

CUTTING MANAGEMENT VERSUS BIOMASS AND CARBON STOCK OF OAK UNDER HIGH DENSITY PLANTATION IN CENTRAL HIMALAYA, INDIA

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Abstract. Tree growth and productivity are influenced by silvicultural strategies such as tree density and cutting management, which determine the potential of tree species to store carbon in the vegetation. A field experiment was conducted at Vivekananda Institute of Hill Agriculture, Almora, India in a 30-year-old *Quercus leucotrichophora* to evaluate the changes in vegetation carbon pools as a function of four cutting management (1m, 2m, local practice, and above 1/3rd part undisturbed), under high density plantation (1.0m × 1.0m). Tree cutting management significantly (<0.01) influenced the carbon stocks of *Q. leucotrichophora* trees. Total vegetation (aboveground + below ground) carbon stock was highest for the above 1/3rd part undisturbed (356.9 Mg ha⁻¹) and lowest in the cutting at 1m (86.7 Mg ha⁻¹). Overall, less disturbance to stands promote carbon storage, but intense cutting management (e.g., cutting at 1m) may adversely affect tree growth and productivity, reducing vegetation carbon pools. Cutting management effects are very much visible on carbon stock of *Q. leucotrichophora* under high density plantation. By extension, stand cutting exerts negative or positive feedbacks on biomass accretion, which may also influence the amount of carbon sequestered by the trees.

Keywords: biomass, carbon stock, cutting management, high density plantation, Himalaya, oak plantation

Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) is one of the instruments of the global efforts to stabilize the greenhouse gases (GHGs) in the atmosphere (UNFCCC, 1993). Among the climate change lessening strategies trees are the economical means to capture and store atmospheric carbon dioxide (CO₂) in vegetation (Malhi et al., 2008) which has encouraged screening of trees with high carbon (C) storage potential (Delaney et al., 1997; Paquette et al., 2009). Multipurpose tree species such as *Quercus leucotrichophora* A. Camus have an imperative position for C storage potential (Singh et al., 2014). Tree management practices and site characteristics (Nair et al., 2010) in addition to the inherent production potential of the species affect C sequestration (removal of CO₂ from the atmosphere). In a given species, according to edapho-climatic conditions various silvicultural practices are adopted to improve tree productivity, which also alters C sequestration potential (Dixon, 1997; Jiménez et al., 2011; Coletta et al., 2016).

Oaks (*Quercus* spp.) are the dominant, climax tree species of the moist temperate forests of the Indian Himalayan region (Troup, 1921), where about 35 species of *Quercus* are extensively distributed between 1000-3500 m elevations. *Q. leucotrichophora* is an evergreen tree, locally known as “Banj oak” and it is a valuable

keystone species with great societal relevance (Ramakrishnan, 2001). Banj is among the main forest-forming species in the densely populated mid-altitudinal zones of the Central Himalaya and provides a variety of ecosystem services (Zobel and Singh, 1997; Sharma et al., 2009). The oaks, particularly *Q. leucotrichophora* is intricately associated not only with agro-ecosystems but also with the life support systems of the inhabitants of the hills in the Himalaya (Makino, 2011). High calorific value of banj wood makes it an excellent fuel, its leaves are palatable which makes them major source of cattle fodder in the winter and dry seasons (Negi et al., 1997; Yadav and Bisht, 2013) and can be correlated with natural springs and wildlife (Singh, 1981).

Information on the effects of planting density and thinning on C sequestration by multipurpose tree species is scarce (Jandl et al., 2007) but on conifers particularly in Europe are available (Marziliano et al., 2015; Coletta et al., 2016); similarly, thinning and pruning interaction may influence growth and development of tree by affecting resources availability (Beadle et al., 2007). However, information on the impact of various cutting management levels in combination with high density plantation (HDP) on the biomass and carbon stock of woody perennial based land use systems is still unavailable. Despite the widespread use of *Q. leucotrichophora* in the Himalayan region (Yadav and Bisht, 2013) species-specific information on HDP and cutting management regimes and its impact on C sequestration are deficient. The *Q. leucotrichophora* plantation, like farm plantations of other species in Himalayan region, is multipurpose. Besides timber products and diversification of farm income the objective is to deliver a range of environmental benefits.

The focus of this article is cutting management influence in *Quercus leucotrichophora* on biomass and carbon stock under HDP of the Central Himalaya. A field investigation was carried out to evaluate the aboveground and belowground (root) C stocks of this species under HDP with tree cutting management practices (i.e. fodder harvesting techniques) in the Central Himalayan region of India. In this paper, we report growth, biomass C stocks and C sequestration rate of HDP of *Q. leucotrichophora* under different cutting management practices.

Materials and Methods

Study area

The study was conducted at experimental farm Hawalbagh (29° 36' N and 79° 40' E, 1250 m amsl) of Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, India. The site experiences a sub-temperate climate and annual rainfall of 1100 mm with 96 + rainy days most of which is received during the monsoon season (June–September) and the remaining from October to May. Temperature ranges between 32 °C during summer and the minimum temperature from below freezing during winter. The experimental site was neutral in pH (6.6) and had 0.85% organic C (0–15 cm). The pH of each soil was determined using a digital pH meter and Walkey's and Blacks titration method (Jackson, 1967) was used to measure soil organic carbon.

Plantation

Q. leucotrichophora was planted at this site in 1983 with high density at a spacing of 1 × 1 m and managed properly for many years. Seedling survival was excellent and mortality, if any, was replaced immediately. In the year of 1997 four cutting

management, i.e. coppicing at 1 m height, pollarding at 2 m height, local practice, and keeping above 1/3rd part undisturbed practices introduced in the plantation for fodder harvesting. So, in this article cutting management practices means fodder harvesting techniques which are being used in this trial. Fodder harvested during lean period, i.e. winter season due to drying of grasses and rainfed farming no source of fodder than trees in mid hills of Himalaya. Here in this article we have used some terms such as 'least disturbed tree' synonymous with 'less intense cutting' means minimum biomass removed from the trees such as local practice and keeping above 1/3rd part undisturbed of the trees and 'increased disturbance' synonymous with 'high intense cutting' means maximum biomass of the trees removed such as coppicing at 1 m height and pollarding at 2 m height of the trees. The trial was laid out in a randomized block design with replicates block wise.

Estimation of carbon stocks

In the plantation a total of 240 trees, comprising 60 trees from each plot of cutting management practices were measured for girth at breast height (gbh) except for basal area in 1 m height cutting management plots and height with the help of measuring tape and Ravi multimeter, respectively. The gbh and basal area is then converted to diameter at breast height (dbh) and basal diameter. Equation, $\text{Volume}/d^2=5009470+0.00563/d^2$ (FSI, 2009) was used to calculate volume and biomass measured by multiplying volume with tree density. Below ground biomass of trees was calculated by Cairns (1997) and as per the IPCC guidelines. Carbon stock was estimated by considering carbon content 0.45 (Magnussen and Reed, 2004) and biomass carbon dioxide by multiplying with a factor 3.67. Standing stock of biomass and C was converted on area basis (per ha) by multiplying the mean tree values with the corresponding density of trees.

Statistical analysis

Data from the completely randomized block design experiment were analyzed using one way analysis of variance (AGRES ANOVA).

Results and Discussion

Growth

The mean height and diameter per tree among different cutting management practices was significantly highest (10.14 m and 12.21 cm) for the trees which were kept 1/3rd top portion undisturbed followed by others and lowest (2.02 m and 5.35 cm) for trees coppiced at 1 m height, respectively (*Table 1*). Though, the height of trees coppiced at 1 m was on par with trees pollarded at 2 m height. Similar results were also obtained for mean volume per tree significantly highest (0.0833 m³) for the trees kept 1/3rd top portion undisturbed followed by other practices and lowest (0.0202 m³) for trees which were coppiced at 1 m height which was on par with the pollarding at 2 m height among different cutting management practices.

Table 1. Effect of cutting management on the growth of oak in Central Himalaya

Treatment	Height (m)	Diameter (cm)	Mean volume (m ³)
Coppicing at 1m	2.02	5.35	0.0202
Local	6.76	8.11	0.0396
Pollarding at 2m	2.93	6.70	0.0288
1/3 rd top portion undisturbed	10.14	12.21	0.0833
LSD (.01)	1.32	1.77	0.0212

The mean height, diameter and volume decreased with increasing cutting intensity, meaning growth parameters were less in more intense cutting management practices, i.e. cutting at 1 m and 2 m height as compared to for the trees which were managed with less intense cutting, i.e. 1/3rd top portion undisturbed and local practice. In general, removal of higher proportion of leaves during pruning operations may adversely affect photosynthetic rates and would depress tree growth including decrease in annual diameter growth (Gyenge et al., 2010). The volume on area basis showed the same trend as the mean height and diameter and ranged from 202 to 833 m³ ha⁻¹ for different cutting management practices (Figure 1).

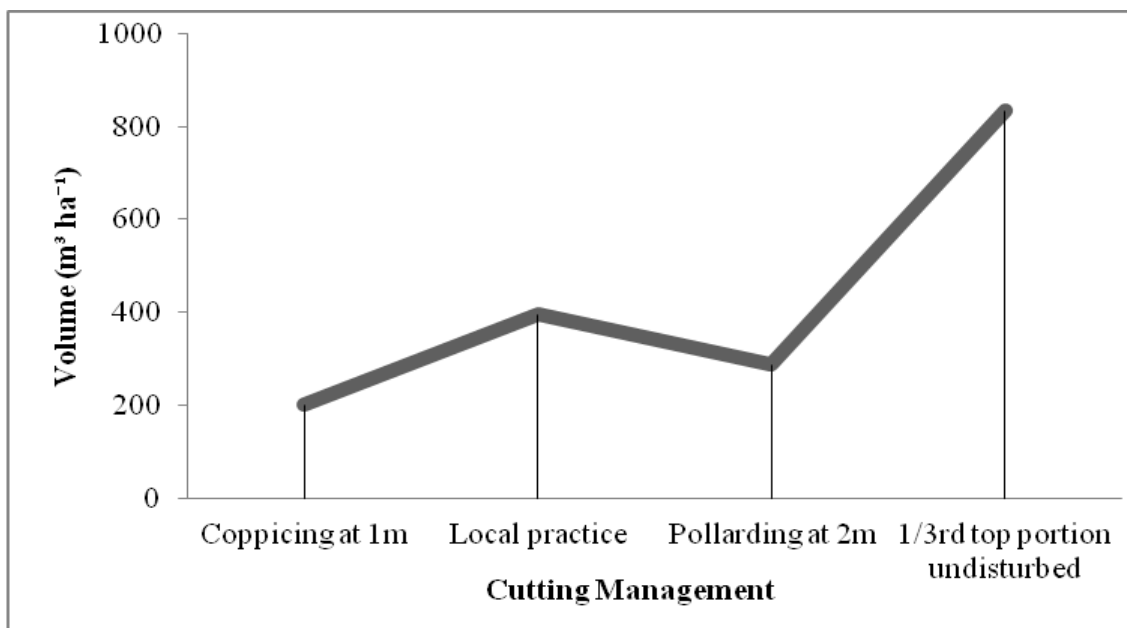


Figure 1. Total volume of oak influenced by cutting management in Central Himalaya

Biomass accumulation

Highly significant ($p < .01$) variation in total biomass was observed among different cutting management practices. Total tree biomass including aboveground and belowground biomass, ranged from 192.6 to 793.2 Mg ha⁻¹ (Table 2). The Least disturbed trees, i.e. 1/3rd top portion undisturbed practice recorded the significantly highest (793.2 Mg ha⁻¹) total tree biomass accumulation and it declined with increasing tree disturbance, i.e. coppicing at 1 m recorded significantly lowest (192.6 Mg ha⁻¹) in the form of cutting management practices. The results are in conformity with the

findings of Singh et al. (2014); Yadav and Bisht (2014). It is well known that limitations imposed by cutting management of trees on the lateral expansion and roots may restrain resource acquisition potential of trees leading to reductions in their biomass production. Similarly in a five year old plantation of Shisham with 625 trees ha⁻¹ the total vegetation biomass was 58.7 Mg ha⁻¹ and annual biomass accumulation 12.6 Mg ha⁻¹ yr⁻¹ (Lodhiyal et al., 2002), which is quite low than this study.

Table 2. Cutting management influence on biomass of oak in Central Himalaya

Treatment	Biomass (Mg ha ⁻¹)		
	Aboveground	Belowground	Total
Coppicing at 1m	151.6	40.9	192.6
Local	296.7	80.1	376.8
Pollarding at 2m	215.8	58.3	274.1
1/3 rd top portion undisturbed	624.6	168.6	793.2
LSD (.01)	158.8	42.8	201.7

Carbon stock

Total plantation C stocks (aboveground + belowground) followed a reverse trend and it decreased with increased disturbance in the form of cutting management practices (Table 3). Almost one and a half-fold increase in C stocks have been observed in the pollarding at 2 m (123.4 Mg ha⁻¹) compared to that of the cutting at 1m (86.7 Mg ha⁻¹) and two fold in the 1/3rd top portion undisturbed (356.9 Mg ha⁻¹) as compared to local practice (169.6 Mg ha⁻¹).

Table 3. Carbon stocks of oak as influenced by cutting management in Central Himalaya

Treatment	Carbon stock (Mg ha ⁻¹)			C sequestration rate (Mg ha ⁻¹ yr ⁻¹)
	Aboveground	Belowground	Total	
Coppicing at 1m	68.1	18.4	86.7	2.9
Local	133.4	36.1	169.6	5.7
Pollarding at 2m	97.2	26.2	123.4	4.1
1/3 rd top portion undisturbed	281.2	75.9	356.9	11.9
LSD (.01)	71.4	19.3	90.7	3.4

Cutting at 1 m height depressed two fold and four fold C stock and pollarding at 2 m height of the tree reduced half fold and almost three fold C stock in comparison to local and 1/3rd top portion undisturbed practices, respectively. Carbon stocks being a function of the overall tree growth (Table 1), this is not surprising. Singh et al. (2014) reported the impact of human-induced small-scale disturbances (lopping of branches and leaf removal) adversely impacts the functioning of banj oak (*Quercus leucotrichophora* A. Camus) forests of Central Himalaya. Majid and Paudyal (1992) noted reductions in tree growth when crown length removal from below exceeded 40% in the *A. mangium* plantation of peninsular Malaysia. The biomass carbon Co₂ mitigation by the Oak high density plantation followed the trend of biomass and carbon stock and varied between 317-1306 Mg ha⁻¹ among different cutting management practices (Figure 2).

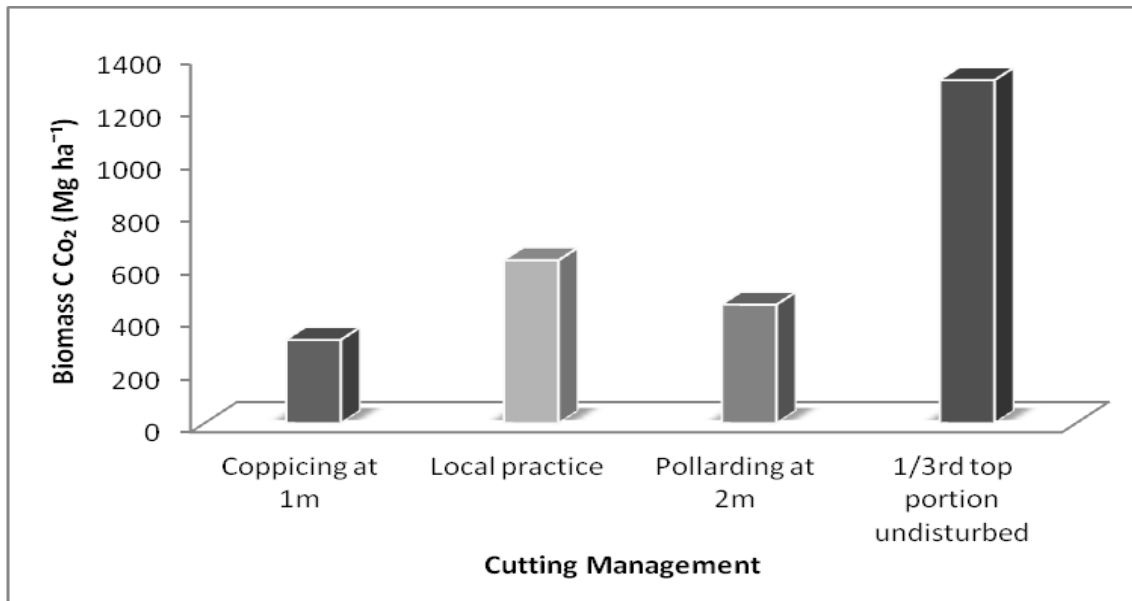


Figure 2. Cutting management influence on total biomass CO₂ in Central Himalaya

Biomass and carbon stock estimates for 30 year old *Q. leucotrichophora* in the present study reveal its potential as a promising tree species for C sequestration. Higher rate of total C sequestration was with the minimal disturbance cutting management practice, i.e. in 1/3rd top portion undisturbed (11.9 Mg ha⁻¹ yr⁻¹) followed by other practices and least in cutting at 1 m height (2.9 Mg ha⁻¹ yr⁻¹) which was the intense cutting management practice (Table 3). The varying rate of C sequestration of plantations can be attributed to their differential cutting management practices. Results of the C sequestration rates were almost within range to those obtained in earlier studies (KTGAL, 2004; Yadav and Bisht, 2014; Yadav et al., 2015). According to Table 4 Pearson correlation shows that diameter is highly correlated to volume, total biomass and carbon sequestration rate of oak under high density plantation.

Table 4. Pearson correlations among different parameters of oak under high density plantation

Parameters	Height	Diameter	Volume	Total biomass	C sequestration rate
Height	1	.970*	.951*	.951*	.951*
Diameter	.970*	1	.995**	.995**	.995**
Volume	.951*	.995**	1	1.000**	1.000**
Total biomass	.951*	.995**	1.000**	1	1.000**
C sequestration rate	.951*	.995**	1.000**	1.000**	1

Conclusion

This paper shows the potential of *Q. leucotrichophora*, a Himalayan woody species, to sequester atmospheric CO₂ and influence of cutting management practices on high

density plantation C pools. Intense cutting management practices, i.e. cutting at 1 m and 2 m height depressed overall tree growth, biomass and C stocks of this species. On the other hand the less disturbed, i.e. 1/3rd top portion undisturbed and local practices which stored good amount of C in plantation. Local inhabitants of Himalayan region can harvest fodder from this species while still allowing the storage of carbon by planting and choosing appropriate cutting management practices in agroforest for sustainable development. Overall, species, site, age and good silvicultural practices may favor tree growth and productivity and promote plantation CO₂ sequestration and C conservation.

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