$

3.5.1.6 Leaf area

All the four agroforestry tree species at all the cutting heights were studied for variations in leaf area. The leaf area was measured during the month of September, 1998. Twenty leaves per replication were selected for this purpose. The leaves were randomly detached from different heights of the canopy and collected in the envelopes. These leaves were brought to the laboratory and the leaf area was determined using CI-203 Portable Leaf Area Meter. Each leaf was placed under the arm of leaf area meter and thereafter scanned to determine the leaf area digitally. Same procedure was repeated for the rest of the samples. Leaf area is expressed in cm^2.

3.5.1.7 Leaf area index (LAI)

The observations for LAI in all the four agroforestry tree species at all the four cutting heights were made every month begining from the month of May till September during 1998. The observations were made with the help of 2000 Canopy Analyzer. Before proceeding for taking the observations, proper caliberation of the instrument was done. LAI for each treatment combination was computed by taking one above canopy (A) and four below canopy (B) readings. The above canopy reading was taken by holding the instrument (sensor rod) parallel to the eyes and away from any shade causing object nearby. The bubble on the rod was adjusted by keeping the rod still. The button was pressed and a beep sound was heard. After the reading was complete, the beep sound was again heard. In all, four (B) readings were taken below the tree crown in all the four directions. A 45° view cap was used to restrict the view of the sensor. After five readings i.e., one above crown and four below crown, the instrument automatically computed the LAI and standard error thereby completing one file. One file per replication was computed. The instrument was taken to the other tree and the same procedure was followed for rest of the treatment combinations. The readings were stored in the instrument and after completing all the readings, they were either downloaded into the computer and then a print was taken out or noted down manually by viewing all the files using the specific commands. Measurements for LAI were made in shade before the sunset.

3.5.2 Root characteristics

The root studies were carried out in the month of January, 1998 when the growth of the trees had apparently ceased. The marked trees were selected for the root system pattern. The root system of the trees was exposed up to 30 cm depth by excavation. Proper tools were used for this purpose and utmost care was taken while excavating. No or minimum injuries were inflicted to the roots. While digging, the soil was being removed simultaneously so that underlying roots could become clearly visible. After completing the vertical and lateral excavation, the exposed roots were defined as proximal roots and lateral roots. All the proximals and laterals of the first order were counted. The distribution of the roots along the four directions was noted down depending upon their direction of penetration. To measure the diamèter of the proximal and lateral roots, a digital calliper was used. Lastly, the root angles of the proximals was measured indirectly. The root angles were calculated by using the trigonometric ratios ($\theta = \tan^{-1}$). The root angles were measured by using 2 scales, one, kept horizontal (i.e. perpendicular to the stem) and a perpendicular was dropped by using another scale onto the root. The perpendicular was dropped on the root up to the point it was straight. Further bending of the root was not taken into consideration. The horizontal scale was designated as base, and its distance from the tree trunk was measured. The length of the perpendicular was also measured. tan θ was now calculated by dividing perpendicular by base and taking its inverse tan value. Root angle is expressed in degree.

3.5.3 Studies on resource capturing

3.5.3.1 Photosynthesis

Measurements to underline the variations in photosynthetic rate within and between agroforestry tree species at different cutting heights were recorded on the marked trees from May to September in 1998. The observations were made every month with the help of CI-300 Portable Photosynthesis System. The battery operated system included a leaf chamber, incorporated with humidity, temperature and PAR sensors. Before taking the readings, the instrument battery was charged for five to six hours. The measurements for photosynthesis was made between 1000 to 1300 hours. The instrument was carried to the field and all the attachments were connected properly. The leaf chamber was connected to the sensor rod. PAR sensor was attached to the leaf chamber. Temperature sensor was also attached to the leaf chamber. The two way tube from the sensor rod was attached to IN_2 on the main body of the system. The U tube was attached to IN_1 and Out. Exhaust was left as such. The cable from the sensor rod was connected to the main body of the system. The system was then turned on. After warming up and calibration the instrument was programmed to record the required parameters. The system was now ready for measurements. The measurements were made on sunlit foliage. Leaves from each tree were randomly selected for measureing photosynthetic rate. Each time a single tree leaf was selected and then inserted into the leaf chamber which was opened to accomodate the leaf. After properly placing the leaf into the chamber, it was closed. 'Enter' was then pressed on the system, to start the measurement. A beep sound was heard everytime,'Enter' was pressed. To save the reading, "Mode" switch on the instrument was pressed. Thereafter, the leaf from the chamber was removed and replaced with a new leaf. This procedure was followed for recording the photosynthetic rate in the rest of the treatment combinations.

After the completion of readings in the field, the instrument was brought to the laboratory and connected to the computer with the downloading software RS232. The data from the Photosynthesis System was dumped into the computer and the print of the recorded data was taken out. The rate of photosynthesis is expressed as μ mol $m^{-2}s^{-1}$ and is the mean of four replications.

3.5.3.2 Transpiration

Transpiration rate of the leaves was determined for all the four agroforstry trees at all the cutting heights during the study period. Transpiration rate was measured with the help of CI-300 Portable Photosynthesis System. As in the case of photosynthesis, the leaves were inserted into the leaf chamber of the instrument one after the other in order to record transpiration rate. The recorded data was downloaded into the computer and the printout was taken. Transpiration rate has been expressed as m mol $m^{-2}s^{-1}$.

3.5.3.3 Transpiration (g H_2O tree^{-1} hr^{-1})

The amount of water transpired by an individual tree at a particular cutting height has also been determined and has been expressed as g H_2O tree^{-1} hr^{-1}. Each value is the mean of four replications. Here transpiration was recorded with the help of photosynthesis system, whereas, LAI was computed by canopy analyzer.

3.5.3.4 Stomatal conductance

Data was also collected with regard to leaf stomatal conductance for all the four agroforestry tree species at all the cutting heights during the study period. Stomatal conductance was measured with the help of a Portable Photosynthesis System (CI-300). Stomatal conductance is expressed as m mol m^{-2} s^{-1}. Each value is the mean of four replications.

3.5.3.5 Light transmission ratio (LTR)

Photosynthetically active radiations (PAR) was measured strictly on cloudless days between 1100 and 1230 hours. PAR readings were made every month. For this purpose, Portable Photosynthesis System CI-300 was used. This system included PAR sensor attached to the leaf chamber. For measuring PAR, the instrument was carried to the field, properly assembled, calibrated and programmed accordingly to estimate PAR. In all, three readings were taken per replication, out of which one reading was taken in the open, away from the tree and two readings under the tree canopy. This procedure was followed to determine PAR beneath the tree canopy of remaining tree species at all the cutting heights. After completing the observations, the instrument was brought to the laboratory and connected to a computer to download the data from the system. After transferring the data from the instrument to the computer, it was printed. PAR is expressed as μ mol $m^{-2}s^{-1}$. Light transmission ratio (LTR) was calculated from the PAR readings taken in the open and beneath canopy in the shade by using the following formula:

$$\text{LTR (\%)} = \frac{\text{Total solar radiations beneath canopy}}{\text{Total solar radiations in the open}} \times 100$$

3.5.3.6 Difference in above and below canopy air temperature

It was also desired to determine the difference in tempeature between above and beneath tree canopy for all the four agroforestry tree species at all the cutting heights. Temperature sensor attached to the leaf chamber of the Portable Photosynthesis System (CI-300) was used to determine the temperature in the open, and also below the tree crown. The temperature sensor attached to the leaf chamber was placed in the open to record the above canopy air temperature. Thereafter the sensor was placed below the tree canopy and air temperature at different places under the shade was recorded. The recorded data in the system was downloaded into the computer. The temperature difference above and beneath tree canopy was computed from the printed data for all the treatment combinations for all the months during the study period.

3.5.3.7 Water use efficiency (WUE)

Water use efficiency for each tree species at all the cutting heights was calculated monthly. It was done on the basis of the data recorded for photosynthesis and transpiration every month.

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

3.5.3.8 Soil moisture

The soil moisture content was determined gravimetrically. The samples were drawn at two depths up to one metre distance from the tree trunk. The depths being 0-15 cm and 16-30 cm, respectively.

An auger was used to draw the soil samples. It was driven into the ground up to the desired depth and the soil samples were taken out, which were then collected in the soil moisture boxes. These boxes were then marked and were transferred to the laboratory immediately. The fresh weight of the soil samples was determined and they were then kept in the oven for drying. They were dryed at 105°C to a constant weight. After removing them from the oven, their dry weight was recorded. The moisture content of each sample is expressed in per cent, calculated by using the following formula:

$$\text{Per cent moisture} = \frac{F_w - D_w}{F_w} \times 100$$

where,

F_w = Fresh weight of soil

D_w = Dry weight of soil

3.6 Statistical analysis

The entire data generated from the present investigation was put to statistical analysis in accordance with the procedure outlined by Gomez and Gomez (1984).

EXPERIMENTAL RESULTS

4

EXPERIMENTAL RESULTS

The results of the present investigation entitled, "Influence of coppicing and pollarding on water use efficiency, light transmission and root characteristics in agroforestry tree species", conducted during the year 1998 are described below :

4.1 Root characteristics

During the present investigation, it was desired to underline the impact of coppicing and pollarding treatments on the root parameters in four agroforestry tree species i.e. *Grewia optiva*, *Celtis australis*, *Bauhinia variegata* and *Morus* M-5. The results so obtained are described as under:

4.1.1 Proximal root number

Four coppiced and pollarded tree species were studied for variation in number of proximal roots. The data presented in figure 1 was recorded after three years of coppicing and pollarding treatments. It was observed that the interspecific and intraspecific variations in root number was non-significant. The proximal root number in *Grewia optiva* (T_1) was found to be maximum (14.00) at 1.5 m (H_3), whereas the minimum number (8.00) was found at 0.5 m (H_1) cutting height (Fig. 1).

In case of *Celtis australis* (T_2) the maximum number of roots (14.50) were observed at the cutting height of 0.5 m (H_1) followed by a decline in the number of proximal roots (10.00), (10.00) and (6.00) with the increase in cutting heights from

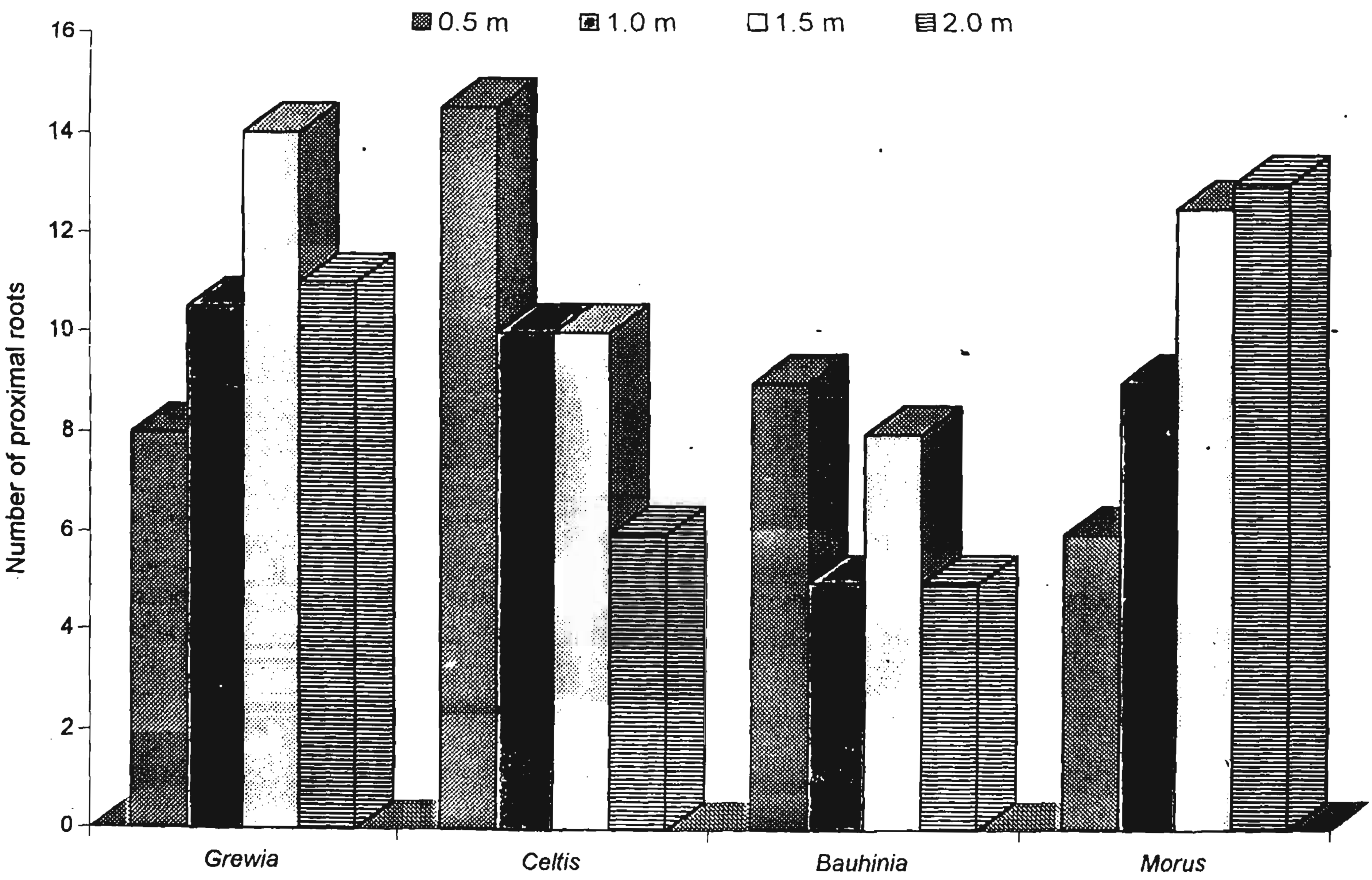

Fig. 1. Effect of coppicing and pollarding on number of proximal roots in four agroforestry tree species

1 m (H_2), 1.5 m (H_3) and 2.0 m (H_4), respectively (Fig. 1). The minimum number of roots were observed at 2.0 m cutting height.

An almost similar pattern was observed in case of *Bauhinia variegata* where maximum proximal roots (9.00) were recorded at 0.5 m (Fig. 1). The minimum number of roots (5.00) were recorded at both 1.0 (H_1) and 2.0 m (H_4) cutting heights, albeit comparatively higher (8.00) number of roots were recorded at 1.5 m (H_3) cutting height (Fig. 1).

In case of *Morus* M-5 (T_4) an increasing trend in the number of proximal roots was observed with increase in the cutting height. The number of proximal roots was lowest (6.00) at 0.5 m (H_1) which increased up to (13.00) at 2.0 m (H_4) cutting hieght. The root number at 1.0 m (H_2) and 1.5 m (H_3) cutting heights was 9.00 and 12.50, respectively (Fig. 1).

4.1.2 Lateral root number

The number of lateral roots arising from the proximal roots were significantly different in different agroforestry trees at coppiced and pollarded heights. It is clear from figure 2 that in *Grewia optiva* (T_1) the maximum number of lateral roots (30.00) originated at 1.5 m (H_3). It was followed by at 2.0 m (H_4) which recorded 28.00 number of roots (Fig. 2). Root number was comparatively lower at 1.0 m (H_2) cutting height (26.50) and the minimum number of lateral roots (22.50) was recorded at 0.5 m (H_1) cutting height (Fig. 2).

In case of *Celtis australis* (T_2), no definite pattern in lateral root number was observed in relation to different cutting heights, although the maximum number of lateral roots (38.00) was recorded at 2.0 m (H_4) cutting height. This was followed by 1.0 m (H_2) where root number was found to be 32.50. At H_3 (1.5 m) cutting height the number of lateral roots was 23.50 whereas the minimum number of lateral roots (21.00) was recorded at 0.5 m (Fig. 2).

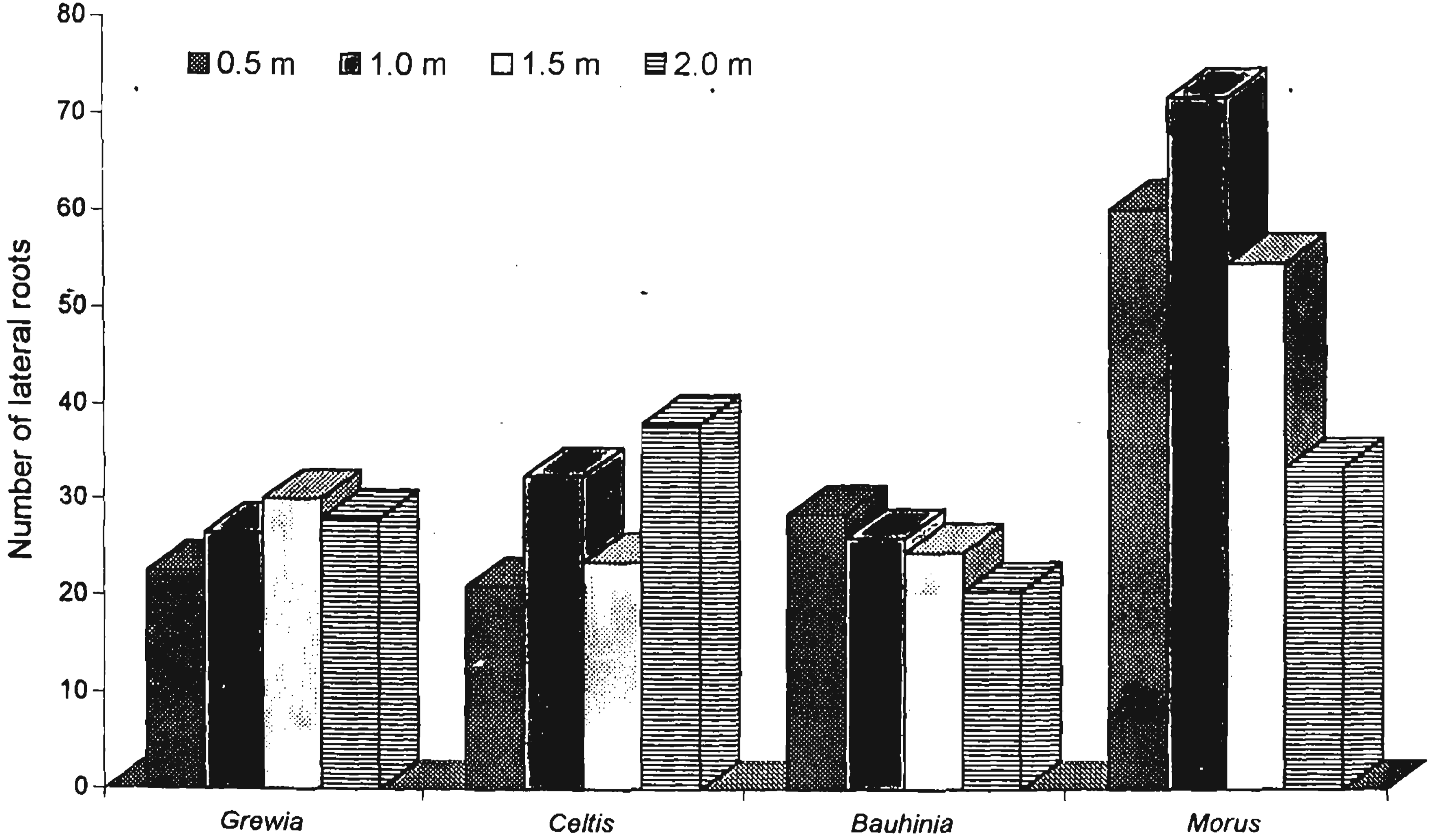

Fig. 2. Effect of coppicing and pollarding on number of lateral roots in four agroforestry tree species. CD(0.05) level to compare interaction between tree species and cutting heights (15.48)

Bauhinia variegata (T_3) recorded the maximum number of lateral roots (28.50) at 0.5 m (H_1) cutting height, which gradually decreased to 26.00 and 24.50 at cutting heights of 1.0 m (H_2) and 1.5 m (H_3), respectively. Minimum number of lateral roots (20.50) was recorded at 2.0 m (Fig. 2).

Morus M-5 (T_4) under similar growing conditions and similar coppicing and pollarding treatments was found to regenerate significantly higher number of total lateral roots as compared to *G. optiva, C. australis and B. variegata* (Fig. 2). Maximum number of lateral roots (71.50) was observed at 1.0 m (H_2) cutting height whereas 2.0 m (H_4) cutting height recorded the minimum (33.50) lateral roots. At 0.5 m (H_1) and 1.5 m (H_3) cutting heights the number of lateral roots were 60.00 and 54.50, respectively (Fig. 2).

4.1.3 Diameter of proximal roots

Significant interspecific differences were observed with respect to variation in diameter of the proximal roots in four agroforestry tree species. It is evident that in *Grewia optiva* (T_1) the diameter of proximal roots increased with the increase in cutting height (Fig. 3). For example, the diameter of proximal roots at 0.5 m (H_1) was found to be 9.98 mm which increased to 18.44 mm up to 2.0 m (H_4) cutting height (Fig. 3). The diameter of proximal roots at the remaining cutting heights i.e., 1.0 m (H_2) and 1.5 m (H_3) was 17.91 and 18.10 mm, respectively.

Like *G. optiva,* in *Celtis australis* (T_2) also a similar trend was observed where with the increase in cutting height, the diameter of proximal roots increased. In C. australis (T_2) the values for the diameter of the proximal roots ranged between 7.20 mm to 25.37 mm. In this case, H_4 (2.0 m) recorded the maximum diameter (25.37 mm) whereas H_1 (0.5 m) recorded the minimum diameter (7.20 mm). However, the cutting heights i.e., H_2 (1.0 m) and H_3 (1.5 m) were at par with each other with diameter values of 13.00 mm and 13.80 mm, respectively (Fig. 3).

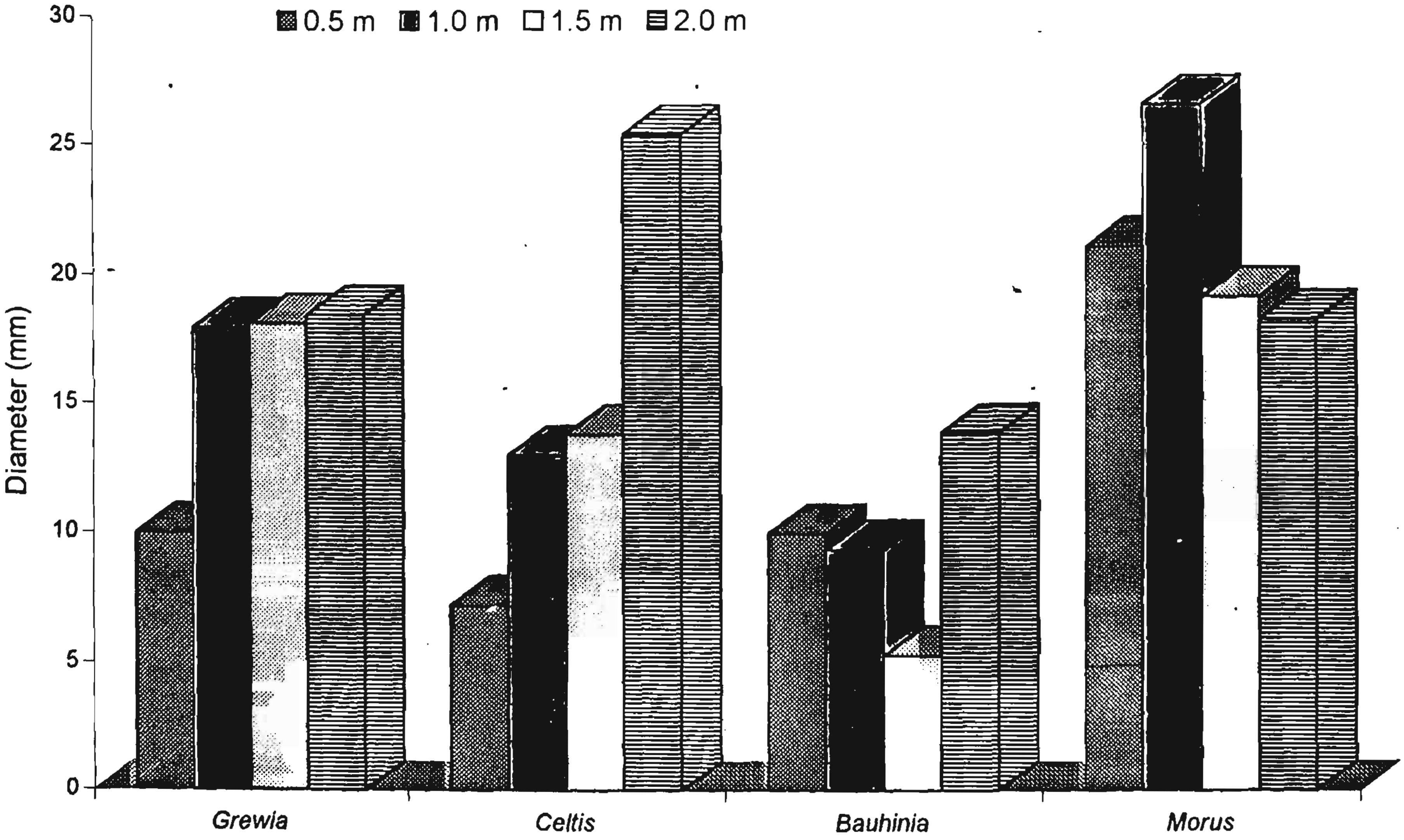

Fig. 3. Effect of coppicing and pollarding on diameter (mm) of proximal roots in four agroforestry tree species

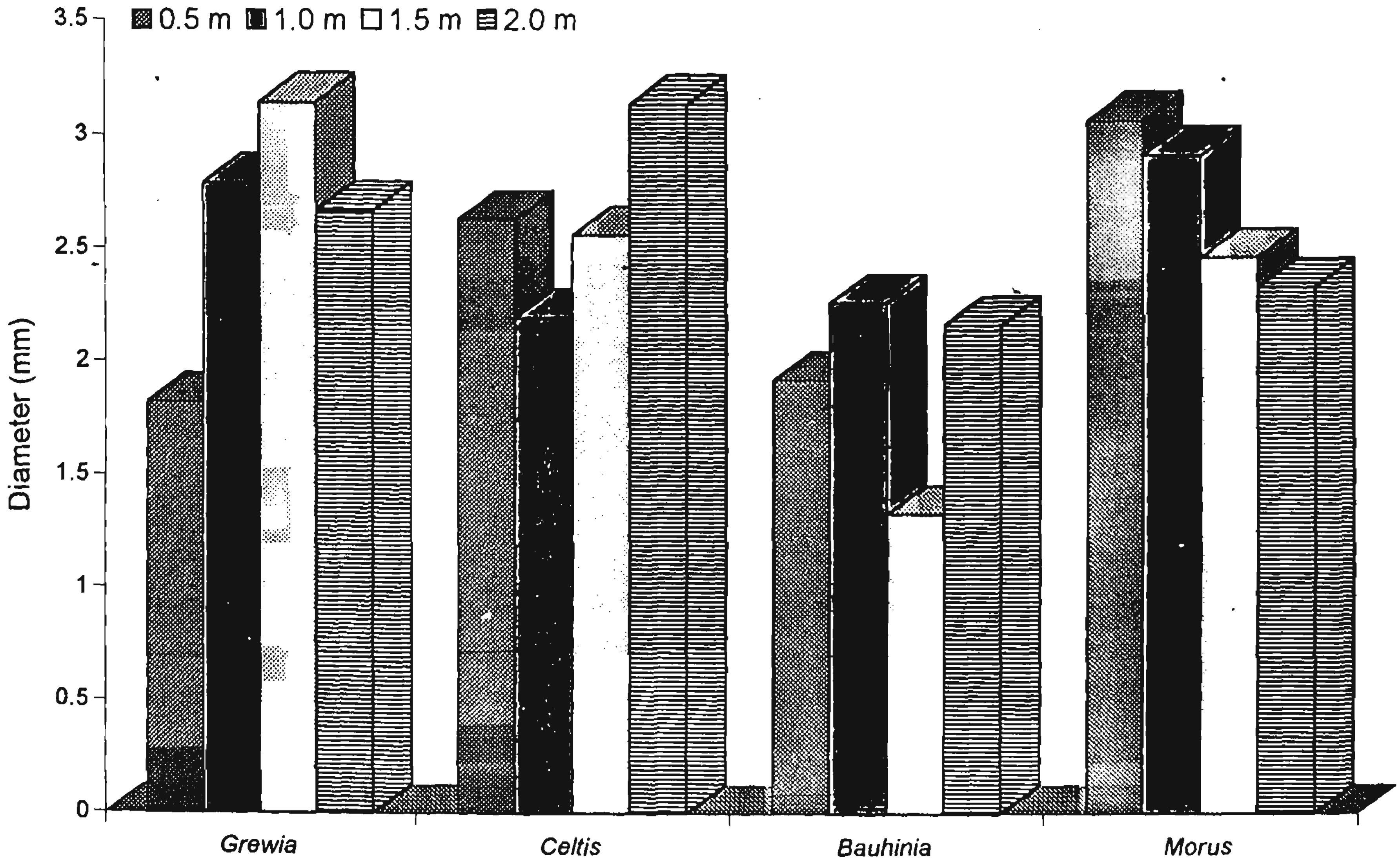

Fig. 4. Effect of coppicing and pollarding on diameter (mm) of lateral roots in four agroforestry tree species

In case of *Bauhinia variegata* (T_3) the maximum diameter of proximal roots (13.86 mm) was recorded at 2.0 m (H_4) and the minimum (5.25 mm) at 1.5 m (H_3). The cutting heights H_1 (0.5 m) and H_2 (1.0 m) were at par with each other having values of 9.97 mm and 9.35 mm, respectively (Fig. 3).

Morus M-5 (T_4) produced the proximal roots with maximum diameter (26.51 mm) at H_2 (1.0 m) pollarding height. The diameter of proximals at the remaining cutting heights was 21.03 mm at H_1 (0.5 m) and 19.13 mm at H_3 (1.5 m). The minimum diameter of proximal roots was recorded at H_4 (2.0 m) cutting height, where the diameter was 18.24 mm (Fig. 3).

The diameter of proximal roots during the present study was found to be statistically significant between all the four agroforestry tree species at all the cutting heights. However, the interaction (T x H) was non-significant (Fig. 3).

4.1.4 Diameter of lateral roots

The diameter of the lateral roots did not show much variation as a result of coppicing and pollarding in four agroforestry tree species. In *Grewia optiva* (T_1) maximum diameter (3.14 m) was observed at 1.5 m (H_3) cutting height whereas in *Celtis austrlis* (T_2) maximum diameter (3.13 mm) was observed at 2.0 m (H_4) cutting height. Maximum diameter of lateral roots in *Bauhinia variegata* (T_3) was observed at 1.0 m (H_2) where the value was 2.26 mm whereas in *Morus* M-5 maximum diameter (3.06 mm) of lateral roots was recorded at 0.5 m (H_1) cutting height (Fig. 4).

4.1.5 Root angle/orientation

Root orientation is another important indicator of root networking which plays a decisive role in resource sharing, especially under agroforestry system. So the information with regard to this parameter was collected during this study for all

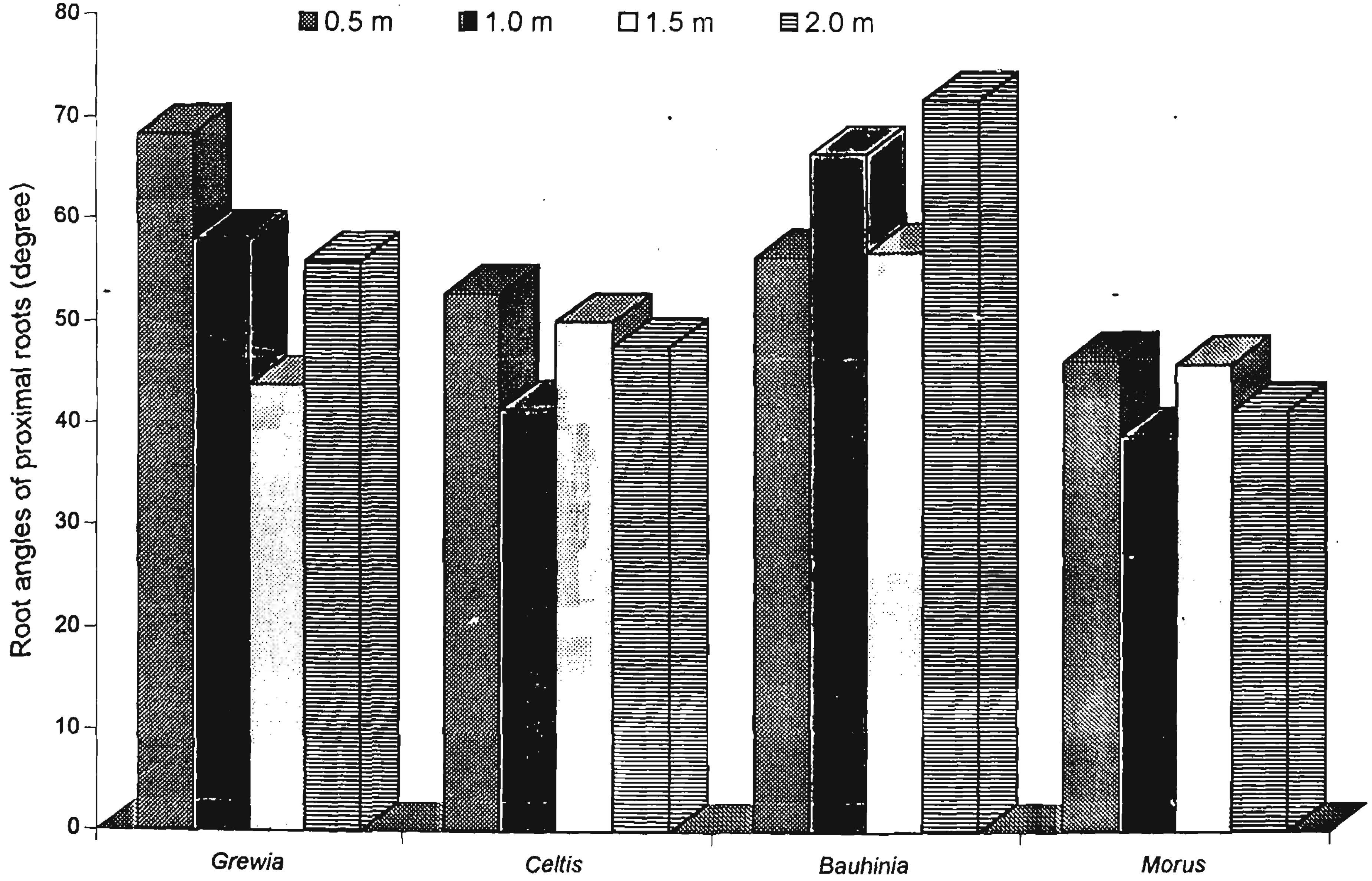

Fig. 5. Effect of coppicing and pollarding on root angles (degree) of proximal roots in four agroforestry tree species

the four agroforestry tree species under coppicing and pollarding treatments. The data in figure 5 shows that there is distinct interspecific differences as far as root angles of the proximal roots are concerned, however the various cutting heights were not observed to affect the root angles significantly in *C. australis* and *Morus* M-5. In *G. optiva* root angle was found to be maximum i.e. 68.34° under coppicing treatment which was followed by decline under pollarding treatments. For example, the root angles were, 57.87° and 55.81° at 1.00 and 2.00 m cutting heights whereas the root angle was minimum (43.91°) at 1.50 m cutting height under similar conditions (Fig. 5).

The values of root angles in case of *C. australis* (T_2) ranged between 41.59 to 52.79°. The minimum root angle (41.59°) was recorded at 1.0 m (H_2) cutting height whereas the maximum value for root angle of proximal roots (52.79°) was recorded at 0.5 m (H_1). The root angles at 1.5 m (H_3) and 2.0 m (H_4) were 50.11° and 47.74°, respectively (Fig. 5).

In case of *B. variegata* (T_3) the proximal root angle was maximum (71.60°) at 2.0 m (H_4) cutting height. The orientation of proximal roots at the remaining cutting heights resulted into root angles of 56.77° at 1.5 m (H_3), 66.44° at 1.0 m (H_2) and 56.28° at 0.5 (H_1), respectively (Fig. 5).

In *Morus* M-5 the root angle of the proximal roots ranged between 38.93° and 46.34°. The maximum root angle (46.34°) was recorded at 0.5 m (H_1) whereas the minimum value for root angle (38.93°) was observed at 1.0 m (H_2). At 1.5 m (H_3) and 2.0 m (H_4) the values for root angles in *Morus* M-5 were 45.97° and 41.37°, respectively (Fig. 5).

4.1.6 Root distribution

The root distribution of proximal roots in four agroforestry tree species were not significantly influenced by coppicing and pollarding treatments. Figure 6 represents the per cent root distribution in four directions viz. East, West, North

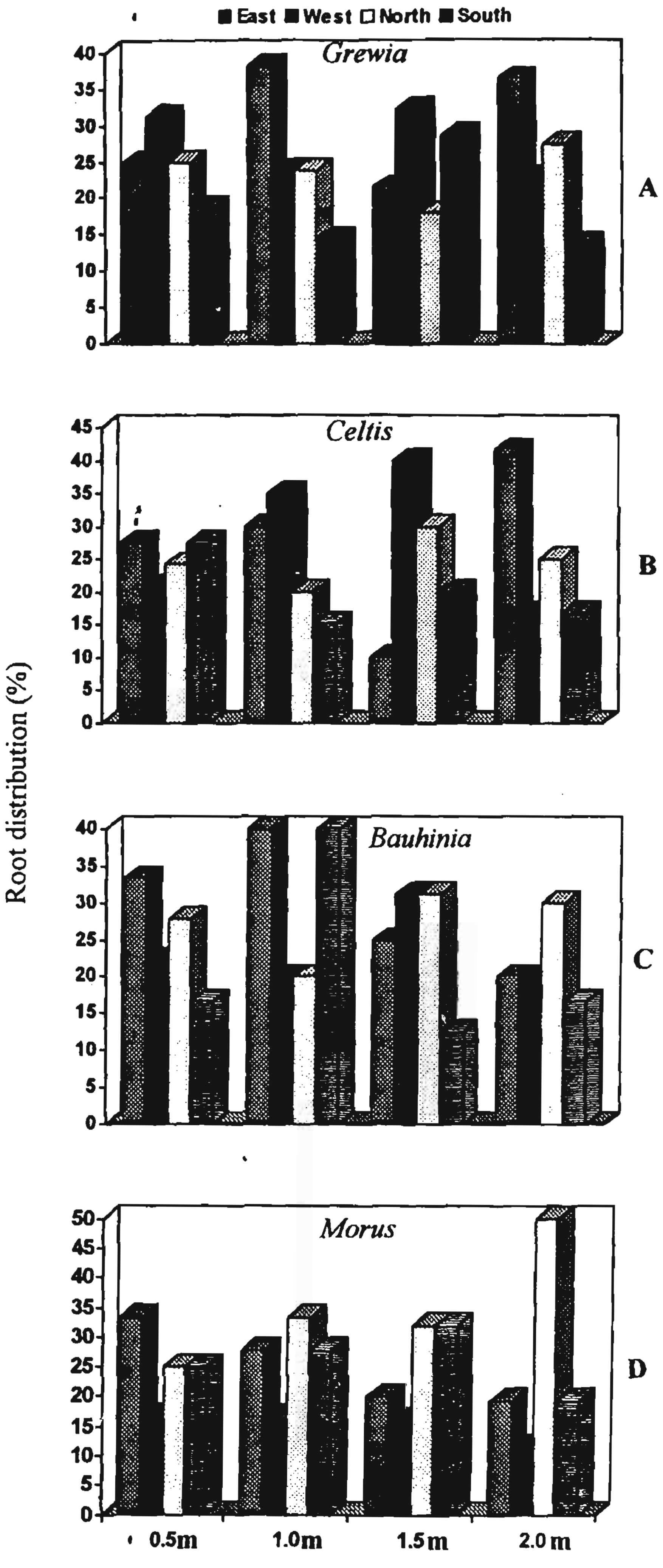

Fig. 6. Effect of coppicing and pollarding on root distribution in four agroforestry tree species

and South in four coppiced and pollarded tree species. In *Grewia optiva* (T_1) the maximum number of roots towards East (38.09%) were recorded at 1.0 m (H_2). Maximum number of roots towards west were recorded at 1.5 m (H_3) amounting to 32.14% of the total. Towards north, the maximum number of roots (27.27%) were recorded at 2.0 m (H_4) cutting height whereas towards south, the maximum roots (28.57%) were recorded at 1.5 m (H_3) cutting height in *Grewia optiva* (Fig. 6A).

In *Celtis australis* (T_2) maximum number of roots (41.66%) towards east were recorded at 2.0 m (H_4) cutting height. Maximum roots towards west (40%) were recorded at 1.5 m (H_3) cutting height. Towards north the maximum number of roots (30%) were recorded at 1.5 m (H_3) whereas the maximum (27.58%) of roots towards south were recorded at 0.5 m (H_1) cutting height (Fig. 6B).

Bauhinia variegata recorded the maximum number of roots towards east (40%) at 1.0 m (H_2) cutting height. Towards west the maximum number of roots (31.25%) was recorded at 1.5 m (H_3) cutting height and a similar number of roots (31.25%) were recorded towards northern direction. Maximum number of roots towards south (40%) were recorded at 1.0 m (H_2) cutting height (Fig. 6C).

In *Morus*, towards east maximum number of roots (33.33%) were recorded at 0.5 m (H_1) cutting height. Towards west both 0.5 m (H_1) and 1.0 m (H_2) had 16.66% roots whereas the highest number of roots towards north (50%) were recorded at 2.0 m (H_4). Maximum number of roots towards south (32%) were recorded at 1.5 m (Fig. 6D).

No effect of coppicing and pollarding treatments on proximal root distribution in four agroforestry tree species was evident *per se*. In general, the maximum proximal roots in *G. optiva* were found to be distributed in east-north direction while in *C. australis* west-north direction contained maximum roots. East-south direction in case of *B. variegata* and north-east direction in *Morus* M-5 had the maximum share of total proximal roots irrespective of cutting height (Fig. 6).

4.2 Resource capturing attributes

Coppiced and pollarded trees of all the four agroforestry species i.e. *Grewia optiva*, *Celtis australis*, *Bauhinia variegata* and *Morus* M-5 were studied for their resource sharing/capturing parameters under similar growing conditions. The data have been expressed in the form of tables hereunder :

4.2.1 Transpiration rate

Transpiration rate was measured at monthly intervals in all the four coppiced and pollarded tree species starting from May, 1998. The data so obtained has been presented in Table 1. The data reveal significant variations in the monthly transpiratin rate between the species as well as the interaction between the species and the cutting heights.

In May the transpiration rate in *Grewia optiva* (T_1) was maximum (1.27 mmol $m^{-2}s^{-1}$) at 0.5 m (H_1) cutting height. However, there was not much difference in the transpiration rate (0.66, 0.77 and 0.80 mmol $m^{-2}s^{-1}$) at 1.0 m (H_2), 1.5 m (H_3) and 2.0 m (H_4) cutting heights. A decrease in the transpiration rate was observed (0.85 mmol $m^{-2}s^{-1}$) at 0.5 m (H_1) cutting height in June which further dropped during July and August. In September, the transpiration rate at 0.5 m (H_1) cutting height was 0.37 mmol $m^{-2}s^{-1}$. The cutting heights 1.0 m (H_2), 1.5 m (H_3) and 2.0 m (H_4) also recorded a decrease during the months of July and August as compared to May and June.

Celtis australis (T_2) had comparatively higher transpiration rates than *Grewia optiva* (T_1) during the entire study period (Table 1). In May the cutting heights 0.5 m (H_1) and 1.5 m (H_3) recorded higher transpiration rates (1.34 and 1.10 mmol $m^{-2}s^{-1}$) as compared to 1.0 m (H_2) and 2.0 m (H_4) where the transpiration rates were 0.77 and 0.40 mmol $m^{-2}s^{-1}$, respectively (Table 1). The transpiration rate increased during June, and July at 1.0 and 2.0 m cutting heights (Table 1) and decreased in August but then again recorded an increase in September at all the

Table 1. Monthly variation in transpiration rate (m mol $m^{-2} s^{-1}$) in four coppiced and pollarded agroforestry tree species

Tree species x Cutting heights	May	June	July	August	September
T_1H_1	1.27	0.85	0.42	0.25	0.37
T_1H_2	0.66	1.35	0.20	0.37	0.57
T_1H_3	0.77	0.75	0.40	0.62	1.12
T_1H_4	0.80	0.85	092	0.72	0.77
Mean	0.87	0.95	0.48	0.49	0.71
T_2H_1	1.34	1.00	1.12	0.75	1.72
T_2H_2	0.77	1.85	1.32	1.05	2.20
T_2H_3	1.10	0.85	1.90	1.00	2.40
T_2H_4	0.40	2.22	2.37	0.17	2.22
Mean	0.90	1.48	1.68	0.74	2.13
T_3H_1	3.17	2.37	2.22	1.00	0.72
T_3H_2	2.65	3.55	2.82	1.52	1.10
T_3H_3	2.20	1.57	2.30	1.42	1.65
T_3H_4	2.55	1.60	2.57	1.57	1.72
Mean	2.64	2.27	2.48	1.38	1.30
T_4H_1	1.95	0.72	0.97	1.52	0.32
T_4H_2	1.30	0.85	1.07	0.75	0.60
T_4H_3	1.75	2.32	1.42	0.92	1.65
T_4H_4	1.32	2.15	0.82	0.75	1.32
Mean	1.58	1.51	1.07	0.98	0.97

$CD_{0.05}$ Species x Month 0.26
Species x Height x Month 0.53

cuttng heights. For example, the transpiration rate at 2.0 m (H_4) cutting height was 0.40 mmol $m^{-2}s^{-1}$ in May which increased to 2.22 mmol $m^{-2}s^{-1}$ in June and then to 2.37 mmol $m^{-2}s^{-1}$ in July. In August it dropped to 0.17 mmol $m^{-2}s^{-1}$ and in September it was again 2.22 mmol $m^{-2}s^{-1}$.

In *Bauhinia variegata* (T_3) the transpiration rate was high during the months of May, June and July and then it decreased during August and September (Table 1). In May, at 0.5 m (H_1) the transpiration rate was highest (3.17mmol $m^{-2}s^{-1}$) as compared to that at 1.0 m (H_2), 1.5 m (H_3) and 2.0 m (H_4) cutting heights, which were at par with each other having values 2.65, 2.20 and 2.55 mmol $m^{-2}s^{-1}$, respectively. During July, although the transpiration rate was high but there was not much diference in the transpiration rate at all the cutting heights (2.22, 2.82, 2.30 and 2.57 mmol $m^{-2}s^{-1}$) which were at par with each other. *Bauhinia variegata* had higher transpiration rate throughout the study period when compared with the other three tree species.

Morus M-5 (T_4) recorded the highest transpiration rate (1.95 mmol $m^{-2}s^{-1}$) at 0.5 m (H_1) in May. However, there was not much difference in the transpiration rate (1.95, 1.30, 1.75 and 1.32 mmol $m^{-2}s^{-1}$) at all the cutting heights which were at par with each other. A decrease in transpiration rate was observed at 0.5 m cutting height from May to September. In general, the transpiration rates in *Morus* were comparatively higher during the month of May, June and July (Table 1).

Overall transpiration rate was found to be maximum in *B. variegata* followed by *Morus* M-5 and *C. australis* whereas it was minimum in case of *G. optiva* (Table 1).

4.2.2 Amount of water transpired (g H_2O tree^{-1} hr^{-1})

Total amount of water transpired per tree per hour was determined for all the four agroforestry tree species at all the cutting heights from May to September 1998. The data so obtained has been presented in Table 2. From the table it is

Table 2. Monthly variation in total amount of water transpired (g H_2O tree^{-1} hr^{-1}) in four coppiced and pollarded agroforestry tree species

Tree species x Cutting heights	May	June	July	August	September
T_1H_1	100.6	70.02	43.42	23.08	30.26
T_1H_2	46.00	115.60	21.06	41.20	51.43
T_1H_3	71.68	82.49	47.30	62.73	99.05
T_1H_4	63.65	94.24	110.90	89.00	82.07
Mean	70.48	90.59	55.68	54.00	65.70
T_2H_1	76.72	68.59	80.89	53.15	102.60
T_2H_2	47.48	117.60	99.03	78.54	145.80
T_2H_3	57.06	51.13	118.40	63.36	136.50
T_2H_4	23.21	123.60	143.60	10.21	115.60
Mean	51.12	90.23	110.50	51.31	125.10
T_3H_1	217.40	170.60	209.70	100.20	77.66
T_3H_2	174.50	253.20	251.60	155.70	108.00
T_3H_3	138.50	101.90	166.20	94.12	102.70
T_3H_4	130.30	94.11	155.70	97.17	92.89
Mean	165.20	154.90	195.80	111.80	95.32
T_4H_1	179.80	76.33	118.00	188.90	38.10
T_4H_2	147.80	103.4	135.20	72.33	43.35
T_4H_3	171.00	215.0	191.20	96.08	140.50
T_4H_4	140.40	252.60	111.20	87.11	153.70
Mean	159.70	161.90	138.9	111.1	93.92

$CD_{0.05}$		
	Species x Months	28.52
	Species x Height x Month	57.07

clear that there is significant monthly variations between the cutting heights within the species as well as among different species studied during the present investigation.

Grewia optiva (T_1) transpired maximum amount of water (100.6 g H_2O tree^{-1} hr^{-1}) at 0.5 m (H_1) cuting height in May. At 1.5 (H_3) and 2.0 m (H_4) the amount of water transpired was 71.68 and 63.65 g H_2O tree^{-1} hr^{-1}, respectively whereas at 1.0 m (H_2) the minimum (46.00 g H_2O tree^{-1} hr^{-1}) water was transpired (Table 2). The amount of water transpired increased during June as compared to May whereas it decreased during July and August and again a slight increase was observed in September (Table 2). *Grewia optiva* at pollarding height at 2.0 m was found to transpire maximum (110.90 g H_2O tree^{-1} hr^{-1}) amount of water during the month of July (Table 2).

In *Celtis australis* (T_2) the maximum amount of water transpired (76.72 g H_2O tree^{-1} hr^{-1}) was recorded at 0.5 m (H_1) followed by 57.06 and 47.48 g H_2O tree^{-1} hr^{-1} at 1.5. m (H_3) and 1.0 m (H_2) cutting heights, respectively. Minimum (23.21 g H_2O tree^{-1} hr^{-1}) was recorded at 2.0 m (H_4) cutting height (Table 2). The amount of water transpired increased in June and July. A decrease in transpired water was observed in August and then again an increase in September. For example at 1.5 m (H_3) the maximum value of water transpired was 136.50 g H_2O tree^{-1} hr^{-1} in September as compared to 57.06 g H_2O tree^{-1} hr^{-1} in May. A similar trend was observed at the remaining three cutting heights (Table 2).

Bauhinia variegata (T_3) in May transpired maximum 217.40 g H_2O tree^{-1} hr^{-1} at 0.5 m (H_1) cutting height followed by 174.50, 138.50 and 130.30 g H_2O tree^{-1} hr^{-1} at 1.0 m (H_2), 1.5 m (H_3) and 2.0 m (H_4), respectively. *B. variegata* was found to transpire significantly higher amount of water during July at all the cutting heights (Table 2). However, a decline in amount of water transpired was recorded during August and Septermber (Table 2).

The amount of water transpired in *Morus* M-5 ranged between 140.40 and 179.80 g H_2O tree^{-1} hr^{-1} in May with maximum value at 0.5 m cutting height and the minimum at 2.0 m (Table 2). No definite pattern of total amount of water transpired was observed with relation to coppicing and pollarding heights in *Morus* M-5, however, the maximum amount of water transpired (252.60 g H_2O tree^{-1} hr^{-1}) was observed at 2.0 m cutting height in June (Table 2).

Comparison of data for total amount of water transpired (Table 2) reveals that coppicing and pollarding treatment have significantly affected the amount of water loss. Nevertheless on the basis of data on amount of water transpired at four agroforestry tree species can be categorized as *B. variegata* > *Morus* M-5 > *C. australis* > *G. optiva*.

4.2.3 Stomatal conductance

The observations for the stomatal conductance were initiated in the month of May 1998 in all the four coppiced and pollarded tree species. Stomatal conductance was recorded at monthly intervals till September, 1988 after which the coppiced and pollarded tree species were harvested. The data so obtained has been presented in Table 3. It is evident from the data that there was significant differences in stomatal conductance within the species as well as inbetween the species.

In May *Grewia optiva* (T_1) had maximum stomatal conductance (37.50 m mol m^{-2}s^{-1}) at 0.5 m (H_1) cuting height followed by a stomatal conductance of 23.60 and 22.79 m mol m^{-2}s^{-1} at 2.0 m (H_3) and 1.5 m (H_4) cutting height which were at par with each other. Minimum stomatal conductance (19.48 m mol m^{-2}s^{-1}) was recorded at 1.0 m (H_2) cutting height (Table 3). Stomatal conductance values increased in June followed by a decrease in July and August and then again increased in September. For example, at 0.5 m (H_1) stomatal conductance decreased from 37.50 in May to 25.00 m mol m^{-2}s^{-1} in June. It decreased to 12.50 m mol m^{-2}s^{-1} in July and a further decrease was observed in August where stomatal

Table 3. Monthly variation in stomatal conductance (m mol $m^{-2} s^{-1}$) in four coppiced and pollarded agroforestry tree species

Tree species x Cutting heights	May	June	July	August	September
T_1H_1	37.50	25.00	12.50	7.35	11.03
T_1H_2	19.48	39.70	5.88	11.03	16.91
T_1H_3	22.79	22.06	11.76	18.38	33.09
T_1H_4	23.60	25.00	27.20	21.32	22.79
Mean	25.84	27.94	14.34	14.52	20.95
T_2H_1	39.48	29.41	33.09	22.06	50.73
T_2H_2	22.79	54.41	38.97	30.88	64.70
T_2H_3	32.35	25.00	55.88	29.41	70.58
T_2H_4	11.76	65.44	69.85	5.14	65.44
Mean	26.60	43.56	49.45	21.87	62.86
T_3H_1	93.38	69.85	65.44	29.41	21.32
T_3H_2	77.94	104.40	83.08	44.85	32.35
T_3H_3	64.70	46.32	67.64	41.91	48.53
T_3H_4	75.00	47.06	75.73	46.32	50.73
Mean	77.75	66.91	72.97	40.62	38.23
T_4H_1	57.35	21.32	28.67	44.85	9.55
T_4H_2	38.23	25.00	31.62	22.06	17.65
T_4H_3	51.47	68.38	41.91	27.20	48.53
T_4H_4	38.97	63.23	24.26	22.06	38.97
Mean	46.50	44.48	31.62	29.04	28.67

$Cd_{0.05}$		
	Species x Month	7.88
	Species x Height x Month	15.76

conductance was found to be 7.35 m mol $m^{-2}s^{-1}$. In September stomatal conductance increased to 11.03 m mol $m^{-2}s^{-1}$ (Table 3). Variation in stomatal conductance was also observed at the remaining cutting heights but at 2.0 m (H_4) not much difference in stomatal conductance was observed from May to September where the values were at par with each other (Table 3).

In *Celtis australis* (T_2) the maximum stomatal conductance was 39.48 m mol $m^{-2}s^{-1}$ at 0.5 m (H_1) cutting height followed by 32.35 m mol $m^{-2}s^{-1}$ at 1.5 m (H_3) and 22.79 m mol $m^{-2}s^{-1}$ at 1,0 m (H_2) cutting height. Minimum stomatal conductance (11.76 m mol $m^{-2}s^{-1}$) was observed at 2.0 m (H_4) cutting height (Table 3). Stomatal conductance increased at 1.0 m (H_2) and 2.0 m (H_4) in June whereas a decrease was observed at 0.5 m (H_1) and 1.5 m (H_3) cutting heights (Table 3). An increase in stomatal conductance was observed at all the cutting heights in July except at 1.0 m (H_1) (Table 3). In August comparatively lower stomatal conductance was observed as compared to July whereas the stomatal conductance during September was highest at all the cutting heights (Table 3).

In *Bauhinia variegata* (T_3) stomatal conductance values in May varied between 64.70 and 93.38 m mol $m^{-2}s^{-1}$ at different cutting heights. Maximum stomatal conductance (93.38 m mol $m^{-2}s^{-1}$) was recorded at 0.5 m (H_1) followed by 1.0 m (H_2) and 2.0 m (H_4) with stomatal conductance values of 77.94 and 75.00 m mol $m^{-2}s^{-1}$, respectively (Table 3). Stomatal conductance was minimum (64.70 m mol $m^{-2}s^{-1}$) at 1.5 m (H_3) cutting height (Table 3).

A decrease in stomatal conductance was observed from May to September at all the cutting heights except at 1.5 m during June and July where an increase was observed. Stomatal conductance at 0.5 m (H_1) cutting height was 93.38 m mol $m^{-2}S^{-1}$ in May, decreasing to 69.85 m mol $m^{-2}s^{-1}$ in June. During July, August and September a further decrease was observed with stomatal conductance values being 65.44, 29.41 and 21.32 m mol $m^{-2}s^{-1}$ respectively (Table 3).

Stomatal conductance in *Morus* M-5 ranged between 38.23 and 57.35 m mol $m^{-2}s^{-1}$ in May. A decrease in stomatal conductance was observed from May to September at 0.5, 1.0, and 1.5 m cutting heights. For example at 0.5 m (H_1) stomatal conductance was 9.55 m mol $m^{-2}s^{-1}$ in September as compared to 57.35 m mol $m^{-2}s^{-1}$ in May. The maximum stomatal conductance of 68.38 m mol $m^{-2}s^{-1}$ was recorded at 1.5 m cutting heights in June which was followed by decline till September (Table 3).

In general *B. variegata* has shown the highest stomatal conductance followed by *Morus* M-5, *C. australis* and *G. optiva* under similar conditions

4.2.4 Photosynthetic rate

The observations for the photosynthetic rate were started with the emergence of new leaves in the month of May, 1998 in all the four coppiced and pollarded tree species. The photosynthetic rate was recorded at monthly intervals till September, 1998 after which the coppiced and pollarded tree species were harvested for their foliage and branchwood biomass. The data so obtained have been presented in Table 4. It is clear from the data for photosynthetic rates in four agroforestry tree species viz. *G. optiva, C. australis, B. vareigata and Morus* M-5 that in addition to monthly variations, interspecific variations are also statistically significant.

In May, the highest photosynthetic rate (9.31 μ mol $m^{-2}s^{-1}$) in *Grewia optiva* (T_1) was recorded at 0.5 m (H_1) cutting height, followed by 1.5 m (H_3) and 1.0 m (H_2) where the photosynthetic rate was 6.02 and 5.36 μ mol $m^{-2}s^{-1}$, respectively. The minimum photosynthetic rate (4.90 μ mol $m^{-2}s^{-1}$) was recorded at 2.0 m (H_4) cutting height (Table 4). An increasing trend in photosynthetic rate in *G. optiva* (T_1) was observed from the month of May till September. Photosynthetic rate iln May was 9.31 μ mol $m^{-2}s^{-1}$ which increased to 13.85 μ mol $m^{-2}s^{-1}$ in the month of September at 0.5 m (H_1) cutting height. The maximum photosynthetic rate at 0.5 m (H_1) cutting height (14.60 μ mol $m^{-2}s^{-1}$) was recorded during July. Similarly an

Table 4. Monthly variation in photosynthetic rate (μ mol $m^{-2} s^{-1}$) in four coppiced and pollarded agroforestry tree species

Tree species x Cutting heights	May	June	July	August	September
T_1H_1	9.31	12.67	14.60	10.80	13.85
T_1H_2	5.36	12.75	14.32	15.57	14.30
T_1H_3	6.02	10.55	10.32	14.15	12.30
T_1H_4	4.90	10.55	10.97	8.97	10.25
Mean	6.39	11.63	12.56	12.37	12.67
T_2H_1	5.44	9.27	11.82	7.22	8.62
T_2H_2	4.11	6.60	8.90	8.32	7.37
T_2H_3	4.17	7.60	9.65	9.05	10.00
T_2H_4	2.50	5.15	10.67	12.45	4.32
Mean	4.05	7.15	10.26	9.26	7.58
T_3H_1	7.32	8.22	7.80	12.47	10.72
T_3H_2	7.07	8.57	6.30	10.17	5.57
T_3H_3	8.62	8.80	7.32	12.25	11.62
T_3H_4	7.55	10.70	8.27	9.82	9.85
Mean	7.64	9.07	7.42	11.18	9.44
T_4H_1	6.55	14.12	12.42	11.87	16.70
T_4H_2	10.15	15.52	13.30	12.50	12.40
T_4H_3	7.50	11.02	13.02	13.00	10.60
T_4H_4	5.62	10.90	12.00	12.00	10.87
Mean	7.45	12.89	12.69	12.34	12.64

$CD_{0.05}$	Species x Months	1.30
	Species x Height x Month	2.60

increase in the photosynthetic rate was observed at the remaining cutting heights (1.0, 1.5 and 2.0 m) from May to September. Maximum photosynthetic rate was recorded during July and August at all the cutting heights (Table 4).

In *Celtis australis* (T_2) the photosynthetic rate in May was maximum (5.44 µ mol $m^{-2}s^{-1}$) at 0.5 m (H_1) cutting height whereas the minimum (2.50 µ mol $m^{-2}s^{-1}$) was recorded at 2.0 m (H_4) cutting height. However, the cutting heights 1.0 m (H_2) and 1.5 m (H_3) were at par with each other having photosynthetic rates of 4.11 and 4.17 µ mol $m^{-2}s^{-1}$, respectively. Monthly variations with regards to the photosynthetic rate were clear where increasing photosynthetic rate was observed from May to September. For example, value for photosynthetic rate was 5.44 µ mol $m^{-2}s^{-1}$ at 0.5 m (H_1) cutting height which was followed by further increase and was found to be 8.62 µ mol $m^{-2}s^{-1}$ in September (Table 4). Similar was the pattern at 1.0 m (H_2), 1.5 m (H_3) and 2.0 m (H_4) cutting heights. In this tree species, the maximum photosynthetic rate was observed during July and August at all the four cutting heights which was significantly higher than for the remaining months (Table 4).

Bauhinia variegata (T_3) in May did not reveal much differences in photosynthetic rates at different cutting heights except 1.5 m (H_3), where the photosynthetic rate was maximum (8.62 µ mol $m^{-2}s^{-1}$) during May. The cutting heights 0.5 m (H_1), 1.0 m (H_2) and 2.0 m had the respective photosynthetic rates of 7.32, 7.07 and 7.55 µ mol $m^{-2}s^{-1}$ (Table 4). In this species very little monthly variations with respect to photosynthetic rates were noticed, except that photosynthetic rate was comparatively higher during the month of August where values ranged between 9.82 and 12.47 µ mol $m^{-2}s^{-1}$ as compared to 7.07 and 8.62 µ mol $m^{-2}s^{-1}$ during May (Table 4).

During May, *Morus* M-5 (T_4) recorded the maximum photosynthetic rate (10.15 µ mol $m^{-2}s^{-1}$) at 1.0 m (H_2) cutting height followed by 1.5 m (H_3) where the photosynthetic rate was 7.50 µ mol $m^{-2}s^{-1}$. At 0.5 m (H_1) cutting height the photosynthetic rate was 6.55 μ mol $m^{-2}s^{-1}$ which dropped to 5.62 μ mol $m^{-2}s^{-1}$ at 2.0 m (H_4) cutting height (Table 4).. *Morus* M-5 also recorded an increasing trend in photosynthetic rate from May to September. The photosynthetic rate increased from 6.55 μ mol $m^{-2}s^{-1}$ at 0.5 m (H_1) in May to 16.70 μ mol $m^{-2}s^{-1}$ in September at the same cutting height. As far as the remaining cutting heights viz., 1.0 m, 1.5 m and 2.0 m are concerned, an increase in the photosynthetic rate was observed with the passage of time from May to September. These cutting heights had higher photosynthetic rate during June, July and August.

During the present investigation *G. optiva* and *Morus* M-5 have been found to be the tree species with higher photosynthetic rates as compared to *C. australis* and *B. variegata* under similar growing conditions (Table 4). Nevertheless all the tree species irrespective of coppicing and pollarding treatments have recorded higher photosynthetic rate during June, July, August and September as compared to May (Table 4).

4.2.5 Light transmission ratio (LTR)

Light transmission ratio was recorded in all the four coppiced and pollarded tree species starting from May till September. The data so obtained have been presented in Table 5. The data in the table suggested that there were signiicant monthly variations in light transmission ratio, both within and among the tree species at four cutting heights.

Grewia optiva (T_1) recorded the maximum LTR during May (12.32%) at 1.5 m (H_3) cutting height followed by 1.0 m (H_2) 2.0 m (H_4) and 0.5 m (H_1) where LTR was 12.15, 11.75 and 11.30%, respectively. Light transmission ratio decreased during the months of June and July, but again increased in September (Table 5). For example, in *G. optiva* at 2.0 m (H_4) LTR was 11.75% in May which decreased to 8.75 and 8.67% in June and July, respectively. In August a slight increase in LTR (9.07%) was observed, which further increased to 10.97% in September.

Table 5. Monthly variation in light transmission ratio (%) in four coppiced and pollarded agroforestry tree species

Tree species x Cutting heights	May	June	July	August	September
T_1H_1	11.30	10.10	9.97	9.17	12.80
T_1H_2	12.15	10.90	9.75	8.75	10.25
T_1H_3	12.32	9.15	8.50	8.97	9.90
T_1H_4	11.75	8.75	8.67	9.07	10.97
Mean	11.88	9.72	9.22	8.99	10.98
T_2H_1	13.70	11.30	10.05	11.75	13.80
T_2H_2	12.75	9.72	9.15	10.00	13.95
T_2H_3	13.85	13.00	11.45	12.37	15.45
T_2H_4	14.42	11.90	11.52	13.00	16.45
Mean	13.68	11.48	10.54	11.78	14.91
T_3H_1	13.65	11.82	10.00	8.55	11.37
T_3H_2	11.17	9.10	9.02	7.80	9.90
T_3H_3	14.55	11.25	9.47	10.85	10.82
T_3H_4	12.20	10.15	9.80	12.92	13.22
Mean	12.89	10.58	9.57	10.03	11.33
T_4H_1	10.07	8.12	8.00	7.90	11.22
T_4H_2	9.55	8.80	8.27	8.82	11.20
T_4H_3	9.47	8.30	8.05	8.25	11.85
T_4H_4	9.05	8.07	7.47	7.30	8.47
Mean	9.53	8.32	7.95	8.06	10.69

$CD_{0.05}$	Species x Months	0.89
	Species x Height x Month	1.79

Celtis australis (T_2) showed maximum light transmission ratio (14.42%) at 2.0 m (H_4) cutting height in May. LTR decreased to 13.85% at 1.5 m (H_3) followed by 0.5 m (H_1) where LTR was 13.70%. Minimum LTR (12.75%) was observed at 1.0 m (H_1) (Table 5). In June and July LTR decreased at all the cutting heights, however, the minimum LTR was observed at 1.0 m during this period where the LTR was 9.72 and 9.15%, respectively. In August and September the light transmission ratio again increased. LTR at 1.0 m (H_2) cutting height during this period was 10.00 and 13.95%, respectively (Table 5). A similar trend was followed at other cutting heights. However, maximum increase in LTR during August and September was observed at 2.0 m (H_4) cutting height where LTR increased from 13.00 to 16.45% (Table 5).

In *Bauhinia variegata* (T_3) maximum LTR (14.55%) during May was observed at 1.5 m (H_3) cutting height, followed by 13.65 and 12.20% at 0.5 m (H_1) and 2.0 m (H_4) cutting heights. Minimum LTR (11.17%) was recorded at 1.0 m (H_2) cutting height during this month (Table 5). Light transmission followed a decreasing trend from May to September, especially at 0.5, 1.0 and 1.5 m cutting heights (Table 5). Light transmission continued a decreasing trend until August at 0.5 m and 1.0 m cutting heights where the values for LTR during August were 8.55 and 7.80%, respectively. At 1.5 m (H_3) and 2.0 m (H_4) during August an increase in LTR was observed where values were 10.85 and 12.92%, respectively. During September there was a further increase in LTR in *B. variegata* at all the cutting heights, except 1.5 m (H_3) which was at par with that in August (Table 5).

Morus M-5 (T_4) allowed the minimum light transmission through its canopy at all the cutting heights when compared with the other three tree species. In May, the light transmission decreased with increase in cutting heights from 0.5 m (H_1) to 2.0 m (H_4) where values at 1.0 m (H_2), 1.5 m (H_3) and 2.0 m (H_4) were 9.55, 9.47 and 9.05%, respectively (Table 5). Light transmission decreased at all the cutting heights from May onward till August whereas it increased in September. For example, at 2.0 m (H_4) the light transmission was 7.30% during August which increased to 8.47% in September. An almost similar trend was observed at other three pollarding heights (Table 5).

During the present investigation it was observed that among all the species *Morus* M-5 had the lowest values for LTR followed by *G. optiva* and *B. variegata*. Maximum LTR values were observed in case of *C. australis*. However, all the species had relatively low LTR values during June and July (Table 5).

4.2.5 Difference in above and beneath canopy air temperature

Above and below canopy differences in air temperatures were recorded at monthly intervals in all the four coppiced and pollarded agroforestry tree species. The data so obtained have been presented in Table 6. A significant difference in above and below canopy air temperature was observed both within and between the tree species.

In *Grewia optiva* (T_1) during May, beneath canopy temperature at 0.5 m (H_1) was found to be 0.75°C less than the above canopy temperature. At 1.0 m (H_2) the temperature difference was 0.60°C followed by 0.27°C at 2.0 m (H_4) cutting height. Minimum difference in temperature (0.25°C) was recorded at 1.5 m (H_3) cutting height. The difference between above and beneath canopy temperature decreased during June at 0.5 m (H_1) and 1.0 m (H_2) cutting height whereas it increased at 1.5 m (H_3) and 2.0 m (H_4) cutting heights. The values for temperature differences were 0.55°C at 1.0 m (H_1) and 0.82°C at 2.0 m (H_4) cutting height. At 0.5 m (H_1) and 1.5 m (H_3) the difference in temperature beneath the tree canopy was 0.62 and 0.75°C, respectively (Table 6). In July there was maximum decrease in beneath canopy temperature. With the increase in cutting heights there was an increase in air temperature difference. For example, at 1.5 m (H_1) the difference between above and beneath canopy air temperature was 0.25°C in May, which increased to 0.75°C in June and 0.90°C in July. In August and September the difference was 0.60°C which was lower than 0.90°C observed in July. An almost same trend was observed at rest of the cutting heights (Table 6).

Table 6. **Difference in above and beneath canopy air temperature (°C) at monthly intervals in four coppiced and pollarded agroforestry tree species**

Tree species x Cutting heights	May	June	July	August	September
T_1H_1	0.75	0.62	0.72	0.55	0.35
T_1H_2	0.60	0.55	0.80	0.67	0.35
T_1H_3	0.25	0.75	0.90	0.60	0.60
T_1H_4	0.27	0.82	1.05	0.67	0.85
Mean	0.46	0.68	0.86	0.62	0.53
T_2H_1	0.15	0.55	0.32	0.40	0.30
T_2H_2	0.62	0.87	0.80	0.50	0.37
T_2H_3	0.20	0.67	0.75	0.35	0.25
T_2H_4	0.45	0.45	0.42	0.40	0.20
Mean	0.35	0.63	0.57	0.41	0.28
T_3H_1	0.47	0.92	1.05	0.82	0.50
T_3H_2	0.70	0.87	1.00	0.65	0.72
T_3H_3	1.25	1.42	1.37	0.92	1.00
T_3H_4	1.17	1.02	0.92	0.75	0.60
Mean	0.90	1.06	1.08	0.78	0.70
T_4H_1	1.10	0.27	1.40	0.72	0.57
T_4H_2	1.02	1.02	1.17	0.35	0.30
T_4H_3	0.67	1.15	1.32	0.65	0.52
T_4H_4	1.10	1.72	1.97	0.95	0.82
Mean	0.98	1.29	1.40	0.66	0.55

$CD_{0.05}$	Species x Month	0.17
	Species x Height x Month	0.36

In *Celtis australis* (T_2) the maximum difference in above and beneath canopy temperature was observed at 1.0 m (H_2) cutting height followed by 2.0 m (H_4) and 1.5 m (H_3) where the values for temperature difference were 0.45 and 0.20°C, respectively. Minimum decrease was observed at 0.5 m (H_1) cutting height where the difference in temperature was 0.15°C. In June and July the difference in beneath canopy temperature increased and then decreased during August and September. For example, at 1.5 m (H_1) cutting height the difference in above and beneath canopy temperature was 0.20°C in May. It increased to 0.67°C in June and reached maximum (0.75°C) in July. Thereafter, it decreased to 0.35 and 0.25°C in August and September (Table 6). Somewhat similar trend was observed at rest of the cutting heights (Table 6), with maximum difference being observed during June and July.

Bauhinia variegata (T_3) in May recorded maximum difference in air temperature (1.25°C) at 1.5 m (H_3) cutting height whereas the minimum difference in temperatue (0.47°C) was recorded at 0.5 m (H_1) cutting height. At 1.0 m (H_1) and 2.0 m (H_4) the difference in temperature was 0.70 and 1.17°C, respectively (Table 6). In June and July there was further increase in temperature difference (0.92 and 1.05°C) at 0.5 m (H_1) cutting height followed by a decrease in August and September where the values for temperature difference were 0.82 and 0.50°C. More or less similar trend was followed at other three cutting heights (Table 6).

In case of *Morus* M-5 the maximum difference in above and beneath canopy temperature (1.10°C) was recorded at 0.5 m (H_1) and 2.0 m (H_4) cutting heights followed by 1.0 m (H_2) and 1.5 m (H_3) with a temperature difference of 1.02 and 0.67°C, respectively during May. In June the difference in beneath canopy temperature was higher than May, except at 0.5 m (H_1) cutting height where a decrease was observed. A further increase in above and below canopy temperatue was observed at all the cutting heights in July. During August and September a decreasing trend in the temperature difference was observed at all the cutting heights. For example, at 2.0 m (H_4) cutting height the difference in above and beneath canopy temperature was 1.10°C in May, increased to 1.72 and 1.97°C in June and July and followed by a decrease (0.95 and 0.82°C) in August and September (Table 6). The rest of the cutting heights also seemed to follow the same pattern (Table 6).

Irrespective of cutting heights, a comparison among all the four species reveals that maximum difference in above and beneath canopy air temperature was observed under *Morus* M-5, followed by *B. variegata* and *G. optiva*. Minimum difference was, however, recorded under *C. australis* (Table 6).

4.2.7 Water use efficjency (WUE)

During the course of present investigation the WUE of all the four agroforestry tree species was determined at all the four cutting heights at monthly intervals. Significant variation in WUE was observed within the tree species at different cutting heights as well as in between the four agroforestry tree species studied.

Grewia optiva (T_1) in May registered all the maximum water use efficiency (0.0082) at 1.0 m (H_2) cutting height followed by H_3 (1.5 m) and H_1 (0.5 m) where WUE were 0.0077 and 0.0076, respectively which were at par with each other. At 2.0 m (H_1) WUE was the minimum (0.0061). An increase in WUE was observed till September in comparison to May. WUE was maximum in July and August at all the cutting heights. For example, at 0.5 m (H_1) cutting height WUE in May was 0.0076 which increased to 0.0579 in September. Similarly an increase in WUE was observed at the remaining cutting heights. However, maximum values for WUE were recorded during July and August at all the four cutting heights (Table 7).

Celtis australis (T_2) recorded maximum WUE (0.0065) at 2.0 m (H_4) cutting height. Minimum WUE (0.0036) was recorded at 1.5 m (H_3). At 0.5 m (H_1) and 1.0

Table 7. Monthly variation in water use efficiency (WUE) in four coppiced and pollarded agroforestry tree species

Tree species x Cutting heights	May	June	July	August	September
T_1H_1	0.0076	0.0150	0.0591	0.0449	0.0579
T_1H_2	0.0082	0.0095	0.0830	0.0844	0.0256
T_1H_3	0.0077	0.0144	0.0289	0.0248	0.0110
T_1H_4	0.0061	0.0131	0.0121	0.0148	0.0146
Mean	0.0074	0.0130	0.0458	0.0422	0.0273
T_2H_1	0.0040	0.0127	0.0111	0.0104	0.0053
T_2H_2	0.0053	0.0047	0.0066	0.0106	0.0033
T_2H_3	0.0036	0.0142	0.0051	0.0091	0.0042
T_2H_4	0.0065	0.0029	0.0047	0.0997	0.0019
Mean	0.0048	0.0086	0.0069	0.0325	0.0037
T_3H_1	0.0023	0.0035	0.0035	0.0128	0.0108
T_3H_2	0.0027	0.0024	0.0023	0.0071	0.0098
T_3H_3	0.0039	0.0059	0.0033	0.0091	0.0072
T_3H_4	0.0029	0.0081	0.0032	0.0062	0.0057
Mean	0.0029	0.0050	0.0031	0.0088	0.0084
T_4H_1	0.0033	0.0197	0.0136	0.0079	0.0766
T_4H_2	0.0080	0.0227	0.0163	0.0317	0.0215
T_4H_3	0.0042	0.0065	0.0102	0.0185	0.0066
T_4H_4	0.0042	0.0059	0.0214	0.0186	0.0084
Mean	0.0049	0.0137	0.0154	0.0192	0.0283

$Cd_{0.05}$	Species x Month	0.011
	Species x Height x Month	0.023

m (H_2) WUE was 0.0040 and 0.0053, respectively. An increase in WUE was observed during June, July and August whereas WUE decreased in September at all the cutting heights (Table 7). No particular trend in WUE at different cutting heights was observed in *C. australis*.

In *Bauhinia variegata* (T_3) not much variation in WUE was observed at monthly intervals as compared to other species. In May WUE was maximum (0.0039) at 1.5 m cutting height followed by 0.0029, 0.0027 and 0.0023 at 2.0 m (H_4), 1.0 m (H_2) and 0.5 m (H_1) cutting heights, respectively. WUE increased from 0.0023 at 0.5 m (H_1) in May to 0.0108 in September. A similar trend was observed at other three cutting heights. Higher values of WUE were observed during August and September at all the cutting heights (Table 7).

In May, *Morus* M-5 (T_4) recorded the maximum WUE (0.0080) at 1.0 m (H_2) followed by 0.0042 at 1.5 m (H_3) and 2.0 m (H_4) whereas WUE was minimum (0.0033) at 0.5 m (H_1) (Table 7). An increase in WUE was observed during the remaining months at all the cutting heights. Where values were significantly higher than that during the month of May. *Morus* when pollarded at 1.0 m has been found to have higher WUE during May, June, July and August as compared to other cutting heights (Table 7).

Overall comparison of WUE, irrespective of cutting heights reveals that *G. optiva* had highest values of WUE followed by *Morus* M-5 and *C. australis* whereas *B. variegata* had the minimum WUE.

4.3 Soil moisture utilization

Soil moisture was determined during the study period from May to September 1998 in all the four coppiced and pollarded tree species. The data have been presented in Table 8. Differences have been observed in the soil moisture content at different depths.

Table 8. Monthly variation in soil moisture (%) at two depths in four coppiced and pollarded agroforestry tree species

Tree species x Cutting heights	May		June		July		August		September	
	Soil depth (cm)									
	0-15	16-30	0-15	16-30	0-15	16-30	0-15	16-30	0-15	16-30
T_1H_1	6.55	7.31	7.55	8.31	12.55	13.31	10.31	9.55	15.31	14.55
T_1H_2	7.24	7.54	8.54	8.79	13.59	13.82	10.79	10.54	15.82	15.30
T_1H_3	7.12	7.25	8.16	8.33	13.04	13.27	10.33	10.16	15.27	15.04
T_1H_4	7.24	7.55	8.26	8.73	13.31	13.80	10.73	10.26	15.80	15.31
T_2H_1	6.07	6.29	7.13	7.27	13.17	13.23	10.27	10.13	15.23	15.39
T_2H_2	6.04	6.17	6.75	7.17	12.85	13.22	10.17	9.75	15.22	14.85
T_2H_3	6.16	6.34	7.16	7.32	13.19	13.45	10.32	10.16	15.45	15.19
T_2H_4	6.06	6.25	7.83	7.27	13.10	13.32	10.27	10.10	15.32	15.10
T_3H_1	5.82	6.20	6.75	7.20	12.80	13.27	10.20	9.77	15.27	14.80
T_3H_2	5.85	6.55	6.81	7.31	12.91	13.37	10.31	9.81	15.37	14.91
T_3H_3	6.09	6.42	7.09	7.54	13.17	13.57	10.54	10.10	15.57	15.17
T_3H_4	6.00	6.40	7.00	7.42	13.02	13.47	10.42	10.02	15.47	15.02
T_4H_1	7.78	7.94	8.84	8.90	13.82	13.90	10.90	10.79	15.90	15.82
T_4H_2	7.64	7.92	8.64	8.92	13.70	13.92	10.92	10.64	16.12	15.70
T_4H_3	7.57	7.90	8.60	8.90	13.60	13.87	10.93	10.63	15.87	15.60
T_4H_4	7.72	7.96	8.68	8.95	13.74	13.97	11.00	10.70	15.97	15.74

$CD_{0.05}$

Species x Height x Month 0.24

Grewia optiva (T_1) during May depicted lower moisture of 6.55% at 0-15 cm soil depth as compared to 7.31%at 16-30 cm soil depth at 0.5 m (H_1) cutting height. A similar trend was observed during June and July whereas in August and September more moisture was found at 0-15 cm as compared to 16-30 cm soil depth. The rest of the cutting heights also followed the similar trend. However, much higher soil moisture was observed in September as compared to May at all the cutting heights (Table 8).

Celtis australis (T_2) had comparatively lower soil moisture than *G. optiva*. In May, at 0.5 m (H_1) cutting height, the soil moisture was 6.07% at 0-15 cm soil depth whereas at 16-30 cm comparatively higher soil moisture of 6.29% was recorded. The soil moisture increased in June and July in a similar way whereas, a decrease was observed in the soil moisture content in August (Table 8). In September the soil moisture content was 15.23 and 15.39% at 0-15 and 16-30 cm soil depth respectively, at 0.5 m (H_1) cutting height. An increase in soil moisture was observed at all the cutting heights from May to September (Table 8).

In *Bauhinia variegata* (T_3) in May the soil moisture was 5.82 and 6.20 per cent at 0-15 and 16-30 cm respectively, at 0.5 m (H_1) cutting height. The soil moisture increased in June and July followed by a decrease in August. In September high soil moisture of15.27 and 14.80% respectively was observed at 0-15 and 15-30 cm soil depth at 0.5 m (H_1) cutting height which was comparatively higher than May (Table 8). Similarly, high soil moisture was observed in September than in May in rest of the cutting heights (Table 8).

Morus M-5 had comparatively high soil moisture at all the cutting heights when compared with other three species. The soil moisture at 0.5 m (H_1) was 7.78 and 7.94 per cent in May whereas it increased to 15.90 and 15.82 per cent in September at 0-15 and 16-30 cm soil depths respectively (Table 8). A similar trend was observed at the other three cutting heights (Table 8).

4.4 Growth and biomass productivity

During this investigation the impacts of coppicing and pollarding treatments in *G. optiva*, *C. australis*, *B. variegata* and *Morus* M-5 in addition to root characteristics and resource sharing were also studied on growth attributes and biomass productivity potential under similar growing conditions.

4.4.1 Number of shoots per stump

The number of shoots per stump were counted in four agroforestry tree species at all the four cutting heights. In *Grewia optiva* (T_1) maximum number of shoots (80.0) were recorded at 1.0 m (H_2) cutting height, which was closely followed by 2.0 m (H_4) where the number of shoots were 79.5 (Fig. 7). At 1.5 m (H_3) the number of shoots per stump were 73.0 and the minimum number (30.2) was recorded at 0.5 m (Fig. 7). So significantly higher number of shoots per tree were observed under pollarding treatments (i.e. 1.0, 1.5 and 2.0 m) as compared to coppicing (0.5 m).

Likewise in *Celtis australis* the pollarding trees produced significantly higher number of shoots per tree than that in coppiced one. *Celtis australis* (T_2) recorded the maximum number of shoots per stump (48.5) at 1.5 m (H_3) cutting height (Fig. 7). Cutting height 1.0 m (H_2) and 2.0 m (H_4) were at par with each other with 35.7 and 35.5 shoots per stump, respectively (Fig. 7). Minimum number of shoots per stump (21.0) was recorded at 0.5 m (H_1).

In *Bauhinia variegata* (T_3), both 1.5 m (H_3) and 2.0 m (H_4) had equal (14.5) number of shoots per stump. At 1.0 m (H_2) the number of shoots per stump were 13.7 whereas at 0.5 m (H_1) the number of shoots per stump was 7.0 (Fig. 7).

Morus alba M-5 had maximum number of shoots (63.2) at 2.0 m (H_4) followed by 1.5 m (H_3) where the number of shoots were 48.5. At 0.5 m (H_1) the

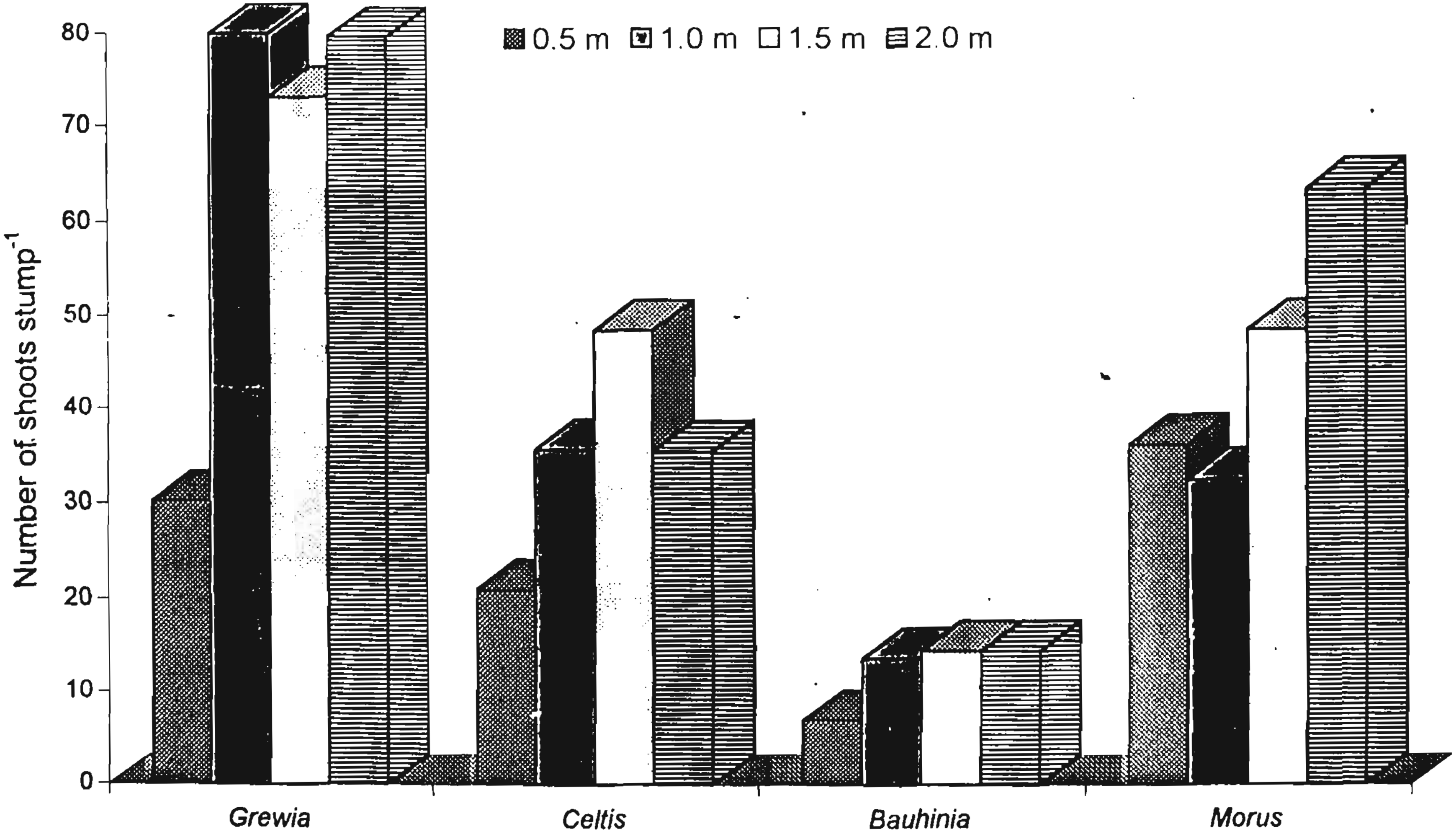

Fig. 7. Effect of coppicing and pollarding on number of shoots stump^{-1} in fou agroforestry tree species. CD(0.05) level to compare interaction between tree species and cutting heights (16.63)

number of shoots per stump was 36.2 and 1.0 m (H_2) recorded the minimum number of shoots (32.5) per stump (Fig. 7).

An overall comparison amongst all the four species at all the four cutting heights reveals that the maximum number of shoots per stump (80) were recorded at 1.0 m cutting height in G. optiva (T_1H_2) while minimum number of sprouts per stump (7) were recorded at 0.5 m cutting height in *B. variegata* (T_3H_1) (Fig. 7). Nevertheless it also becomes clear that pollarding treatments are more effective in producing higher number of shoots per tree over the coppicing treatment. In all the four agroforestry trees, *G. optiva* excells in shoot production.

4.4.2 Number of nodes in longest shoot

Number of nodes per longest shoot was counted in all the four tree species at all the cutting heights. There was a significant difference in the number of nodes per longest shoot implying the relative difference in the length of the respective shoots (Fig. 8).

In *Grewia optiva* (T_1) maximum number of nodes per longest shoot (29.75) was recorded at 2.0 m (H_4) cutting height, whereas the minimum number of nodes (25.75) were recorded at 0.5 m (H_1) cutting height. At 1.0 m (H_1) and 1.5 m (H_2) the number of nodes per longest shoot were 26.5 and 27.0, respectively (Fig. 8).

Celtis australis (T_2) recorded higher number of nodes as compared to *Grewia optiva* (T_1). Maximum number of nodes per longest shoot (48.25) were recorded at 1.0 m (H_1) cutting height followed by 0.5 m (H_1) where the number of nodes per longest shoot were 41.5 (Fig. 8). The number of nodes per longest shoot decreased at 1.5 m (H_3) and 2.0 m (H_4) cutting heights. At 1.5 m (H_3) the number of nodes per longest shoot were 33 whereas the minimum number of nodes per longest shoot (28.75) were recorded at 2.0 m (H_4) cutting height.

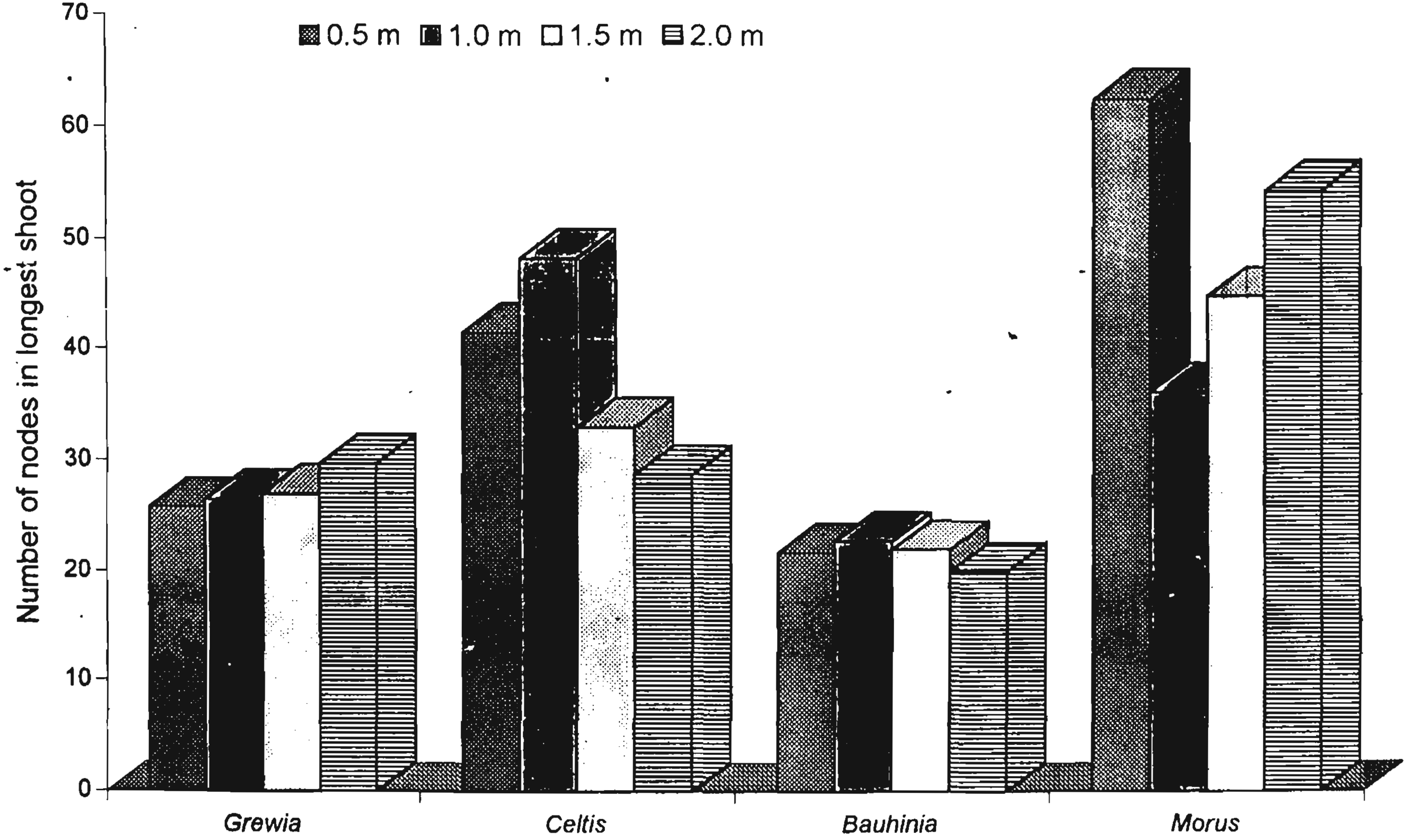

Fig. 8. Effect of coppicing and pollarding on number of nodes in longest shoot in four agroforestry tree species. CD(0.05) level to compare interaction between tree species and cutting heights (8.49)

Bauhinia variegata (T_3) did not show much difference in the number of nodes per longest shoot (Fig. 8). Here, all the cutting heights were at par with each other. Maximum number of nodes per longest shoot (22.75) were recorded at 1.0 m (H_1) cutting height whereas the minimum number of nodes per longest shoot (20) were recorded at 2.0 m (H_4) cutting height (Fig 8).

In *Morus* M-5 (T_4) there was a significant difference in the number of nodes per longest shoot as a result of coppicing and pollarding treatments (Fig. 8). At 0.5 m (H_1) cutting height the maximum number of nodes (62.25) per longest shoot were recorded followed by 2.0 m (H_4) and 1.5 m (H_3) cutting heights, where the number of nodes per longest shoot were 54.25 and 44.75, respectively (Fig. 8). At 1.0 m (H_2) the number of nodes per longest shoot were minimum (36).

A comparison between all the four tree species at all the four cutting heights reveals that the maximum number of nodes per longest shoot were observed in *Morus* M-5 whereas the minimum number of nodes per longest shoot in *B. variegata* (Fig. 8).

4.4.3 Shoot angle

The shoot angle for all the species was measured at all the four cutting heights. It is clear from Fig. 9 that statistically the variation in shoot angle was non-significant at different cutting heights.

Grewia optiva (T_1) recorded the maximum shoot angle (42.25°) at 1.5 m (H_3) followed by 0.5 m (H_1) and 2.0 m (H_4) where the shoot angles were 40.52 and 40.22°, respectively (Fig. 9). Minimum shoot angle (38.05°) was recorded at 1.0 m (H_2) cutting height.

Celtis australis (T_2) had shoot angles less than *G. optiva* (T_1), especially at 0.5 m (H_1), 1.5 m (H_3) and 2.0 m (H_4). *C. australis* recorded the maximum shoot

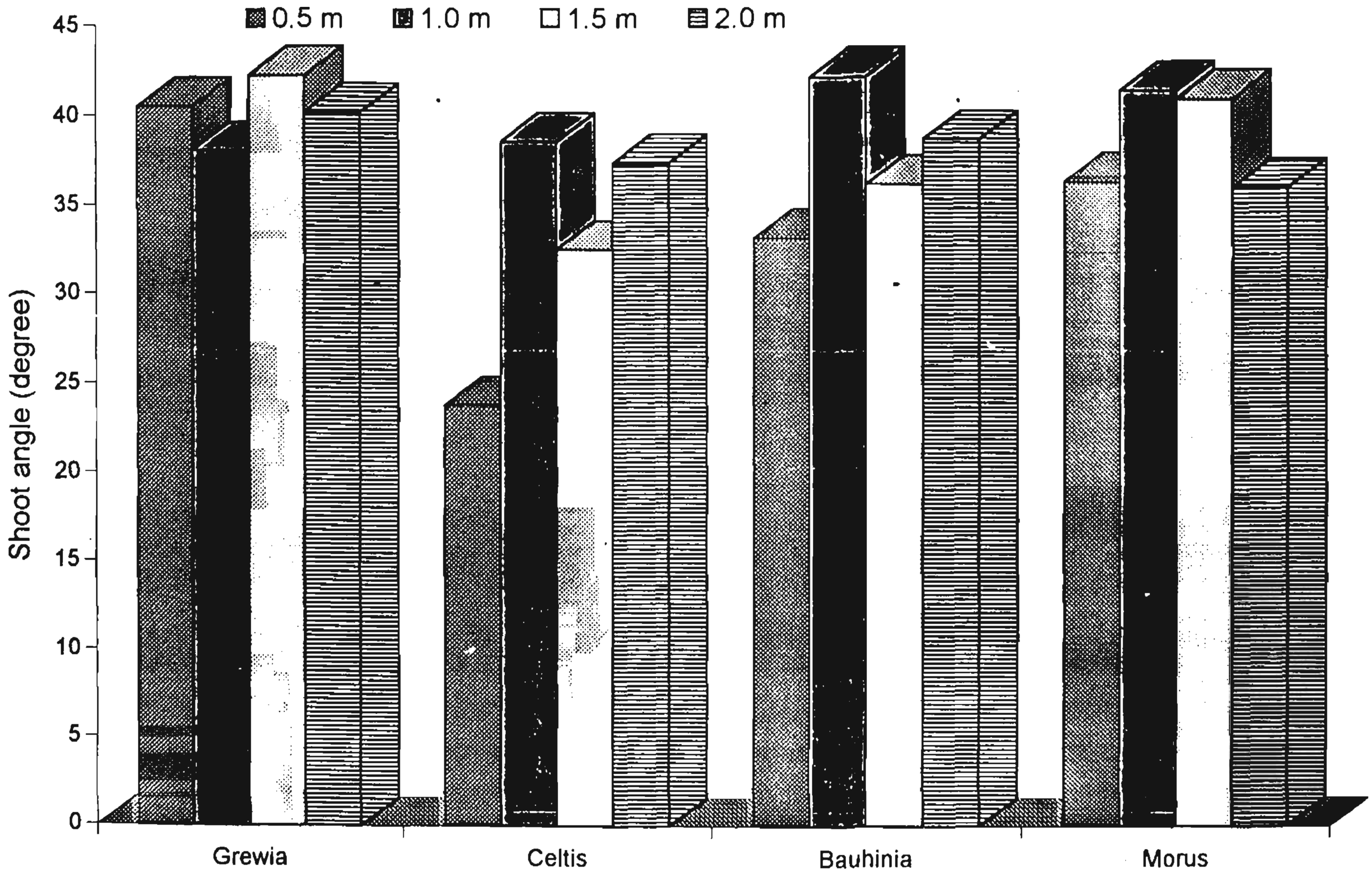

Fig. 9. Effect of coppicing and pollarding on shoot angle (degree) in four agroforestry tree species

angle (38.55°) at 1.0 m (H_2) cutting height whereas the minimum shoot angle (23.82°) was recorded at 0.5 m (Fig. 9). At 1.5 m (H_3) and 2.0 m (H_4) the shoot angles were 32.55 and 37.37°, respectively (Fig. 9).

In *Bauhinia variegata* (T_3) the shoot angle was maximum (42.17°) at 1.0 m (H_2) whereas the minimum (33.22°) at 0.5 m (H_1). The shoot angles at 1.5 m (H_3) and 2.0 m (H_4) were 36.20 and 38.70°, respectively (Fig. 9).

In *Morus* M-5 (T_4) the cutting height 1.0 m (H_2) recorded the maximum shoot angle (41.42°), closely followed by 1.5 m (H_3) with a shoot angle of 40.95°. At 0.5 m (H_1) and 2.0 m (H_4) the shoot angles were 36.35 and 36.02° (Fig. 9). The minimum shoot angle being at 2.0 m.

4.4.4 Leaf area

Leaf area was measured at all the four cutting heights in all the four agroforestry tree species. The leaf area was significantly affected by the cutting heights, both within and among the different tree species.

In *Grewia optiva* (T_1) the leaf area was maximum (54.30 cm²) at 2.0 m (H_4) followed by 1.5 m (H_3) where the leaf area was 53.67 cm². At 0.5 m (H_1) the leaf area was 51.37 cm². Minimum leaf area (49.03 cm²) was recorded at 1.0 m (H_2) (Fig. 10).

Celtis australis (T_2) had significant difference in leaf area at different cutting heights (Fig. 10). Maximum leaf area (17.65 cm²) was recorded at 0.5 m (H_1) followed by 16.72 cm² at 1.5 m (H_3) which was at par with 0.5 m (H_1). The leaf area at 1.0 m (H_2) was 14.15 cm² whereas the minimum leaf area (11.05 cm²) was recorded at 2.0 m (H_4) cutting height (Fig. 10).

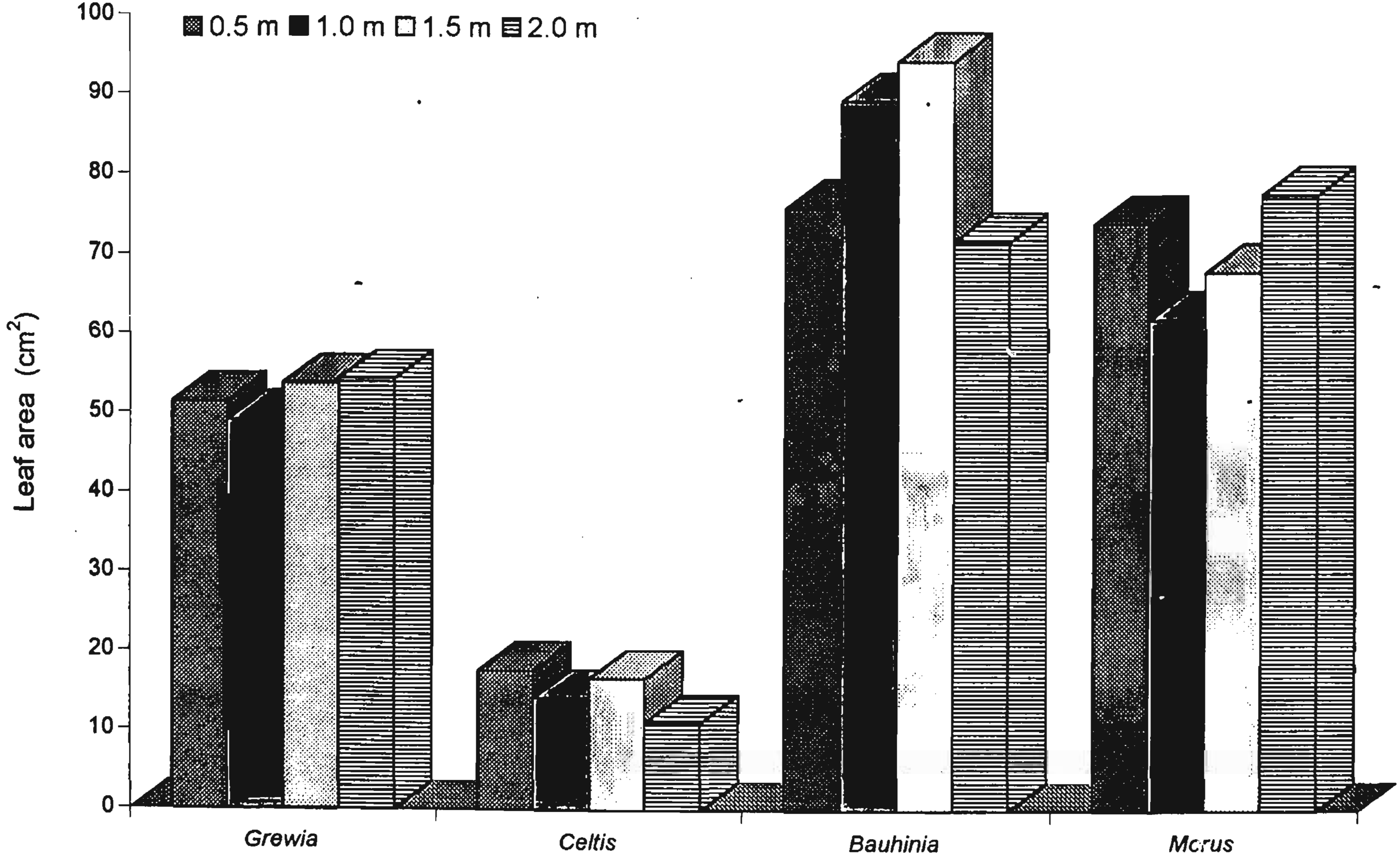

Fig. 10. Effect of coppicing and pollarding on leaf area in four agroforestry tree species. CD(0.05) level to compare interaction between tree species and cutting height (2.31)

Bauhinia variegata (T_3) showed the maximum leaf area (94.10 cm²) at 1.5 m (H_3) cutting height whereas the minimum leaf area (71.66 cm²) was recorded at 2.0 m (H_4) cutting height. The leaf area at cutting heights 0.5 m (H_1) and 1.0 m (H_2) were 75.72 and 89.02 cm², respectively (Fig. 10).

Morus M-5 (T_4) had maximum leaf area (77.52 cm²) at 2.0 m (H_4) cutting height. At 0.5 m (H_1) the leaf area was 73.90 cm², whereas the leaf area was 67.92 cm² at 1.5 m (H_4) cuttihg height. Minimum leaf area (62.02 cm²) was recorded at 1.0 m (Fig. 10).

On comparison amongst all the four tree species at all the cutting heights, it is inferred that the maximum leaf area is registered by *B. variegata* followed by *Morus* M-5 and *G. optiva* whereas the minimum in *C. australis* under similar growing conditions (Fig. 10).

4.4.5 Leaf area index (LAI)

Leaf area index (LAI) was determined for all the four coppiced and pollarded agroforestry trees. LAI was recorded at monthly intervals from May to September, 1998. Significant monthly variations in LAI were observed during the study period. The data representing LAI has been presented in Table 9.

In May the maximum LAI in *Grewia optiva* (T_1) was observed at 1.5 m (H_3) followed by 2.0 m (H_4) and 0.5 m (H_1) cutting height. The values of LAI corresponding to these cutting heights were 1.43, 1.22 and 1.17, respectively. Minimum LAI (1.10) was however, recorded at 1.0 m (Table 9). An increase in LAI was obsered from May onward at all the cutting heights in *G. optiva*. For example, at 2.0 m (H_4) cutting height LAI increased from 1.22 in May to 1.68 in June and 1.83 in July. In August, LAI at 2.0 m reached to a maximum of 1.87 and then decreased to 1.64 in September (Table 9). Similarly, the other cutting heights recorded an increasing trend from May onward, however, maximum LAI was

Table 9. Monthly variation in leaf area index (LAI) at different cutting heights in four agroforestry tree species

Tree species x Cutting heights	May		June		July		August		September	
	LAI	SE	LAI	SE	LAI	SE	LAI	SE	LAI	SE
T_1H_1	1.17	±0.22	1.24	±0.06	1.44	±0.17	1.42	±0.20	1.21	±0.16
T_1H_2	1.10	±0.14	1.31	±0.25	1.61	±0.15	1.69	±0.22	1.38	±0.29
T_1H_3	1.43	±0.21	1.70	±0.26	1.83	±0.13	1.66	±0.14	1.39	±0.19
T_1H_4	1.22	±0.29	1.68	±0.25	1.83	±0.18	1.87	±0.22	1.64	±0.18
Mean	1.23		1.48		1.68		1.66		1.40	
T_2H_1	0.85	±0.29	1.05	±0.18	1.09	±0.24	1.08	±0.21	0.92	±0.20
T_2H_2	0.93	±0.12	1.00	±0.20	1.16	±0.31	1.10	±0.20	1.03	±0.23
T_2H_3	0.80	±0.28	0.91	±0.24	0.97	±0.24	0.98	±0.21	0.87	±0.17
T_2H_4	0.88	±0.14	0.91	±0.12	0.96	±0.12	0.94	±0.22	0.79	±0.22
Mean	0.86		0.97		1.04		1.02		0.90	
T_3H_1	1.05	±0.11	1.10	±0.13	1.44	±0.11	1.57	±0.19	1.50	±0.13
T_3H_2	1.02	±0.15	1.11	±0.09	1.38	±0.17	1.57	±0.25	1.51	±0.12
T_3H_3	0.96	±0.25	1.01	±0.19	1.09	±0.09	1.03	±0.13	0.93	±0.15
T_3H_4	0.78	±0.09	0.89	±0.11	0.94	±0.12	0.95	±0.20	0.82	±0.16
Mean	0.95		1.03		1.21		1.28		1.19	
T_4H_1	1.42	±0.36	1.62	±0.11	1.86	±0.10	1.88	±0.26	1.68	±0.17
T_4H_2	1.71	±0.30	1.75	±0.20	1.94	±0.28	1.60	±0.16	1.11	±0.19
T_4H_3	1.49	±0.32	1.56	±0.16	2.01	±0.15	1.64	±0.27	1.31	±0.22
T_4H_4	1.62	±0.38	1.92	±0.33	2.32	±0.46	1.97	±0.08	1.80	±0.15
Mean	1.56		1.71		2.03		1.77		1.46	

$CD_{0.05}$	Species x Month	0.13
	Species x Height x Month	0.26

observed at 2.0 m (H_4) cutting height as compared to rest of the cutting heights (Table 9).

Celtis australis (T_2) had lower values of LAI as compared to *G. optiva* (T_1). As in case of *G. optiva*, LAI also increased from May to September at all the cutting heights in *C. australis*. In May the LAI was maximum (0.93) in *C. australis* at 1.0 m (H_2) cutting height followed by 0.88 at 2.0 m (H_4). At 0.5 m (H_1) the LAI was 0.86 whereas it was minimum (0.80) at 1.5 m (H_3) (Table 9). During June, LAI increased at all the cutting heights, it was found maximum (1.05) at 0.5 m (H_1), closely followed by 1.0 m (H_1) whereas in July maximum LAI (1.16) was observed at 1.0 m (H_2). During August and September there was a slight decrease in LAI. For example, LAI at 1.0 m decreased to 1.10 in August and a further decrease was observed in September where LAI was 1.03 (Table 9). A similar trend was observed at the remaining cutting heights (Table 9).

Bauhinia variegata (T_3) had higher values of LAI than *C. australis* at all the cutting heights (Table 9). In May, maximum LAI (1.05) was observed at 0.5 m (H_1) cutting height which decreased with the increase in cutting height. At 1.0 m (H_2) and 1.5 m (H_3) LAI was 1.02 and 0.96, respectively. Minimum LAI 0.78 was observed at 2.0 m (H_4) cutting height. Like other species, the LAI followed an increasing trend from May till September but here the LAI values were maximum during the month of August and a very little decline was observed in LAI even up to September as compared to rest of the species, especially at 0.5 (H_1) and 1.0 m (H_2) cutting heights (Table 9).

In *Morus* M-5 (T_4) in May, LAI ranged between 1.42 to 1.71 within the four cutting heights. Maximum LAI (1.71) was recorded at 1.0 m (H_1) cutting height followed by 2.0 m (H_4) and 1.5 m (H_3) where the values for LAI were 1.62 and 1.49, respectively while at 0.5 m (H_1) the minimum LAI (1.42) was recorded (Table 9). In *Morus* too, an increasing trend in LAI was observed with LAI reaching maximum during July where LAI was maximum (2.32) at 2.0 m (H_4). However, a sharp fall in LAI was observed in Morus after July. LAI recorded a decrease during August which continued up to September (Table 9).

Irrespective of cutting heights maximum LAI was observed in *Morus* M-5 followed by *G. optiva* and *B. variegata*. Minimum LAI was observed in case of *C. australis*. All the tree species recorded higher values for LAI during the months of June, July and August (Table 9)

4.4.6 Foliage biomass

In September, 1998 all the four coppiced and pollarded tree species were harvested. Foliage biomass for each tree was determined and expressed as kilogram per tree on fresh weight basis.

In *Grewia optiva* (T_1) the foliage biomass increased with increase in the cutting heights. Maximum foliage biomass (1.13 kg tree^{-1}) was recorded at 2.0 m (H_4) cutting height followed by 1.5 m (H_3) where the foliage biomass was 0.64 kg tree^{-1}. At 1.0 m (H_2) foliage biomass decreased to 0.51 kg tree^{-1} whereas at 0.5 m (H_1) the foliage biomass (0.39 kg tree^{-1}) was minimum (Fig. 11).

Celtis australis (T_2) recorded the maximum foliage biomass (0.34 kg tree^{-1}) at 1.0 m (H_2) cutting height, followed by 0.5 m (H_1) cutting height with a foliage biomass of 0.24 kg tree^{-1}. At 1.5 m (H_3) the foliage biomass was 0.20 kg tree^{-1} whereas the minimum foliage biomass (0.18 kg tree^{-1}) was recorded at 2.0 m (Fig. 11).

In *Bauhinia variegata* (T_3) maximum foliage biomass (0.77 kg tree^{-1}) was recorded at 1.0 m (H_2) followed by 0.54 kg tree^{-1} at 1.5 m (H_3) cutting height. Cutting heights 0.5 m (H_1) and 2.0 m (H_4) were at par with each other with a foliage biomass of 0.45 kg tree^{-1} (Fig. 11).

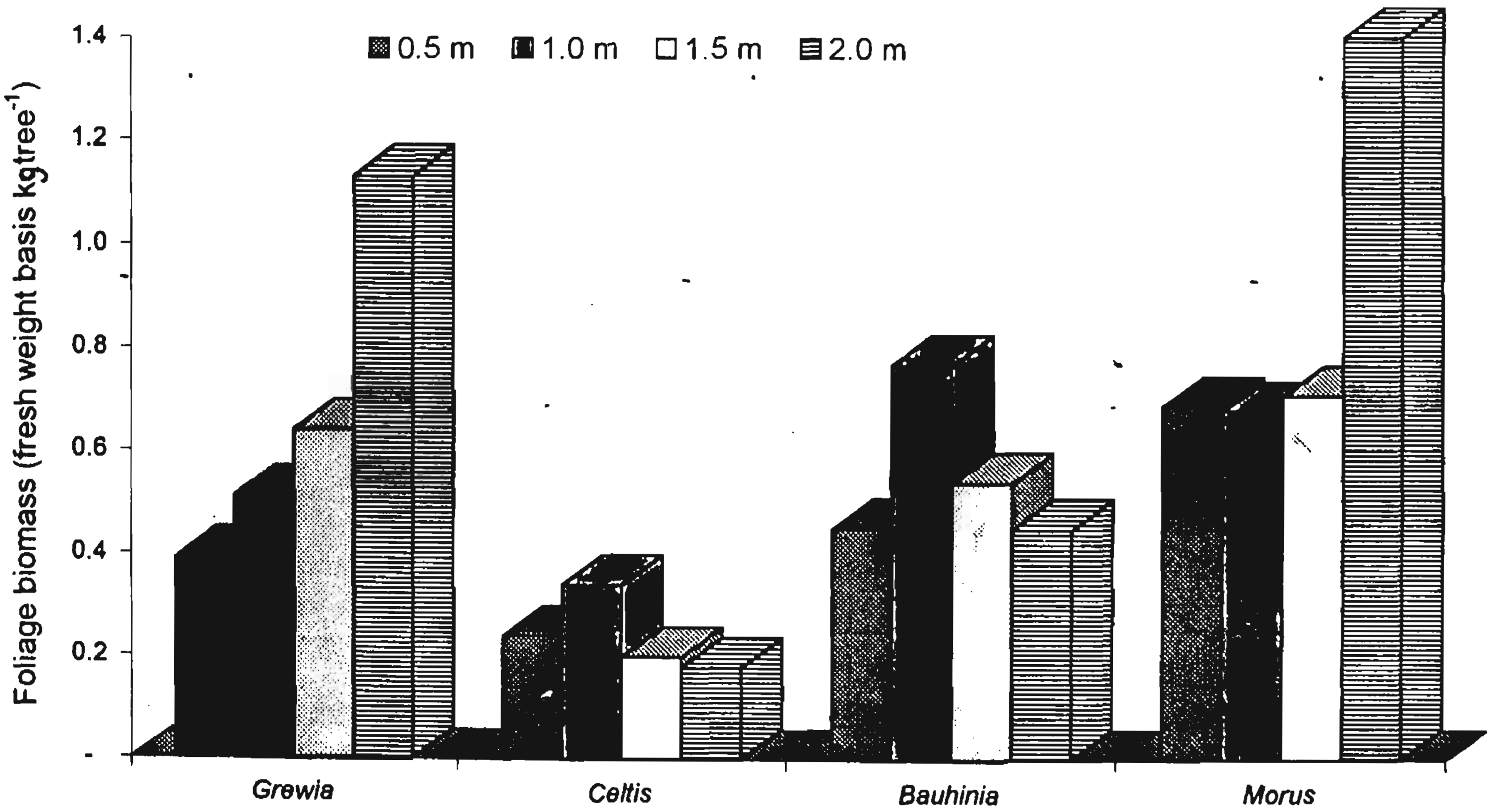

Fig. 11. Effect of coppicing and pollarding on foliage biomass in four agroforestry tree species. CD(0.05) level to compare interaction between tree species and cutting heights (0.053)

Morus M-5 (T_4) had the maximum foliage biomass (1.40 kg tree^{-1}) at 2.0 m (H_4) which decreased to 0.71 kg tree^{-1} at 1.5 m (H_3) cutting height. Cutting heights 0.5 m (H_1) and 1.0 m (H_2) had the foliage biomass of 0.69 and 0.68 kg tree^{-1}, respectively (Fig. 11).

From Fig. 11 it is clear that coppicing and pollarding significantly influenced the foliage biomass (kg tree^{-1}) in all the four agroforestry tree species. An overall comparison shows the maximum foliage biomass production in *Morus* at 2.0 m (T_4H_4) followed by *G. optiva* and *B. variegata* whereas the minimum in *C. australis* under similar conditions (Fig. 11)

4.4.7 Branchwood biomass

Coppicing and pollarding treatments resulted in a significant difference in the production of branchwood biomass (fresh weight basis, kg tree^{-1}) in all the four agroforestry tree species (Fig. 12).

In *Grewia optiva* (T_1) the branchwood biomass increased with the increase in the cutting heights from 0.5 m (H_1) to 2.0 m (H_4). At 2.0 m (H_4) the maximum branchwood (2.21 kg tree^{-1}) was recorded, followed by 1.26 kg tree^{-1} at 1.5 m (H_3). However, there was not much difference in the branchwood biomass at 1.0 m (H_2) and 0.5 m (H_1) where the branchwood biomass was 0.76 and 0.73 kg tree^{-1}, respectively (Fig. 12).

Celtis australis (T_2) recorded the maximum branchwood biomass (0.73 kg tree^{-1}) at 1.0 m (H_2) cutting height whereas the minimum branchwood biomass (0.35 kg tree^{-1}) was recorded at 2.0 m (H_4) cutting height. At 0.5 (H_1) and 1.5 m (H_3) the branchwood biomass was 0.49 and 0.40 kg tree^{-1}, respectively (Fig. 12).

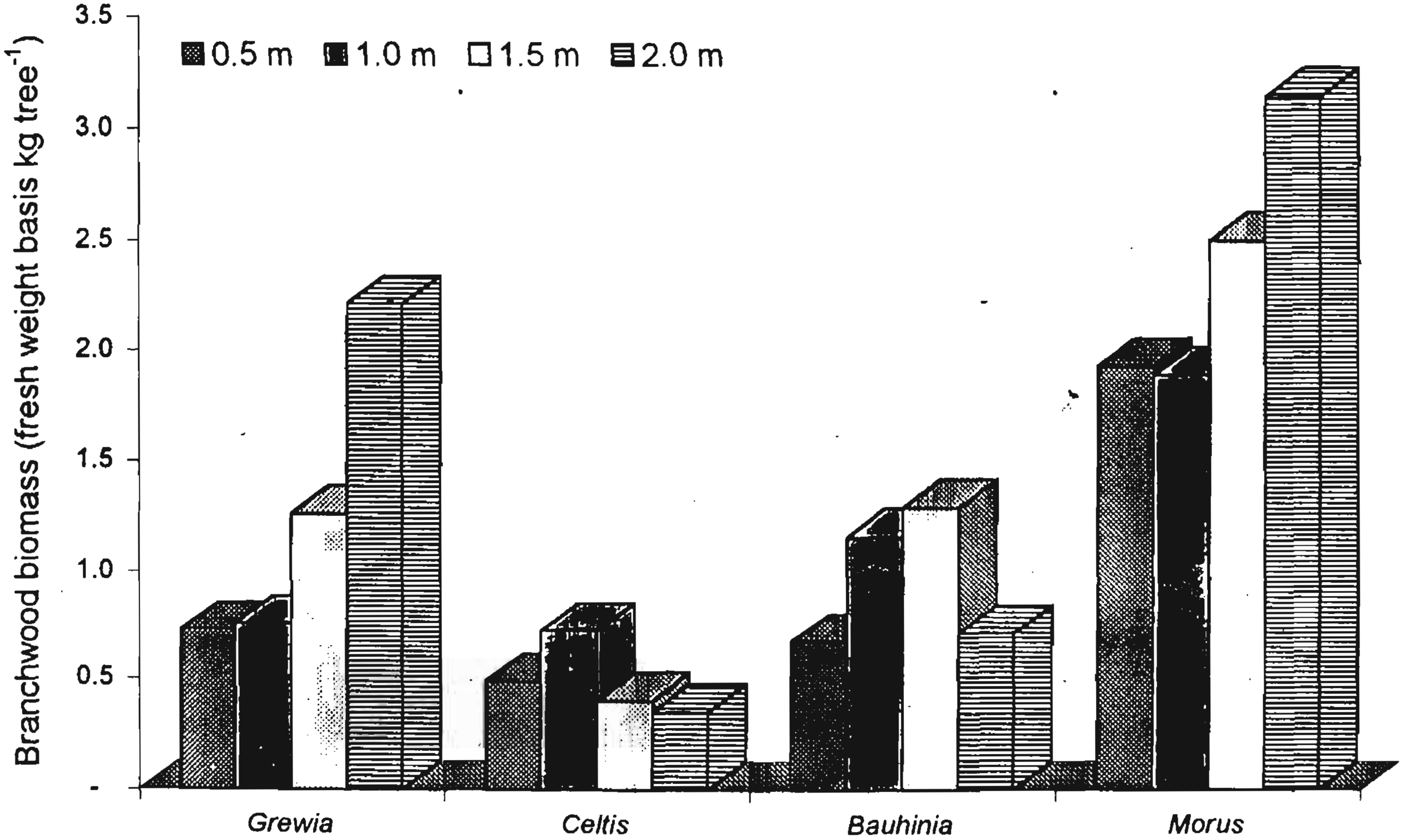

Fig. 12. Effect of coppicing and pollarding on branchwood biomass in four agroforestry tree species. CD(0.05) level to compare interaction between tree species and cutting heights (0.20)

In *Bauhinia variegata* (T_3) the branchwood biomass registered increasing trend from 0.5 m (H_1) to 1.5 m (H_3) after which it again decreased. Maximum branchwood biomass (1.29 kg tree^{-1}) was recorded at 1.5 m (H_3), followed by 1.0 m (H_2) and 0.5 m (H_1) where the branchwood biomass was 1.16 and 0.68 kg tree^{-1}. At 2.0 m (H_4) the branchwood biomass was 0.72 kg tree^{-1} (Fig. 12).

Morus M-5 recorded the maximum branchwood biomass (3.14 kg tree^{-1}) at 2.0 m (H_4) followed by (2.50 kg tree^{-1}) 1.5 m (H_3). The branchwood biomass at cutting heights 0.5 m (H_1) and 1.0 m (H_2) were at par with each other with values of 1.89 and 1.93 kg tree^{-1}, respectively (Fig. 12).

On comparison *Morus* M-5 and *G. optiva* have been found to excell over *B. variegata* and *C. australis* with relation to branchwood biomass production.

4.4.8 Leaf to shoot ratio (%)

The results with respect to leaf to shoot ratio during the present investigation have been shown in Fig. 13. It is clear that coppicing and pollarding treatments have not affected this attribute in *G. optiva*. The values for leaf to stem ratio have been found to vary between 50.60 to 53.47% (Fig. 13)

Similar results were obtained for *C. australis* where treatments did not affect leaf to shoot ratio significantly. The values ranged between 46.64 and 50% with minimum value i.e. 46.64% at 1.0 m cutting height (Fig. 13).

In case of *B. variegata*, the values for leaf to shoot ratio were found to be significantly influenced by coppicing and pollarding treatments. For example, leaf to shoot ratio was found to be maximum i.e. 66.67 and 66.50% at 0.5 m and 1.0 m cutting height, respectively whereas the value for the same was minimum (41.67%) at 1.5 m cutting height (Fig. 13). Foliage contribution was found to be 59.90% at 2.0 m cutting height (Fig. 13).

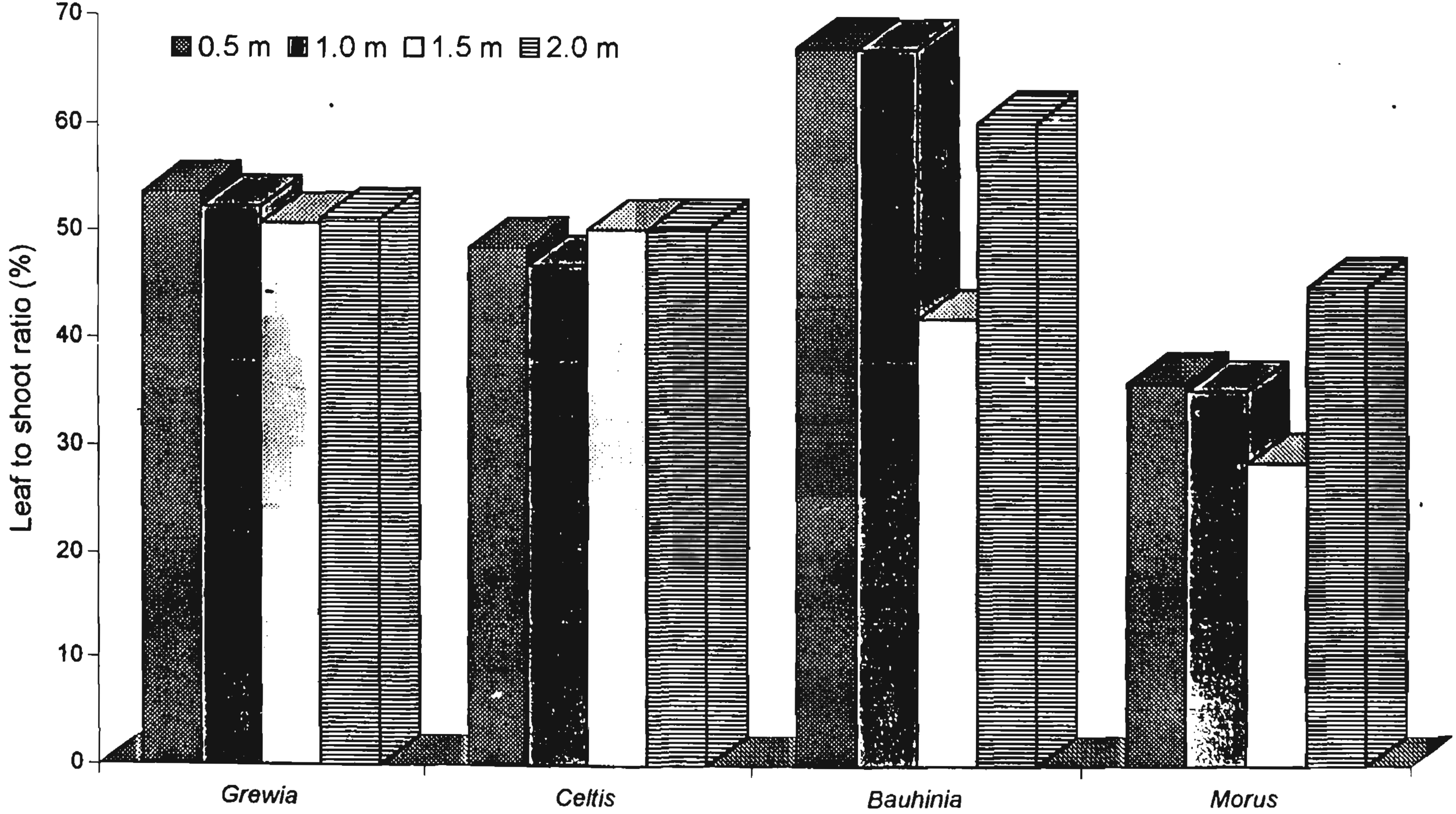

Fig. 13. Effect of coppicing and pollarding on leaf to shoot ratio in four agroforestry tree species. CD(0.05) level to compare interaction between tree species and cutting heights (2.30)

In *Morus* M-5, the maximum leaf to stem ratio was found at 2.0 m cutting height where value was 44.60% while the minimum was observed at 1.5 m cutting height. Leaf to shoot ratio at the remaining heights were 35.90 and 35.10% under similar conditions (Fig. 13).

4.4.9 Total biomass

Total biomass (fresh weight basis) was significantly affected by the coppicing and pollarding treatments in all the four agroforestry trees as evident from Fig. 14.

In *Grewia optiva* (T_1) the total biomass increased with increase in cutting heights up to 2.0 m. At 2.0 m (H_4) cutting height the total biomass was maximum (3.33 kg tree^{-1}) which decreased to 1.90 kg tree^{-1} at 1.5 m (H_3) cutting height. At 1.0 m (H_2) it further decreased to 1.27 kg tree^{-1} and at 0.5 m (H_1) the minimum biomass (1.11 kg tree^{-1}) was recorded (Fig. 14).

Celtis australis (T_2) recorded an increase in the total biomass up to 1.0 m (H_2) cutting height after which it started decreasing with an increase in the cutting height. Maximum total biomass (1.07 kg tree^{-1}) was recorded at 1.0 m (H_2) cutting height whereas the minimum biomass (0.53 kg tree^{-1}) was recorded at 2.0 m (H_2) cutting height. At 0.5 m (H_3) and 1.5 m (H_1) the total biomass was 0.72 and 0.60 kg tree^{-1}, respectively (Fig. 14).

Bauhinia variegata (T_3) also recorded an increase in total biomass with the increase in cutting height up to 1.0 m (H_2). Total biomass in *B. variegata* was 1.12 kg tree^{-1} at 0.5 m (H_1) cutting height which increased to 1.93 kg tree^{-1} at 1.0 m (H_2) cutting height (Fig. 14). At 1.5 m (H_3) the total biomass was 1.83 kg tree^{-1} which was at par with 1.0 m (H_2). At 2.0 m (H_4) the total biomass decreased to 1.17 kg tree^{-1} (Fig. 14).

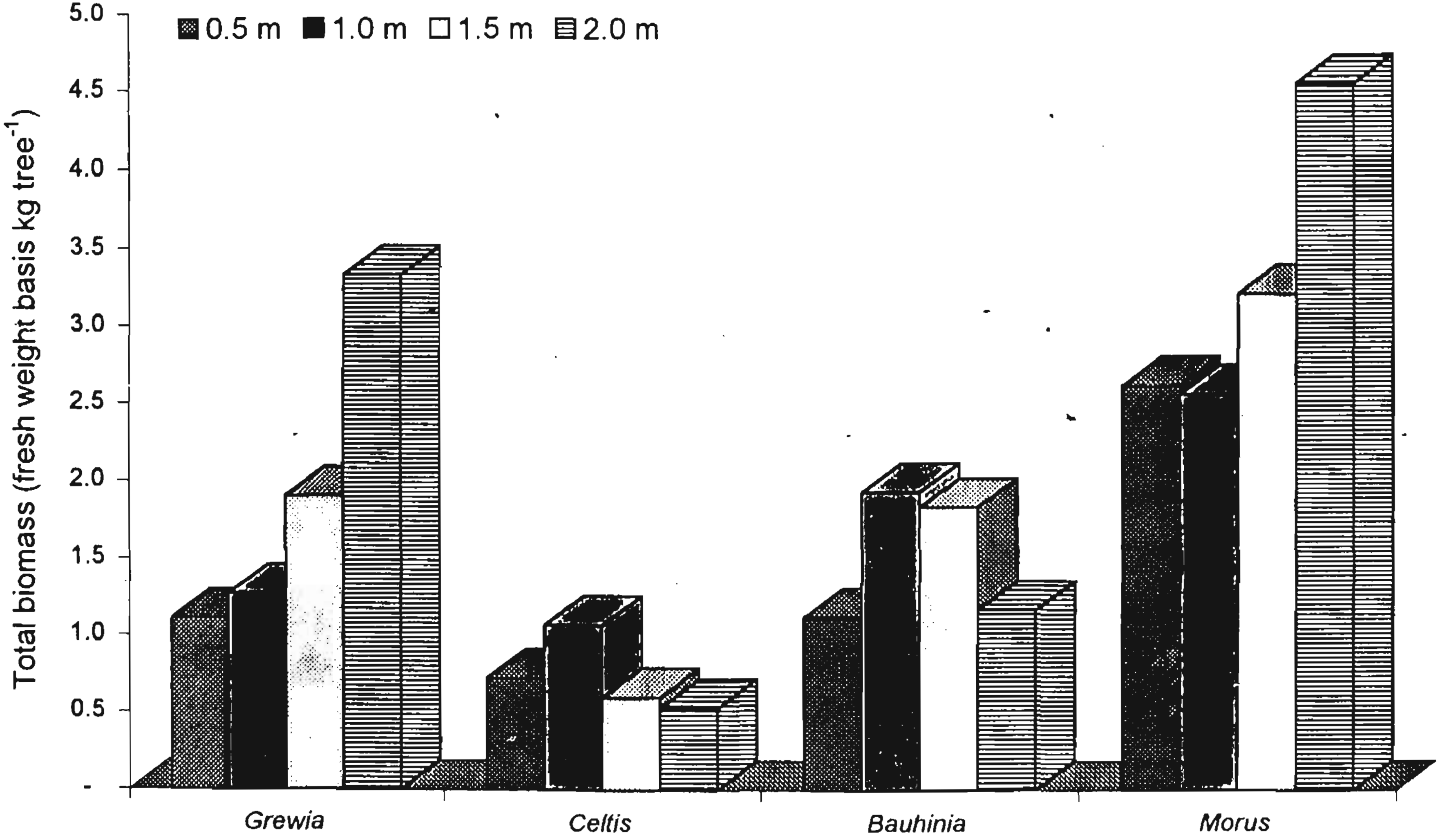

Fig. 14. Effect of coppicing and pollarding on total biomass in four agroforestry tree species. CD(0.05) level to compare interaction between tree species and cutting heights (0.23)

In *Morus* M-5 (T_4) the total biomass was maximum (4.54 kg tree^{-1}) at 2.0 m (H_4) cutting height followed by 3.21 kg tree^{-1} at 1.5 m (H_3) cutting height (Fig. 14). The cutting heights 0.5 m (H_1) and 1.0 m (H_2) were at par with each other with total biomass of 2.62 and 2.56 kg tree^{-1}, respectively.

Morus M-5 recorded an overall highest total biomass 4.54 kg tree^{-1} (T_4H_4) whereas *C. australis* at 2.0 m (T_2H_4) recorded the lowest total biomass of 0.53 kg tree^{-1} among all the four tree species at all the four cutting heights (Fig. 14).

Table 10. Effect of coppicing and pollarding on total biomass (fresh weight basis) in t ha^{-1} in four agroforestry tree species

Cutting height	Tree species			
	G. optiva	*Celtis australis*	*Bauhinia variegata*	*Morus* M-5
0.5 m	2.95	1.91	2.98	6.98
1.0 m	3.38	2.85	5.14	6.82
1.5 m	5.06	1.59	4.87	8.55
2.0 m	8.87	1.41	3.11	12.10

Impact of coppicing and pollarding treatments on total biomass production ha^{-1} in *G. optiva*, *C. australis*, *B. variegata* and *Morus* M-5 has been expressed in Table 10. Maximum total biomass has been observed in *Morus* M-5 where the maximum total biomass production was 12.10 t ha^{-1} at 2.0 m pollarding height. *Morus* was followed by *G. optiva*, where maximum total biomass was 8.87 t ha^{-1} at 2.0 m pollarding height. *B. variegata* produced the maximum total biomass 5.14 t ha^{-1} at 1.0 m cutting height, whereas *C. australis* produced the maximum biomass (2.85 t ha^{-1}) at 1.0 m cutting height.

So, it is also clear that during the present investigation. *Morus* M-5 and *G. optiva* have excelled in total biomass production over *C. australis* and *B. variegata* at all the four cutting heights.

DISCUSSION

5

DISCUSSION

The results of the present investigation entitled, "Influence of coppicing and pollarding on water use efficiency, light transmission and root characteristics in agroforestry tree species", where efforts have been made to underline the impacts of coppicing and pollarding treatments on various aspects including root architecture, resource sharing and capturing, soil moisture utilization, growth and biomass production in *Grewia optiva*, *Bauhinia variegata*, *Celtis australis* and *Morus* M-5 have been discussed under the following heads :

5.1 Root characteristics
5.2 Resource capturing
5.3 Soil moisture utilization
5.4 Growth and biomass production

5.1 Root characteristics

Understanding of the growth, development and biomass production of the above ground portion of most of the agroforestry trees have reached a relatively sophisticated level, however, the quantum of information on the under ground portion of the trees are less advanced. There is practically no information available on the extent to which the root characteristics are influenced through canopy management practices like coppicing and pollarding. This is of increased importance for trees which grow in association with other crops, where interaction between root system characteristics and their resultant activity are likely to be critical to optimising the performance of agroforestry systems. In agroforestry, these considerations influence the success of the system as a whole and their ability to retain nutrients within the tree-crop complex. The supply of soil reserves to the above ground part of the plant is dependent on the root networking available for uptake at particular time in relation to demand . This is modified by allocation of photosynthates from the leaves to the roots. Whenever the above ground parts are manipulated through management practices, the below ground parts do get affected which will have a long lasting effects on the growth, vigour and performance of an individual tree. During the present investigation, coppicing and pollarding treatments in *G. optiva*, *B. variegata*, *C. australis* and *Morus* M-5 have been found to have significant regulative impacts on various root attributes.

5.1.1 Number of proximal roots

It is evident from data in figure 1 that significant interspecific differences with relation to number of proximal roots were observed where *G. optiva* was found to have the highest number of proximal roots followed by *Morus* M-5 and *C. australis*. *B. variegata* showed the minimum number of proximal roots. However, coppicing and pollarding treatments have not affected the number of proximal roots significantly. This is true for all the four agroforestry tree species. This is probably due to the fact that coppicing and pollarding treatments were imposed on these tree species four years after their establishment. The formation of proximal roots must have been completed much earlier, it is the growth and development which continue with the passage of time.

5.1.2 Number of lateral roots

It is true that not only the upward flow of resources from the soil depend on the root networking, constituted by the formation of lateral roots but nevertheless confirms the firmness of the plant in the soil. It is this part of the root system which alongwith finer roots of second and third order makes the entire feeding zone. The development of this portion of a tree is a complex process in which development at any point in time is influenced both by the current provision of assimilates and the previous development of the root system. During the present investigation, coppicing and pollarding treatments have been found to significantly affect the affect the growth and development of lateral roots. This is important since this will have direct bearing on the vigour, performance and sustainable production of biomass in these agroforestry tree species. Out of these four agroforestry tree species *Morus* M-5 have produced significantly higher number of lateral roots as compared to *G. optiva*, *C. australis* and *B. variegata*. Minimum number of lateral roots were observed in *B. variegata* under similar growing conditions (Fig. 2). In *G. optiva* lateral root number increased with cutting heights up to 1.5 m while in *C. australis* the maximum number was observed at 2.0 m cutting height. In case of *B. variegata* reverse trend was observed where lateral roots decreased with increasing cutting heights. *Morus* produced maximum root number (71.50) at 1.0 m cutting height, however, the same declined to 33.5 at 2.0 m cutting height. This decline in numbr of lateral roots at higher pollarding height in *Morus* may be the result of allocation of higher photosynthates to the growth and development of higher number of proximal roots, at this height. Whatsoever may be the reasons but one thing is clear that coppicing and pollarding certainly regulate the formation and subsequent growth of lateral roots which, indeed, will go a long way in deciding the longevity and vigour of trees. As mentioned earlier the provision of assimilates and their partitioning which can be influenced by range of factors within the root system have direct bearing on the root networking. Berta *et al.* (1990); Hooker *et al.* (1992) and Atkinson (1992) have also made similar observations where many factors are amenable for the development of root system in trees.

5.1.3 Diameter of proximal roots

In addition to interspecific variation in diameter of proximal roots, coppicing and pollarding treatments during the present investigation have been found to significantly affect the diameter of proximal roots. In general, the proximal roots in *Morus* M-5 showed the maximum root diameter at all the cutting heights as compared to the remaining tree species (Fig. 3). This was followed by *G. optiva*. The minimum proximal root diameter was observed in *B. variegata*. Root diameter in *G. optiva* and *C. australis* increased with increasing cutting heights, however, the same in *Morus* was observed up to 1.0 m cutting height which declined thereafter at 1.5 and 2.0 m cutting heights. So it is clear that coppicing and pollarding treatments have not significantly affected the number of proximal roots (Fig. 1) although diameter growth is regulated through these management practices. This differential behaviour in diameter growth can be ascribed to the availability and partitioning of resources at the advent of coppicing and pollarding.

5.1.4 Diameter of lateral roots

Diameter growth of lateral roots have also been found to vary in four coppiced and pollarded agroforestry tree species under the similar growing condition. Diameter growth of the lateral roots reflect the congenial growing condition around the root zone although the net root activity is more of a function of total number of lateral roots as well as their further branching pattern. During the present investigation coppicing and pollarding treatments have been found to have more effects on the number rather than the diameter of lateral roots. This may be due to the fact that biological energy in the form of resources is utilized more towards the formation of new and finer roots year after year. Fownes and Anderson (1991) have shown earlier that management practices have little impact on the diameter growth of lateral roots.

5.1.5 Root angle of proximal roots

Root orientation determines the relative penetration of roots into the soil. No distinct pattern was observed in the root angles as a result of coppicing and pollarding treatments, but the root angles differed from one species to another. Comparatively higher root angles were observed in *G. optiva* and *B. variegata* than *C. australis* and *Morus* M-5. A higher proximal root angle signifies more vertical roots whereas a low proximal root angle means more horizontal or shallow rooting network. Lesser the root angle, more root networking will be present in the top most layers of soil resulting in more competition with the agriculture crops.

During this study *Morus* M-5 has shown the minimum proximal root angle as compared to the remaining agroforestry tree species. This means that *Morus* spreads proximal roots horizontaly below the soil surface and produces effective root networking in the upper soil profile. This indicates that *Morus* will be more competitive with the associated agricultural crops, especially when resources are limited.

5.1.6 Root distribution

Root distribution is another parameter which indicates the extent of competition with the associated crops and utilization of resources in a particular direction. Coppicing and pollarding tretments during the present study have not been found to significantly affect distribution of proximal roots. This may be due to the fact that the distribution of proximal roots had already taken place before the management practices were imposed. However, irrespective of the cutting heights, *G. optiva* was found to extend proximal roots in east-north direction. In *C. australis* out of total proximal roots 70% were found in the west-north direction. Similar was the pattern in *B. variegata*. However in *Morus*, out of the total roots about 84% were extended in north-east direction. So root networking in *Morus* and *Grewia* will pose a tough competition with the crops, particularly growing in the north to the tree trunk.

So it is clear from the preceding discussion that tree management practices like coppicing and pollarding are potentially capable of influencing size and quality of root networking mainly through regulating flow and partitioning of assimilates in the root system. It is true that trees at the advent of management practices undergo drastic changes with regards to assimilation and/or utilization of resources. So the accumulation of assimilates and their reallocation will decide the growth and development of both below and above ground parts.

5.2 Resource capturing

Tree management practices like coppicing and pollarding are practiced to get better foliage and branchwood biomass on one hand and to regulate shade in agroforestry systems. These management practices, however, may have different influences on growth, vigour, longevity and/or various vital physiological processes indispensable for the better performance of trees. The vigour, biomass productivity potential etc. of trees in addition to many other factors, depend on how the tree canopy is capturing as well as utilizing the critical resources. It is true that the growth and total biomass production is the cumulative effect of all the resource capturing parameters like water relation, photosynthesis, water use efficiency, light transmission, soil moisture content etc. The diurnal and or monthly variation in resource capturing attributes play an important role in overall performance of tree species. During the present investigation coppiced and pollarded trees of *G. optiva*, *C. australis*, *B. variegata* and *Morus* M-5 have been compared for various resource capturing parameters.

5.2.1 Transpiration rate

During the present study coppiced and pollarded trees of *G. optiva*, *C. australis*, *B. variegata* and *Morus* M-5 have been found to record significant monthly variations in transpiration rate. For example, all the four agroforestry tree species have shown higher mean transpiration rate during the month of May, June and July as compared to August and September, except that *C. australis* has recorded higher transpiration during September than that during the preceding month (Table 1). Out of the four agroforestry tree species *B. variegata* has been observed to be registering highest transpiration rate, followed by *Morus* M-5 and *C. australis*. *G. optiva* has shown low rate of transpiration at all the cutting heights under similar conditions. Significant but no definite pattern has been found with respect to coppicing and pollarding treatment.

Total amount of water transpired per tree reveals that *B. variegata* transpires maximum amount of water where values irrespective of the cutting heights ranged between 77.66 and 253.20 g H_2O tree^{-1} hr^{-1}. This was closely followed by *Morus* where values for transpired water ranged between 38.10 and 215.20 g H_2O tree^{-1} hr^{-1}. The minimum amount of water was transpired by *G. optiva* under similar growing conditions.

Higher transpiration although reflects the better functioning of stomatal apparatus but nevertheless may lead to development of water deficits, if transpiration exceeds water uptake. It is also true that high transpiring tree species will pose a strong competition for available soil moisture content with the agricultural crops, especially when soil moisture is a constraint. The decreased transpiration in lopped trees of Alnus has been reported by Singh and Thompson (1995) whereas other factors have been rendered amenable for variation in transpiration rate by workers like Taylor (1975), Pertti *et al.* (1975), Bhatt (1990).

5.2.2 Stomtal conductance

Significant interspecific variations with respect to stomatal conductance have been observed during the present investigation. Coppicing and pollarding have also been found to affect the stomatal conductance although definite pattern was not observed. Increased stomatal conductance has resulted in increased transpiration rate and vice-versa. Irrespective of the cutting heights, *B. variegata* showed the maximum values of stomatal conductance followed by *Morus* M-5 and *C. australis* while *G. optiva* registered the minimum stomatal conductance under similar growing conditions (Table 3). Sometimes higher stomatal conductance has direct relationship with photosynthetic rate and total biomass production, however, during the present investigation, *B. variegata* with maximum stomatal conductance has neither shown comparatively higher rate of photosynthesis nor higher total biomass production, whereas *G. optiva* under similar conditions with lowest stomatal conductance has shown comparatively higher photosynthetic rate as well as foliage and branchwood biomass. This is mainly because photosynthesis as well as biomass production, in addition to stomatal conductance, are controlled by many extrinsic and intrinsic factors.

5.2.3 Photosynthetic rate

The biomass production potential of tree species, indeed, depends on the ability of an individual tree species to maintain equilibrium in favour of higher anabolic processes. So trees with higher photosynthetic rates have the opportunity for higher assimilation and thereby higher biomass production. The result of present investigation have confirmed this statement where comparatively higher photosynthetic rates in *Morus* M-5, *G. optiva* and *B. variegata* have resulted in higher total biomass production. Monthly variations in photosynthetic rates are equally important as these indicate the efficiency of any plant under the prevailing growing conditions. During this study *G. optiva* and *Morus* M-5 registered an increasing trend in photosynthesis from May to September whereas the same in *B. variegata* was seen at higher cutting height only. *C. australis* did not show any trend.

It is also clear from data in Table 4 that different cutting heights have not affected photosynthetic rate drastically in all the four agroforestry tree species. The higher photosynthetic rates in *Morus* and Grewia during the present study may be ascribed to higher leaf area index and efficient use of available resources. In addition, photosynthetic rate per se depends on canopy size, shape, phyllotaxy, position of leaf, exposed canopy area, light interception, stomatal behaviour, leaf water potential etc. This is reflected in higher interception of photosynthetically active radiations as well as higher water use efficiency in *Morus* and *Grewia* as compared to *Celtis* and *Bauhinia* under similar conditions. This is important and essential, especially under agroforestry systems where highly efficient utilization of limited resources are needed for better productivity. Seasonal variations in photosynthetic rates have also been reported earlier (Pertti *et al.*, 1975; Koike and Sakagami, 1985; Tschaplinski, 1991).

5.2.4 Light transmission

It has been observed during the present investigation that irrespective of the coppicing and pollarding treatments, *Morus* M-5 canopy has intercepted the maximum amount of photosynthetically active radiations from May to August and has permitted only 7 to 11.85 per cent of photosynthetically active radiations to penetrate through the canopy. Light transmission ratio was also comparatively lower in *G. optiva* as compared to *C. australis* and *B. variegata* (Table 5). The lower transmission ratio in *Morus* and Grewia are reflected in greater and better foliage biomass. This is true that light penetration through the tree is usually determined by the size, shape and compactness of canopy. Trees with low LAI (*Celtis* and *Bauhinia*) have transmitted more light beneath canopy. So more interception of PAR as in case of *Morus* and *Grewia* during the present study is beneficial and nevertheless useful for managing higher foliage and fuelwood production. However, this may not provide workable, acceptable and beneficial option in case trees form part of agroforestry system. For example, increase in planting density and crown area will drastically affect the pattern of resource sharing between tree and agricultural crops and may affect productivity through shade effects.

5.2.5 Difference in above and beneath canopy temperature

Canopies of all the four coppiced and pollarded trees of *G. optiva, C. australis, B. variegata* and *Morus* M-5 have maintained lower beneath canopy temperature than that in the open. The maximum difference in below canopy temperature was observed under *Morus* where the decrease in air temperature ranged between 0.30 and 1.97°C. This difference for the remaining tree species was of lower magnitude with the minimum difference in temperature below the canopy of *Celtis*. This decrease in below canopy air temperature is indicative of microsite environment improvement potential of individual tree species as well as the amount of solar radiation reaching beneath tree canopies. This situation under certain circumstances may be of great significance for the better water relations and photosynthetic efficiency of the arable crops grown under the tree canopies.

5.2.6 Water use efficiency

In general, higher water use efficiency have been observed in *Morus* and Grewia as compared to Celtis and Bauhinia. The higher water use efficiency in these tree species have been found to be closely related to biomass production potential. For example, higher WUE have resulted in higher total biomass production in *Morus* and Grewia. Coppicing and pollarding at different heights have not affected WUE drastically. WUE have been found to be comparatively higher from May to August in all the four agroforestry tree species. So a relationship between WUE and biomass production clearly indicates that even if the WUE per se is less for all the four agroforestry tree species, the available water has been used economically for growth processes associated with the production of higher biomass. Blake *et al.* (1984), Steven *et al.* (1992), Singh and Thompson (1995) have also observed relationship between WUE and growth.

5.3 Soil moisture utilization

Monthly variation in soil moisture utilization up to one metre distance from the tree trunk in all the four coppiced and pollarded agroforestry tree species revealed that soil moisture utilization, irrespective of the cutting heights was comparatively higher at 0-15 cm soil depth (lower soil moisture content) from May to July in all the four tree species which declined during August and September. Maximum utilization of soil moisture contents by *B. variegata* is reflected in maximum amount of water transpired in this tree species, however, *Morus* M-5 inspite of comparatively higher transpiration rate than *C. australis* and *G. optiva* has utilized lower soil moisture content as compared to *C. australis* and *G. optiva* under similar conditions. The presence of higher soil moisture contents (lower utilization) exhibited by all the four agroforestry trees, especially during September is the result of lesser amount of water transpired as well as low anabolic activities, so low demand for soil moisture. The utilization of soil moisture per se depends on the root network, water use efficiency as well as the aggressive growth habit of the above ground plant portion. The higher values of WUE in *Morus* M-5 and *G. optiva*, inspite of comparatively low soil moisture utilization, is indicative of the highly economical use of water for biomass production. This is desirable. Nevertheless biomass production is the result of appropriate relationship between various vital processes that take place in below and above ground portion. The findings of the present investigation have hinted at very important relationship between root networking, soil moisture utilization, water use efficiency, photosynthetic activity and biomass production, particularly in *Morus* M-5 and *Grewia optiva*. This is of great importance as this enables trees to maintain higher vigour and biomass production potential for prolonged period.

5.4 Growth and biomass production

The extent of growth and biomass production under any situation and or treatment, indeed, is not only the result of cumulative effect of all the vital processes of the current year but also reflect the sharing and utilization of various resources during the preceding years. During the present investigation four agroforestry, tree species i.e. *G. optiva, C. australis, B. variegata* and *Morus* M-5 have been compared for growth, vigour and foliage and branchwood biomass production potential under coppicing and pollarding treatments.

5.4.1 Number of coppiced and pollarded shoots

Coppicing and pollarding treatments during the present study have significantly influenced the number of shoots per stump. *G. optiva* has produced the highest number of shoots followed by *Morus* M-5 at all the cutting heights. *B. variegata* has been observed to produce lowest number of shoots per stump. Pollarding treatments have been found more effective in case of *G. optiva*, *C. australis* and *Morus* M-5 except that in *Morus*, coppicing at 0.5 m resulted in higher number of shoots as compared to that at 1.0 m cutting height (Fig. 7). So the comparative effectiveness of coppicing and pollarding treatments on the formation of new shoots is clear from the data. The higher number of shoots per stump in *G. optiva*, *C. australis* and *Morus* M-5 can be ascribed to the higher metabolic status resulting in higher accumulation of photosynthates in the stump. So it is possible that the higher amount of stored carbohydrates in the stump at pollarding heights have been instrumental in the higher number of shoots.

5.4.2 Number of nodes

Number of nodes per shoot reflect the length of coppiced and pollarded shoots as well as give an idea about the number of leaves. Coppicing and pollarding have not affected number of nodes per shoot in *G. optiva* and *B. variegata*, however, *C. australis* has produced shoots with significantly higher number of nodes at 0.5 and 1.0 m cutting heights. In case of *Morus* M-5, shoots produced at 0.5 m cutting height were found to have significantly higher number of nodes as compared to that at the remaining cutting heights. The better availability of soluble carbohydrates and subsequent metabolic status in *Morus* M-5, *G. optiva* and *C. australis* may have been responsible for the formation of higher number of nodes per shoot.

5.4.3 Shoot angle

Shoot angle varied from species to species and did not seem to be influenced much by the cutting heights. The shoot angle which was measured only for the coppiced and pollarded shoots arising from the cut end or a little below it show that at 0.5 m cutting height, *C. australis*, *B. variegata* and *Morus* M-5 produced lesser shoot angle implying that the coppiced shoots were more errect in these species as compared to *G. optiva* where shoots with comparatively horizontal orientation were produced. Overall, the shoot angle varied between 23° to 42.25° (Fig. 9) which implies that all the shoot angles were acute angles. These findings are in agreement with the observations of Bisht and Toky (1992) who have also observed branch angle range of 54.9° to 65.8° and an increase in branch angle from top to bottom position in the canopy in case of *Morus*.

5.4.4 Leaf area

Significant interspecific variations in leaf area have been observed during the present study in all the four coppiced and pollarded shoots. Maximum leaf area has been observed for *B. variegata* followed by *Morus* M-5, and *G. optiva*. *C. australis* has shown the minimum leaf area (Fig. 10). Cutting heights have not affected leaf area much in *G. optiva* and *C. australis*, however, *B. variegata* and *Morus* M-5 have shown comparatively higher variation in leaf area at different cutting heights. For example, in *B. variegata* leaf area ranged between 75.72 to 94.10 cm^2 at 0.5 to 1.5 m cutting heights as compared to 71.66 cm^2 at 2.0 m cutting height. In *Morus* M-5 the maximum leaf area was observed at 2.0 m cutting height. Leaves are part of canopy and higher leaf area per se increases the net effective photosynthetic surface area resulting thereby in more light interception by the canopy and more photosynthetic rates. The relationship between leaf area, photosynthetic activities and light interception becomes evident from the present study.

5.4.5 Leaf area index (LAI)

Leaf area index reflects the composition, size and shape of the canopy. The monthly variations in LAI reveal the developing status of canopy. *Morus* M-5, irrespective of the cutting heights has been found to have maximum LAI from May to August. This was followed by *G. optiva* while *C. australis* showed the minimum LAI. All the four agroforestry tree species registered increasing trend in LAI from May to August and decline thereafter in September at all the cutting heights. The decrease in LAI during September may be the result of defoliation or the decrease in total projected canopy area due to temporary imbalances in equilibrium between uptake and losses of water under uncongenial growing conditions. The tree species with higher LAI exhibit superiority over the tree species with lower LAI as this reflects the better capability to cope with the adverse growing conditions. It is true that higher LAI reflects the vigour of the tree but nevertheless brings about considerable modification in the quantity and quality of solar radiations to the ground crops, affecting yield potential.

5.4.6 Foliage biomass

Coppicing and pollarding treatments have been found to significantly affect the production of foliage biomass in all the four agroforestry tree species. During the present study increased foliage production with increased pollarding heights has been observed in *G. optiva* and *Morus* M-5 whereas *C. australis* and *B. variegata* have produced maximum foliage biomass at 1.0 m cutting height under similar growing conditions (Fig. 11). The advantage of pollarding over coppicing in producing higher foliage biomass during the present studies is in conformation with the earlier findings of Basappa (1986) and Singh *et al.* (1998) who have also reported higher leaf biomass at higher cutting heights. Higher foliage biomass production in *Morus* M-5, *G. optiva* and *B. variegata* can be attributed to better utilization of resources for maintaining higher metabolic status and to withstand successive coppicing and pollarding. This is evident from higher photosynthetic rates, light interception and water use efficiency in *Morus*, Grweia and Bauhinia.

5.4.7 Branchwood biomass

Like foliage biomass, branchwood biomass production was also found to be significantly higher in *G. optiva*, *Morus* M-5 and *B. variegata* as compared to *C. australis* under similar growing conditions. Advantage of pollarding over coppicing is clear from the data in Fig. 12. Pollarding at 2.0 m cutting height in *G. optiva* and *Morus* M-5 has resulted in maximum branch wood biomass production. *C. australis* has produced lowest branch wood biomass. Better ability of *G. optiva*, B.variegata and *Morus* M-5 to maintain higher anabolic activities through better utilization of below and above ground resources appear to be the main reasons for production of higher branchwood biomass.

5.4.8 Leaf to shoot ratio

The results in Fig. 13 show that leaf to shoot ratio has been highest in *B. variegata* and the minimum in *Morus* M-5. *G. optiva* and *C. australis* did not show much differences at different cutting heights. Lower cutting heights (0.5 and 1.0 m) in *B. variegata* have produced higher leaf to shoot ratio. Comparatively much lower leaf to shoot ratio in *Morus* M-5 is the indicative of higher proportion of branchwood biomass which can be exploited for production of higher fuelwood. *G. optiva* will be very useful for producing foliage as well as fuelwood biomass. This is true for *C. australis* also, however, this tree species has not been observed to perform better under coppicing and pollarding treatments during the present study. Leaf to shoot ratio plays very important role in maintaining an appropriate correlation between source (leaf) and sinks (shoot).

5.4.9 Total biomass

Production of total biomass per tree as well as per ha has been found to be significantly affected by coppicing and pollarding heights. Pollarding has been more effective in *G. optiva*, *Morus* M-5 and *B. variegata* where significantly higher total biomass production has been observed. *Morus* M-5 and *G. optiva* under pollarding can be regarded as the best tree species which have excelled in biomass production. For example, *Morus* M-5 has produced maximum biomass per ha where values varied between 6.82 and 12.10 t ha^{-1}. This was followed by that in *G. optiva* where biomass production ranged between 2.95 and 8.87 t ha^{-1}. So the probability of producing higher biomass through the mediation of management practices in *Morus* M-5 and *G. optiva* becomes amply clear from the present investigation. The production of higher total biomass in *Morus*, Grewia and Bauhinia reflect the better root net working as well as the efficient and economical use of limited resources for maintaining higher photosynthetic activities, LAI, better light interception and water use efficiency.

So on the basis of the result of the present investigation pollarding at 2.0 m cutting height may be accepted as the best management practice for producing higher total biomass in *Morus* M-5 and *G. optiva*. The lowest total biomass in *C. australis* probably is the outcome of inability of this tree species to withstand successive coppicing and pollarding over the years.

SUMMARY & CONCLUSIONS

6

SUMMARY AND CONCLUSIONS

The results of the present investigation entitled, "Influence of coppicing and pollarding on water use efficiency, light transmission and root characteristics in agroforestry tree species", have been summarized on the following lines :

6.1 Number of proximal roots

Comparatively higher number of proximal roots were observed in *G. optiva* and *Morus* M-5 at higher pollarding heights than that in *C. australis* and *B. variegata.*

6.2 Number of lateral'roots

Morus M-5 recorded the maximum number of lateral roots while *B. variegata* showed the minimum number.Coppicing and pollarding had significant regulatory effect on the production of lateral roots.

6.3 Diameter of proximal and lateral roots

Diameter of proximal roots was highest in *Morus* M-5 followed by *G. optiva* and *C. australis*. *B. variegata* recorded the least diameter of proximal roots. Results with respect to diameter of lateral roots were less prominent. Coppicing and pollarding did not affect the diameter growth significantly.

6.4 Root angle

Lower values of root angle in *Morus* M-5 reflected the spread of root net working more or less in the horizontal direction below the surface of soil whereas in *G. optiva*, *C. australis* and *B. variegata* more of a vertical root orientation was observed. Coppicing and pollarding had little affect on the root angle.

6.5 Root distribution

Grewia optiva extended about 67 per cent root in the north-east direction whereas *Morus* M-5 projected 84 per cent of the total roots in that direction. *C. australis* and *B. variegata* expanded maximum proximal roots in the west-south direction.

6.6 Transpiration

During the present investigation *B. variegata* has been found to transpire maximum amount of water per tree followed by *Morus* M-5, *C. australis* and *G. optiva*. Transpiration rates have been higher in all the four agroforestry tree species during May, June, July and August.

6.7 Stomatal conductance

Increasing stomatal conductance in coppiced and pollarded agroforestry trees resulted in increased transpiration rate at all the four cutting heights. Stomatal conductance was maximum in *B. variegata* as compared to *G. optiva*, *Morus* M-5 and *C. australis* under similar conditions.

6.8 Photosynthetic rate

Out of the four agroforestry tree species, *Morus* M-5 and *G. optiva* recorded higher photosynthetic rates as compared to *C. australis* and *B. variegata*. Photosynthetic activity was least in *C. australis*. Monthly variations were significant, however, cutting heights did not have much impact on photosynthetic rates.

6.9 Light transmission

Morus M-5 excelled in light interception followed by *G. optiva*. Only 7.47 to 12.80 per cent photosynthetically active radiations were allowed to penetrate through the canopy. A positive relationship between the light intercepted and canopy size has been observed during the present study.

6.10 Difference in above and below canopy air temperature

The size and composition of canopies of coppiced and pollarded trees of *G. optiva*, *C. australis*, *B. variegata* and *Morus* M-5 have resulted in 0.15 to 1.97°C decrease in beneath canopy temperature. Maximum temperature difference was observed under *Morus* canopy.

6.11 Water use efficiency

Water use efficiency was found to be significantly higher in *Morus* M-5 and *G. optiva* and minimum in *C. australis* under similar conditions. A close relationship between water use efficiency, photosynthetic activity and biomass production has been observed during the present study.

6.12 Soil moisture utilization

Soil moisture utilization was found to be higher in *B. variegata* as compared to *C. australis* and *G. optiva*, whereas, *Morus* M-5 was found to utilize least soil moisture.

6.13 Number of coppiced and pollarded shoots

Grewia optiva produced the highest number of shoots followed by *Morus* M-5 and *C. australis*. Bauhinia variegata contained lowest of all. Pollarding at higher cutting heights produced comparatively more number of shoots.

6.14 Number of nodes

Maximum number of nodes per shoot were registered for *Morus* M-5 followed by *B. variegata* and *G. optiva*.

6.15 Shoot angle

In general, coppiced stumps produced erect shoots (lower shoot angle) in all the four agroforestry tree species whereas pollarded stumps had more or less shoots with horizontal orientation.

6.16 Leaf area

Bauhinia variegata was found to have the maximum leaf area irrespective of the cutting height followed by *Morus* M-5 and *G. optiva*. Minimum leaf area was seen in case of *C. australis* at all the four cutting heights. Cutting heights did not reveal any definite pattern.

6.17 Leaf area index

Maximum leaf area index was observed in *Morus* M-5 at all the cutting heights which increased from May to August. This was followed by *G. optiva* and *B. variegata*. *C. australis* showed minimum LAI. Increasing trend in LAI from May to August was observed for all the four tree species which declined during September.

6.18 Leaf to shoot ratio

Leaf to shoot ratio has been comparatively low in *Morus* M-5 than that in *G. optiva*, *C. australis* and *B. variegata* at all the cutting heights.

6.19 Biomass

Morus M-5 and *G. optiva* have excelled in foliage and branchwood biomass production over *C. australis* and *B. variegata* under similar growing conditions. *C.*

australis has produced minimum total biomass. Pollarding at higher cutting height (2.0 m) over coppicing has been found more beneficial for higher biomass production.

The perusal of data from the present investigation makes it amply clear that coppicing and pollarding significantly affects biomass production. Root net work including the formation and subsequent growth of lateral roots and their spread seem to be affected more than the growth of proximal roots at the advent of coppicing and pollarding treatments. Coppicing and pollarding have been observed to have strong influence on the various attributes related to biomass production. So the hypothesis that management practices influence vigour, biomass productivity, root architecture and resource capturing stands approved. Nevertheless on the basis of quantum of data generated through this study it is concluded and recommended that *Morus* M-5 and *Grewia optiva* should be pollarded at 2.0 m cutting height for maximum biomass production. *Celtis australis* however, has not at all been benefited from coppicing or pollarding.

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APPENDIX-I

Mean monthly meteorological data during the study period (for the year 1998)

Month	Temperature (°C)		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
January	17.5	2.1	60.0	15.1
February	18.7	4.7	89.5	87.1
March	20.8	6.1	56.3	125.5
April	28.2	11.2	50.9	46.6
May	32.2	15.4	46.3	63.0
June	31.5	17.9	57.5	185.1
July	29.3	20.3	80.0	206.4
August	28.2	20.2	79.0	100.8
September	27.3	17.8	81.0	193.7
October	26.3	12.5	69.0	264.0

Source: Meteorological Observatory, Department of Soil Science, Dr. YS Parmar University of Horticulture and Forestry, Nauni-Solan (HP)

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ABSTRACT

Four agroforestry tree species namely *Grewia optiva*, *Celtis australis*, *Bauhinia variegata* and *Morus alba M-5* were studied to underline the impact of coppicing and pollarding on root architecture, resource capturing and biomass productivity at the experimental farm of Department of Silviculture and Agroforestry, Dr. Y.S.P. UHF, Solan during 1998.Four cutting heights viz. 0.5m, 1.0m, 1.5m and 2.0m were selected where 0.5m cutting height was considered as coppicing height whereas the remaining three cutting heights as pollarding heights. Comparatively higher number of proximal roots were observed in *G. optiva* and *Morus* M-5 at higher pollarding heights as compared to *C. australis* and *B. variegata*. The number of lateral roots was maximum in *Morus* M-5 whereas a decrease in the number of lateral roots was observed in *B. variegata* with the increase in cutting heights. The diameter of proximal and lateral roots were not significantly affected by the coppicing and pollarding treatments. Root angle and root distribution did not seem to be significantly affected by the coppicing and pollarding treatments. However, lower values of root angle in *Morus* M-5 implied the spread of root network more or less in the horizontal direction below the soil surface as compared to other three tree species where slightly higher root angles were observed. Significant monthly variations in transpiration rate, stomatal conductance, WUE and photosynthetic rate were observed in all the four tree species. Highest transpiration rate was observed in *B. variegata* followed by *Morus* M-5, *C. australis* and *G. optiva*. A similar trend was followed for stomatal conductance. Comparatively higher photosynthetic rate was recorded in *Morus* M-5 and *G. optiva*, followed by *C. australis* and *B. variegata*. WUE was found to be higher in *Morus* M-5 and *G. optiva* as compared to *C .australis* and *B. variegata*. Difference in above and below canopy air temperature varied from 0.15 to 1.97°C with maximum temperature difference observed under *Morus* M-5. Canopies of all the four tree species intercepted significant amount of PAR and allowed only 7.47 to 12.80 per cent transmission. Soil moisture utilisation was found to be higher in *B. variegata* as compared to *C. australis*, *G. optiva* and *Morus* M-5. *B. variegata* had the maximum leaf area followed by *Morus* M-5, *G. optiva* and *C. australis* irrespective of the cutting heights. Maximum LAI was observed for *Morus* and the minimum for *C. australis*. LAI increased from May to August. *Morus* M-5 and *G. optiva* have excelled in foliage and branchwood biomass production over *C. australis* and *B. variegata*. Out of the four cutting heights, *Morus* M-5 and *G. optiva* produced the maximum total biomass i.e. 12.10 and 8.87 t ha^{-1}, respectively at 2.0 m cutting height, while the same in *B. variegata* and *C. australis* was 5.14 and 2.85 t ha^{-1} at 1.0 m cutting height.

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