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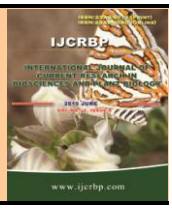

Original Research Article

Tree-crop Combinations, Biomass and Carbon Estimation in Conventional Agrisilviculture (Agroforestry) System along Altitude and Aspects in the Hills of Uttarakhand Himalaya, India

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A b s t r a c t

Study on Tree-Crop combinations, Biomass and Carbon estimation in Conventional Agroforestry (Agrisilviculture) systems along Altitude and Aspects in the Hills of two districts (Tehri Garhwal and Uttarkashi) in Uttarakhand Himalaya, India was carried out during 2012-2013. The study spread in varying altitudinal ranges of 1000 to 1500m, 1500 to 2000m and 2000 to 2500m asl covering northern and southern aspects including twelve study sites with six in each district. The major conventional agroforestry systems recorded in the area were agrisilviculture (AS), agrisilvihorticulture (ASH) and agrihorticulture (AH). However, the AS system was studied in detailed for change in elevation and aspects and their effect on land-use, tree-crop combinations, vegetation and standing biomass and carbon storage in agroforestry trees. The diversity of tree species varied from 7 to 15 in one district to 7 to 13 in another under AS system. The highest diversity was recorded in 1000-1500m elevation while the lowest in higher elevation (2000-2500m), however, the northern aspect was more diverse compared to southern. In Tree-crop combination, the common agroforestry trees reported in the AS were *Grewia optiva, Celtis australis* and *Melia azedarach* with agricultural crops as Triticum *aestivum, Zea mays, Eleusine coracana, Echinochloa frumentacea, Amaranthus caudatus, Phaseolus vulgaris etc* in the elevation ranging 1000 to 1500m. In the middle Himalayan region (1500-2000m) *Grewia optiva, Celtis australis, Quercus leucotrichophora* with agricultural crops like *Triticum aestivum, Eleusine coracana, Amaranthus caudatus, Phaseolus vulgaris, Solanum tuberosum etc*. While in the elevation 2000 to 2500m the agroforestry tree species like *Quercus leucotrichophora, Quercus floribunda* form the basic combination with agricultural crops as *Solanum tuberosum, Pisum sativum, Brassica spp.* The standing volume, biomass and carbon were estimated for AS system. The standing volume of trees under AS systems in Tehri district ranged from 37.82 to 62.78 m^3/ha and in Uttarkashi 33.04 to 63.75 m^3/ha while the standing biomass of trees ranged from 47.81 to 74.71 Mg/ha in Tehri and 47.32 to 80.23 Mg/ha in Uttarkashi. The standing carbon of trees in Tehri district ranged from 23.14 to 37.76 Mg/ha while in Uttarkashi from 23.66 to 40.12 Mg/ha in AS system. The higher amount of biomass was estimated in lower elevation (1000-1500m) compared to middle (1500-2000) and higher elevation (2000-2500m), moreover the northern aspect acquired high quantity of biomass compared to southern aspect.

K e y w o r d s

Agrisilviculture system
Biomass
Carbon
Conventional agroforestry systems
Tree-crop combinations
Vegetation composition

Introduction

Agroforestry practices in the Hills of Uttarakhand Himalayan form essential association with the cultivators or farmers to supplement fuel, fodder, fruits, fibers and organic fertilizer and store abundant amount carbon. The unusually change in altitudinal gradient even at small distances and high endemism make it interesting for studies (Singh and Singh, 1992). The mounting population is consequently creating higher demands for the forest products and the fact is that, even today the production in forestry sector is not enough to meet out the existing demands, which is also bringing down the reserve forest under increased pressure. As per IPCC agroforestry systems can provide significant opportunities of creating synergies linking both adaptation and mitigation actions with a technical mitigation potential of 1.1-2.2 Pg C in terrestrial ecosystems in coming 50 years (IPCC, 2007). In the present context therefore, the agroforestry is the only feasible option, from first to last which the pressure on existing forests can be minimized. There are varying combinations and interaction of agricultural crops with trees present on the farm field of the farmers is an interesting area to study.

Materials and methods

The study on "Tree-Crop combinations, Biomass and Carbon estimation in Conventional Agroforestry (Agrisilviculture) systems along Altitude and Aspects in the Hills of Uttarakhand Himalaya, India" was carried out in districts Tehri Garhwal and Uttarkashi in the state of Uttarakhand, India during 2012-13. The study was done in varying altitudinal ranges of 1000 to 1500m, 1500 to 2000m and 2000 to 2500m asl covering northern and southern aspects comprising twelve study sites, six each in district Tehri and Uttarkashi. Different sampling sites were selected in the varying altitudinal ranges (1000-1500m, 1500-2000m, and 2000-2500m) both in northern and southern aspect of districts Tehri Garhwal and Uttarkashi to study the agroforestry systems, Tree-crop combination, Biomass and Carbon estimation in the traditionally existing agroforestry systems in the hills of Garhwal Himalaya.

Analysis for agroforestry systems in each study site was done by laying randomly placed quadrats of 10×10m size. The stratified random sampling and multi-stage sampling were carried out on each selected site. The measurement of tree diameter/girth and height was done to put in the values in volume equation of tree species and estimate the standing volume, biomass and Carbon using wood density and Biomass Expansion Factor.

Results and discussion

Throughout study, the classification of various tree-crop combinations, tree inventory and important traditional agroforestry systems were notified and studied in detail. The major conventional agroforestry systems recognized in the area viz. agrisilviculture (AS), agrisilvihorticulture (ASH) and agrihorticulture (AH) systems. The influence of elevation and aspects were considered to be the major parameter for land use pattern, vegetation analysis and trees present in agroforestry systems. The estimation of standing volume, biomass and carbon of trees present in AS agroforestry system were analyzed in reference to change in elevation and aspects for the AS.

The tree-crop combinations adopted on the different study sites were dependent on the climatic and geographical situations of the area. In Tehri Garhwal region the very common and important agroforestry trees are *Grewia optiva, Celtis australis* and *Melia azedarach* usually present with agricultural crops as *Triticum aestivum, Zea mays*, *Eleusine coracana*, *Echinochloa frumentacea*, *Amaranthus caudatus*, *Phaseolus vulgaris etc* in the elevation ranging 1000 to 1500m. In the middle Himalayan region (1500-2000m) *Grewia optiva, Celtis australis, Quercus leucotrichophora, Prunus armeniaca* (fruit tree) are the common tree species with agricultural crops like *Triticum aestivum, Eleusine coracana*, *Amaranthus caudatus, Phaseolus vulgaris, Solanum tuberosum etc*. In the elevation 2000 to 2500m the agroforestry tree species like *Quercus leucotrichophora, Quercus floribunda, Malus domestica* (fruit tree) forms the basic combination with agricultural crops as *Solanum tuberosum, Pisum sativum, Brassica oleracea* var. *capitata, Brassica oleracea* var. *botrytis*.

In Uttarkashi region (1000-1500m) the tree species like *Grewia optiva, Celtis australis, Ficus roxburghii* etc commonly present with agricultural crops as *Eleusine coracana, Echinochloa frumentacea, Triticum aestivum, Vigna mungo, Dolichos uniflorus, Oryza sativa, Zea mays, Amaramthus caudatus, Vigna*

sinensis, Phaseolus vulgaris, Cajanus cajan etc. The tree species commonly present in the agroforestry system as *Quercus leucotrichophora, Alnus nepalensis* in the elevation 1500-2000m grown with the crops like *Amaramthus caudatus, Triticum aestivum, Eleusine coracana, Phaseolus vulgaris*. In the higher elevation (2000-2500m) the agroforestry trees as *Quercus floribunda, Quercus leucotrichophora, Quercus semicarpifolia, Juglans regia* commonly associated with agricultural crops like *Triticum aestivum, Amaramthus caudatus, Solanum tuberosum, Phaseolus vulgaris* and *Pisum sativum*.

The standing volume of trees under AS systems in Tehri district ranged from 37.82 to 62.78 m^3/ha and in Uttarkashi 33.04 to 63.75 m^3/ha while the standing biomass of trees ranged from 47.81 to 74.71 Mg/ha in Tehri and 47.32 to 80.23 Mg/ha in Uttarkashi. The higher amount of biomass and Carbon was estimated in lower elevation (1000-1500m) compared to middle (1500-2000) and higher elevation (2000-2500m), among the all elevation the northern aspect acquired high quantity of biomass compared to southern aspect. The standing carbon of trees in Tehri district ranged from 23.14 to 37.76 Mg/ha while in Uttarkashi from 23.66 to 40.12 Mg/ha in AS system. In Tehri the maximum tree carbon 11.17 Mg/ha on northern aspect and 5.01 Mg/ha on southern aspect in 1000-1500m of elevation was observed in *Grewia optiva*. In 1500-2000m, the maximum carbon storage on northern aspect was also recorded by *Grewia optiva* (6.89 Mg/ha) and on southern aspect by *Quercus leucotrichophora* (8.05 Mg/ha). In both the northern and southern aspects in 2000-2500m, the maximum storage of standing carbon was recorded in *Quercus leucotrichophora* as 8.37 Mg/ha and 10.13 Mg/ha respectively. In Uttarkashi district the highest carbon storage in 1000-1500m of elevation on northern and southern aspects was recorded in *Grewia optiva* as 16.76 Mg/ha and 4.62 Mg/ha. In the elevation 1500-2000m for northern and southern aspects the highest carbon storage was observed in *Quercus leucotrichophora* as 10.06 Mg/ha and 9.21 Mg/ha. In the elevation 2000-2500m, the maximum carbon storage on northern aspect was observed in *Quercus leucotrichophora* (7.09 Mg/ha) and on southern aspect by *Quercus semicarpifolia* (7.05 Mg/ha).

The study ground biomass recorded in the present study was comparable with the estimates made by many workers (Singh and Singh, 1991; Roy and Ravan, 1996; Haripriya, 2000). In the present study the difference in estimation of biomass could be due to the biomass was estimated indirectly from volume data, variation in wood density and expansion factors and variation in field measurements. In this study, the wood density values of different species were not precisely estimated, however they were taken from published literature. Moreover, the Carbon was not directly estimated in different plant components, the study considered only 50 per cent of dry biomass as Carbon content as suggested by Brown and Lugo (1982); Dixon et al. (1994) and Houghton et al. (1993). However, Carbon content varies from component to component. It is about 50 per cent for stem biomass and little lower for branch and root components. Singh and Singh (1991) also reported different components of vegetation in dry tropical forests exhibited varied Carbon concentration.

Conclusion

The study concluded that the elevation and aspects played significant role in tree-crop combinations and carbon storage. In lower and middle elevation *Grewia optiva* and *Celtis austarlis* was dominant linking species while in middle and upper elevation *Quercus lecotrchophora* was dominant linking species in agrisilvicultural system of Garhwal Himalaya. The agroforestry system present in lower elevation sequestered more carbon compared to higher elevation. The study showed that the agroforestry systems of Garhwal Himalaya are though partially sustainable but not ecologically and economically as productive and need to be enhanced by various silvicultural means and integration of new components on scientific basis. Irrespective of all these yet in present condition conventional agrisilvicultural systems sequestering adequate amount of Carbon.

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