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Oak (*Quercus floribunda*): A Prominent Indigenous Multipurpose Tree for Carbon Storage and Sequestration Potential

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ABSTRACT

A dynamic growth model (CO2FIX) has been used for estimating the carbon sequestration potential of Oak (*Quercus floribunda*), an indigenous multipurpose tree used for timber, fuel wood, fiber and specially fodder in addition to its ability of soil binder. The present study has been carried out in the campus of V.C.S.G. College of Horticulture, U.U.H.F., Bharsar, Pauri Garhwal, Uttarakhand. It is capable of thriving on snow and heavy rainfall condition. CO2FIX was parameterized for a simulation of 100 years respectively. The results indicate that the long term tree biomass accumulated was 120.11 t/ha in above ground and 79.89 t/ha in below ground (Soil Carbon) component respectively at the end of simulation period assuming a tree density of 825t/ha (approximately). The net annual carbon sequestration for Oak over the entire simulation period was 1.9 Mg C ha^{-1} yr^{-1} (t/ha/yr). Useful for scientific planning and effective implementation of Forestry and Agroforestry developmental programmes at district level as well as at State level for the development of country. For future research work following are few suggestions for better planning and development of State. This type of study can be taken including other parameters/resources such as different trees, different area, and different state and different country as well.

Key words: *Quercus floribunda,* Carbon Sequestration Potential, CO2FIX, Soil Carbon, Tree Biomass.

INTRODUCTION

The Himalaya, youngest mountain range of the world covers about 18% of total geographical area of India. Forests constitute (50% of India's forest cover) an important natural resource base in the Himalaya, most important being the temperate broad leaf forests, which are largely dominated by different species of oak (*Quercus* species)[1]. Oaks (Quercus spp.) are the dominant, climax tree species of the moist temperate forests of the Indian Himalayan region[2] where about 35 species of Quercus are extensively distributed between 1000-3500 m elevations. Five species of evergreen oak *Viz. Quercus glauca* (phaliyant/harinj), *Q. leucotrichophora* (banj), *Q. lanuginosa* (rianj), *Q. floribunda* (tilonj/moru) and *Q. semecarpifolia* (brown/kharsu) grow naturally in the western Himalaya. [3]Bargali *et.al.* (2013) reported Oaks as dominant tree species for fodder, fuel wood and timber for Kumaun region of Uttarakhand. The oak forests are source of fuel wood, fodder and can be correlated with natural springs and wildlife.

According to [4]Bisht *et.al.* (2013) the dominant fodder tree species for western Himalayan region are *Quercus leucotrichophora, Q. floribunda* lindl, *Q. semicarpifolia, Myrica esculenta (kafal), Aesculus indica (Himalayan chestnut), Alunus nepalensis (Utees), Ficus palmata (Anjir), Morus alba (shahtoot) woodforida fruticosa (kurz).* Among these the most prominent species is *Q. Floribanda*;

therefore it was considered for the study. It is medium size tree; having average height of 15 m and maximum of 24 m. [5]Kumar *et.al.* (2011) also reported that out of 14 tree species the *Q. leucotrichophora* found as dominant, best in timber, firewood and leaf fodder in Garhwal Himalayan region. The Young seedlings up to two years old are very shade-tolerant, thereafter the tree needs moderate to full light It needs moderately fertile soils, growing well on clays derived from shales and clay loams, but does not do well on dry sites. It is sensitive to fires and browsing.

The wood is very heavy, weighing about 1020 kg m^{-3}. The calorific value of the heartwood and sapwood is 19,100 and 19,400 kJ kg^{-1} respectively[6], hence it is a good fuel wood. It is not a good timber as it warps and splits badly, but is used occasionally for low-grade construction and, agricultural implements. Blackjack Oak is an evergreen tree found in the Himalayas. It is a large or medium sized tree, with leathery dull green leaves, sharply toothed leaves, 6-16 cm long. Leaves have dense white-woolly hairs on the underside. Because of its abundance it is a very important fodder tree in these localities. In Dehimando Panchayat of Mahakali Forest Division 78 per cent of all privately owned fodder trees were of this species[7].

A number of studies have reported the carbon sequestration potential (CSP) of forest and multipurpose trees in India[8,9,10,11,12,13] however the published literature on assessment of carbon sequestration through the existing trees on croplands is scanty. UNFCC (United Nations Framework Convention on Climate Change) has recognized the importance of planting multipurpose trees as a greenhouse gas mitigation option, as well as the need to monitor, preserve and enhance terrestrial carbon stocks. In addition, production from plantation trees may relieve pressure on timber extraction from natural forest, and thus contribute to forest conservation

A lot of works have been done for the estimation of carbon sequestration potential of different tree species (Under forestry and Agroforestry System) but this is first attempt for Oak tree in western Himalayan region of Uttarakhand for estimation of carbon sequestration potential of Oak on per year basis and also estimated total carbon sequestered on per year and total simulation of carbon at the end of simulation period of 100 years.

MATERIALS AND METHODS

The present study has been conducted in the V.C.S.G. College of Horticulture a campus of Uttarakhand University of Horticulture and Forestry, Bharsar, Pauri Garhwal, Uttarakhand,. which is situated at logitude78.59':20.28'E, latitude 79.00':30.05'N and 2000 m MSL altitude. The temperature ranged from -4.0 to 28.0°c and rainfall of this hilly area lye more than 10000 mm. The campus spread over an area of 174.94ha; out of that area 114.3ha is mixed forest of *Pinus roxburghii*, Oak (3 species of Quercus), Burans (*Rhododendron arbereum*), kafal (*Myrica esculenta*) etc, along with more than 250 spp. of herbs & shrubs. The data has been recorded over selected area of 10 plots, size 5x5 meter in different location of campus. In given plots only number of Oak (*Q. floribanda*) tree counted along with CBH (Circumference at Brest Height) [3]Bargali *et.al.* (2013). The numbers of trees were estimated approximately 825 tree/ha. (Fig-1)

Detail of CO2FIX

The CO2FIX Model used in this present study for simulates the carbon dynamics of single species can handle trees with varied ages. Moreover, CO2FIX outputs the biomass and C separately in above and below ground tree components cohorts wise (i.e. species wise) in addition to soil carbon dynamics. In this study, we are estimating the carbon sequestration potential of existing Oak tree in the dense forest of western Himalayan region of Pauri district of Uttarakhand. CO2FIX v3.2 model is available free of charge for academic/research institutions (http://www.efi.int/projects/casfor/CO2FIX/register32.php). CO2FIX has been used to estimate the carbon storage and sequestration potential of selected trees species in India[14]. The CO2FIX model has been tested and validated for the forest ecosystem in the Phillipines, mixed pine-oak forest of central Mexico, multi-strata AFS and tropical rainforest in Costa Rica and woodlots in Zambia[15].

Input parameters for the CO2FIX model

The main input parameters relevant to CO2FIX model are the cohort wise values for the stem-CAI (current annual increment in m^3 ha^{-1} $year^{-1}$) over years; relative growth of the foliage, branches, leaf and root with respect to the stem growth over years; turnover rates for foliage, branches and roots; and climate data of the site (annual precipitation in mm and monthly values of minimum and maximum temperatures in ^{0}C). Other inputs to the model includes initial surface soil organic carbon (Mg C ha^{-1}), rotation length for the tree species, percent carbon contents in different tree parts, wood density and initial values of baseline carbon (Mg C ha^{-1}) in different tree parts, when the simulation are being carried out for the existing trees as in the present case.

Basic data required for running the CO2FIX model

For the purpose of simulating carbon stocks under oak forest on per ha basis, the modules taken into considerations are biomass, soil and carbon accounting modules. CO2FIX model requires primary as well as secondary data of tree (called 'cohorts' in CO2FIX terminology) for preparing the account of carbon sequestered under oak forest on per hectare basis. The primary data includes name of the existing tree species on forest land along with their number, diameter at breast height (DBH) (Converted to CBH), whereas the secondary data includes the growth rates of tree biomass components (stem, branch, foliage, root) of Oak. The basic parameters *viz*. rotation length, wood density, carbon contents for the tree cohorts have been detailed in **Table 1**. DBH of the surveyed plants has been used to approximately find out the age of the standing trees. To derive the incremental data of tree stem growth, the volume equations published in State Forest Report-2009 by Forest Survey of India (FSI), Dehradun, Ministry of Environment and Forests, were used as the secondary data.

Parameterizations of the tree cohorts

Stem volume equations, available in Forest Survey of India Report (2009) for the Oak has been used to generate the DBH (m) and stem volume (m^3/tree) data and the Wood density data is obtained from Food and Agriculture Organization (FAO) website. These data sets have been used to fit non-linear functions for stem volume–DBH relationships. This tree wise absolute stem volume–DBH relationship has then converted into hectare wise stem volume–DBH relationships, by multiplying the average number of trees found in the 10 patches. This DBH has transformed back into age to obtain hectare wise stem volume–age relationships. Ultimately, this absolute stem volume values have converted into CAI (Current Annual Increment) values of stem volume by taking the difference of current year value from preceding year value. Thus, we obtained the CAI equations for stem volume– age for the Oak **(Table 2).** The relative growth data of foliage, branch and root is available for different tree species (classified under the slow, medium and fast growing categories/cohorts) at National Research Centre for Agroforestry (NRCAF), Jhansi were used to find out the relative growth of foliage, branch and root with respect to stem on slow growing and also compared by given example of CO2FIX software. These relative proportions were parameterized in CO2FIX model for branch, foliage and root growth.

Table 1: Input parameter used in CO2FIX model for simulating tree biomass components in various tree cohorts

Cohorts	Oak (*Quercus floribunda*)
No of tree ha^{-1}	825
Rotation year	100
Starting Age years estimated for 2013	42.5
Average DBH	32
Wood density Mg DM/m^3	0.75*
Carbon content (% dry weight)	50
Turnover rate foliage	1.0
Turnover rate branch	0.02
Turnover rate root	0.03
Product allocation for thinning harvesting	
Stem log wood	0
Stem slash	1.0
Branch log wood	0
Branch slash	1.0
Foliage slash	1.0
Foliage slash soil	0.1

Parameterization of the soil module

The climatic data of district on monthly temperature and precipitation has obtained from substation of IMD (Indian Meteorological Department), which is in the college campus and has fed as the general CAI on per tree basis for Oak tree has been estimated from State Forest Report 2009, Forest Survey of India, Ministry of Environment

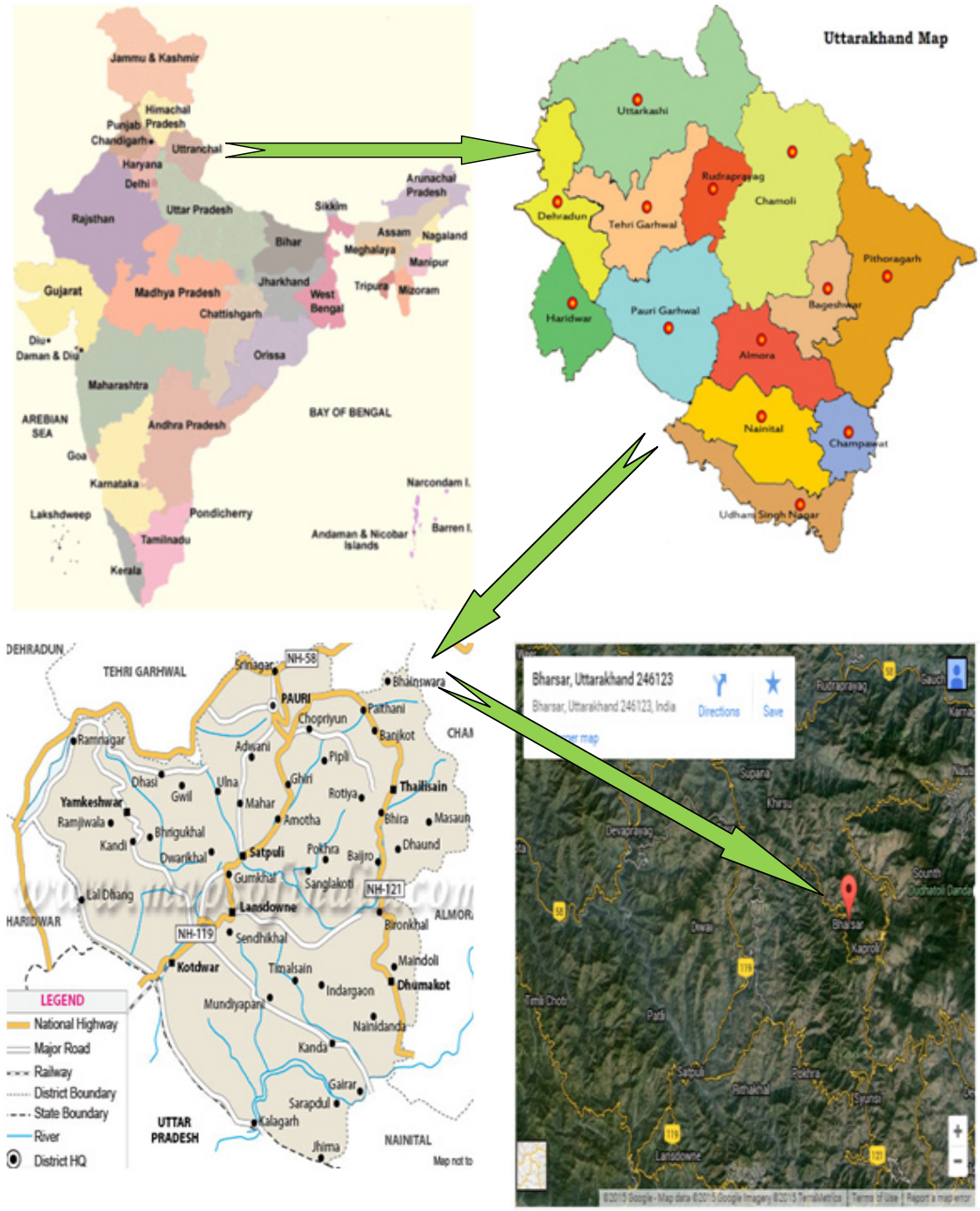

Fig. 1: Map of the study area

and Forests, New Delhi (India). The dynamic soil carbon model YASSO describes decomposition and dynamics of soil carbon in well-drained soils. The soil module consists of three litter compartments (non-woody, coarse-woody and fine-woody) and five decomposition compartments (extractives, cellulose, lignin like compound, humus-1 and humus- 2). Litter is produced in the biomass module through biomass turnover. For the soil carbon module, the litter is grouped as non-woody litter (foliage and fine roots), fine woody litter (branches and coarse roots) and coarse woody litter (stems and stumps). Since the biomass module makes no distinction between fine and coarse roots, root litter is separated into fine and coarse roots according to the proportion between branch litter and foliage litter.

Table 2: Current Annual Increment (CAI) of the stem volume growth (m^3 ha^{-1} $year^{-1}$) over years for Oak

Age	CAI-Vol m^3/ha/year	Age	CAI-Vol m^3/ha/year	Age	CAI-Vol m^3/ha/year	Age	CAI-Vol m^3/ha/year	Age	CAI-Vol m^3/ha/year
0	39.071	25	30.935	50	66.215	75	129.182	100	103.801
5	19.160	30	35.037	55	78.034	80	139.049	105	71.166
10	20.063	35	41.493	60	91.245	85	142.949	110	43.303
15	22.697	40	49.218	65	105.386	90	140.258	115	5.846
20	26.346	45	58.360	70	116.060	95	127.478		

CAI on per tree basis for slow, medium and fast growing trees has been estimated from State Forest Report 2009, Forest Survey of India, Ministry of Environment and Forests, New Delhi India .Wood density data obtained from FAO website.

Table 3: Biomass accumulated in the Oak tree species and carbon sequestered under Western Himalayan Region simulated using CO2FIX model

	Parameters		Observed number of existing trees per hectare in mixed forest of Western Himalayan region of Oak 825 tree/ha
Tree biomass above and below ground Mg DM ha^{-1}	Baseline	Biomass	39.19
	Simulated		418.57
Soil carbon Mg C ha^{-1}	Baseline	Carbon	17.45
	Simulated		97.34
Biomass carbon Mg C ha^{-1}	Baseline	Carbon	2.19
	Simulated		122.3
Total carbon biomass	Baseline	Carbon	19.64
+ soil Mg C ha^{-1}	Simulated		209.21
Net carbon sequestered of Oak forest of Western Himalayan region over the simulated period of 100 years Mg C ha^{-1}		Carbon sequestered	189.61
Estimated annual carbon sequestration potential of Oak forest of Western Himalayan region Mg C ha^{-1} $year^{-1}$			1.9

RESULTS AND DISCUSSION

CO2FIX simulated Oak tree biomass/carbon stock

The tree biomass (above and below ground) during the 100 years simulation period increased from 39.19 to 418.57 Mg DM ha^{-1}. The 100 year simulation results of CO2FIX model predict that biomass carbon would enhance from 19.60 to 209.21 Mg C ha^{-1}. Our result is also incorporated with Subedi (2004)[16], who reported that Above Ground Biomass of *Quercus semicarpifolia* in temperate region of Nepal was ranging from 272 to 479 t/ha.

CO2FIX simulated soil carbon stock

The estimated rate of soil carbon sequestration, showed an increasing trend, which is recorded 0.79 Mg C ha^{-1} $year^{-1}$. The soil carbon is expected to increase from 17.45 to 97.34 Mg C ha^{-1} in 100 year simulation. Similar results have been reported by Singh *et al.* (2011)[17] that agricultural soils of IGPs, on an average, contain 12.4–22.6 Mg ha^{-1} of organic carbon in the top 1 m soil depths.

CO2FIX simulated carbon sequestration potential (CSP) of existing Oak forest

The CSP of existing Oak forest has been estimated to be as 1.9 Mg C ha^{-1} $year^{-1}$ (**Table 3**). The CSP was also influenced by the site's climatic factors viz. monthly average temperature, total precipitation along with its distribution over different months, evapotranspiration etc. The higher CSP in this location to be attributed higher total precipitation as well as some amount of rainfall in each and every month throughout the year. Moreover, Dinajpur is situated in the foot hills, thus there is sufficient moisture in the atmosphere round the year that acts as a positive catalyst favoring enhanced C sequestration[18]. These results are in line with Pathak *et al*. (2011)[19] that organic matter contents across soils are influenced strongly by rainfall. Lal (2004)[20] reported that SOC concentration increased with increased rainfall in several Indian soils. Moreover, as the tree density increases the total biomass increases and hence C-sequestration rate increases. Kongsager and Mertz, (2013)[21] reported carbon sequestration on plantation trees and found best in rubber plantation (214 tC/ha) folloed by Cocoa (65tC/ha) and Orange (76tC/ha). Nowak and Crane (2001)[22] reported that coterminous USA currently store 700 million tonnes of carbon with a gross carbon sequestration rate of 22.8 million tC/yr on 10 cities of USA.

The estimated CSP of existing oak forest in Garhwal Himalayan region are encouraging, as they would add to the forest cart of C sequestration and would definitely reduce the increasing pressure on forests for timber and other commercial requirements. According to its availability of soil binding property on hilly areas, this is a very important, eco friendly and multipurpose tree used for timber, fuel wood, fiber and fodder species.

CONCLUSION

The studies of Carbon sequestration potential of oak at limited area level of a district is very necessary not only for understanding the carbon storage, Sequestration Potential of a tree, but are also useful for scientific planning and effective implementation of Forestry and Agroforestry developmental programmes at district level as well as at State level for the development of country.

For future research work following are few suggestions for better planning and development of State. This type of study can be taken including other parameters/resources such as different trees, different area, and different state and different country as well.

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