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# ABOVE GROUND BIOMASS AND CARBON STOCK OF FRUIT TREE BASED LAND USE SYSTEMS IN INDIAN HIMALAYA

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**ABSTRACT**

This study was undertaken to estimate the standing biomass and carbon buildup in the fruit tree based agrihorticulture farming systems of Himalaya, India. Aboveground biomass, carbon stock and carbon stock equivalent carbon dioxide ($CO_2$) varied from 10.8 to 37.8 Mg ha$^{-1}$, 4.8 to 17.0 Mg ha$^{-1}$, 17.6 to 62.3 Mg ha$^{-1}$, respectively. The significantly ($<0.05$) higher biomass (37.8 Mg ha$^{-1}$), carbon stock (17 Mg ha$^{-1}$) and carbon stock equivalent $CO_2$ (62.3 Mg ha$^{-1}$) was recorded in the pear + wheat and the lowest was observed in wheat monocropping. The highest rate of biomass, carbon and $CO_2$ accumulation was found in pear + wheat (12.0, 5.3, 19.6 Mg ha$^{-1}$ year$^{-1}$) followed by apricot + wheat (11.5, 5.2, 18.9, Mg ha$^{-1}$ year$^{-1}$) and varied with diverse fruit tree species. Fruit tree biomass showed a significant and positive relationship with total biomass, total carbon and total $CO_2$ mitigation. Land use systems like fruit trees + wheat can have higher biomass, carbon stock, carbon stock equivalent $CO_2$ and high rates of carbon accumulation than wheat monocropping implying the synergy between carbon accumulation and maintenance of diverse trees.

**KEY WORDS**
Agrihorticulture
Biomass
Carbon stock,
Carbon accumulation

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## INTRODUCTION

Fruit tree based land use systems i.e. agrihorticulture is a unique and very common practice in the Himalayan region of India. Trees are deliberately incorporated in the land use systems by the farmers to fulfill their varied need namely fodder, fuel, fiber, fruits, small timber, agricultural implements along with the agricultural produce (Yadav and Bisht, 2013). Fruit tree plantation exists in 536,800 ha area of Indian Himalaya and in hills of Indian Himalaya considerable fruit tree plantation areas have been converted into agroforestry. These fruit tree based land use systems which includes the cultivation of agricultural crops in association of horticultural trees on the same piece of land provides the stable and better output to the farmers (Yadav and Bisht, 2014). It is valuable, that in Himalayan region the existence without such systems is difficult because trees reduces land sliding in the fields, protect crops to adverse climatic condition, conserve the moisture, improve the soil quality through nitrogen fixing in addition to carbon sequestration.

Enhancing carbon sequestration in biomass is presently considered as one of the major strategies of reducing atmosphere $CO_2$ concentration (Kimble *et al.*, 2002; Dash, 2010). The exchange of greenhouse gases between terrestrial ecosystems and the atmosphere takes place due to land use and land use changes (Lal, 2002; Upadhyay *et al.*, 2005), because of considerable losses of carbon from vegetation and soil. This has led to an increased interest in reducing carbon dioxide in the atmosphere through tree based carbon sequestration. Moving from lesser biomass land use systems such as grasslands, agricultural fallows and permanent shrub lands to tree based land use systems such as natural forests, forest plantations, and agroforestry, helps in the most noteworthy increases in carbon dioxide sequestration (Zhang, 2010; Kimaro *et al.*, 2011; Quinkenstein *et al.*, 2011) and agroforestry is particularly relevant in this respect.

Considering provision of service and helping in fulfilling needs of the marginal family members, these fruit tree based land use systems are more compassionate and sustainable compare to pure agricultural system. The variety of trees on the edges of the agricultural field is farmer friendly and compatible depends mainly on edapho-climatic conditions of the area, farmer's need/traditions and resource availability. The estimates of carbon sequestration potential in agroforestry systems are highly variable ranging from 0.29 to 15.21 Mg ha$^{-1}$ year$^{-1}$ (Nair *et al.*, 2009). This paper deals with assessing the aboveground biomass, carbon stock, carbon stock equivalent carbon dioxide and the annual rate of carbon accumulation in the fruit tree based land use systems of the Indian Himalaya and to study the relationship between tree species, carbon stock and C accumulation rates.

## MATERIALS AND METHODS

### Study Area and Climatic Conditions

The study was conducted during 2011-12 at experimental farm Hawalbagh (29° 36' N and 79°40' E; 1250 m amsl altitude) of Vivekananda Institute of Hill

Agriculture, Almora, Indian Himalaya. The fruit tree *i.e. Citrus lemon* (hill lemon), *Prunus persica* (plum), *Pyrus communis* (pear) and *Prunus armeniaca* (apricot) plantation was 11 year old, which were planted at a spacing of 6.0 m X 6.0 m (277 trees $ha^{-1}$). In different land use systems i.e. hill lemon + wheat, plum + wheat, pear + wheat, apricot + wheat and wheat (*Triticum aestivum* L.) monocropping, planted with use of inorganic fertilizers and irrigated whenever required. The climate of this region is sub-temperate and temperature ranges between 32ºCelsius during summer and the minimum temperature from below freezing point during winter. Average annual precipitations range 1000 to 1100 mm with 96 + rainy days and mean annual relative humidity is about 79%. About 70% of rainfall is received from June to September and the remaining from October to May.

**Assessing the Biomass, Carbon Stock and Carbon Equivalent $Co_2$**

The diameter of each tree within the land use systems was measured at breast height *i.e.*, 1.37 m above the ground except for trees with trunk irregularities, in such cases; diameter was measured above the irregular part of the stem. Understory biomass was collected from three 1 $m^2$ sub-plot randomly placed within each of the land use systems. All aboveground wheat crops was harvested at ground level, weighed, oven dried and the weights of aboveground wheat crop were converted on hectare basis. Fruit trees plantation were assumed to contain 45% C of their biomass (Schroth *et al.*, 2002) and it can be estimated by (Magnussen and Reed, 2004): CS = 0.45 × B, Where CS is the carbon stock and B is biomass. The biomass (B, dry weight) of fruit trees was calculated with an equation based on cylinder volume (Hairiah *et al.*, 2001): $Biomass = ÀD^2hs / 4$, where biomass is expressed in kg, $D$ = tree diameter (cm), $h$ = height (cm) and $s$ = density (g $cm^{-3}$). The data on wood density was extracted from a wood density database created by ICRAF. Carbon stock was multiplied by a factor of 3.67 (44/12) to get an estimate of equivalent $CO_2$ assimilation and this factor was used by Chauhan *et al.* (2009) for agroforestry tree species. Carbon accumulation rate in aboveground biomass for each land use system was assessed by measuring the C stock in each plot and dividing it by the number of years since establishment of the plot. The data on biomass, carbon stock and carbon accumulation rate were analyzed after one way analysis of variance (ANOVA) using SAS 9.3 statistical software. Significant differences were tested at $p \leq 0.05$ using Tukey's least significant difference test.

## RESULTS

### Biomass

The aboveground biomass estimated for the 5 land use systems varied significantly (10.8-37.8 t $ha^{-1}$; Table 1). The highest biomass was observed in the pear + wheat (37.8 Mg $ha^{-1}$) followed by apricot + wheat (26.5 Mg $ha^{-1}$) > plum + wheat (22.4 Mg $ha^{-1}$) > hill lemon + wheat (18.8 Mg $ha^{-1}$) whereas the lowest was in the wheat monocropping (10.8 Mg

**Table 1: Aboveground biomass and biomass accumulation rate in different land use systems**

| Treatment | Aboveground biomass (Mg $ha^{-1}$) | Standard error | Accumulation rate (Mg $ha^{-1}yr^{1}$) | Standard error |
|---|---|---|---|---|
| Hill lemon + wheat | 18.8 | 1.09 | 11.0 | 0.30 |
| Plum + wheat | 22.5 | 0.67 | 10.8 | 0.25 |
| Pear + wheat | 37.8 | 1.81 | 12.0 | 0.21 |
| Apricot + wheat | 26.5 | 0.99 | 11.5 | 0.23 |
| Wheat | 10.8 | 0.30 | 10.7 | 0.30 |
| C.D. | 3.7 | - | NS | - |

C.D. - Critical difference and NS- Non significant (0.05%)

**Table 2: Aboveground carbon stocks and carbon accumulation rate in different land use systems**

| Treatment | Above ground C stock (Mg $ha^{-1}$) | Standard error | Accumulation rate (Mg $ha^{-1}yr^{1}$) | Standard error |
|---|---|---|---|---|
| Hill lemon + wheat | 8.4 | 0.45 | 4.9 | 0.06 |
| Plum + wheat | 10.0 | 0.33 | 4.7 | 0.01 |
| Pear + wheat | 17.0 | 0.92 | 5.3 | 0.20 |
| Apricot + wheat | 11.9 | 0.65 | 5.1 | 0.24 |
| Wheat | 4.8 | 0.16 | 4.8 | 0.16 |
| C.D. | 1.9 | - | NS | - |

C.D. - Critical difference, C- Carbon and NS- Non significant (0.05%)

**Table 3: Aboveground carbon stock equivalent $Co_2$ and $Co_2$ accumulation rate in different land use systems**

| Treatment | Above ground C stock equivalent $Co_2$ (Mg $ha^{-1}$) | Standard error | Accumulation rate (Mg $ha^{-1}yr^{1}$) | Standard error |
|---|---|---|---|---|
| Hill lemon + wheat | 30.9 | 1.65 | 18.0 | 0.21 |
| Plum + wheat | 36.5 | 1.21 | 17.3 | 0.05 |
| Pear + wheat | 62.3 | 3.36 | 19.6 | 0.72 |
| Apricot + wheat | 43.6 | 2.38 | 18.9 | 0.87 |
| Wheat | 17.6 | 0.60 | 17.6 | 0.60 |
| C.D. | 6.9 | | NS | - |

C.D.- Critical difference, C- Carbon, $Co_2$- Carbon dioxide and NS- Non significant (0.05%)

**Table 4: Pearson correlation matrix between different land use system parameters**

| | Tree biomass | Wheat biomass | Total biomass | Total carbon stock | Total $Co_2$ mitigation |
|---|---|---|---|---|---|
| Tree Biomass | 1.000 | -0.719** | 0.999** | 0.998** | 0.998** |
| Wheat Biomass | -0.719** | 1.000 | -0.685** | -0.693** | -0.693** |
| Total Biomass | 0.999** | -0.685** | 1.000 | 0.999** | 0.999** |
| Total Carbon stock | 0.998** | -0.693** | 0.999** | 1.000 | 1.000** |
| Total $Co_2$ mitigation | 0.998** | -0.693** | 0.999** | 1.000** | 1.000 |

$Co_2$- Carbon dioxide, ** significant at $p < 0.01$ level

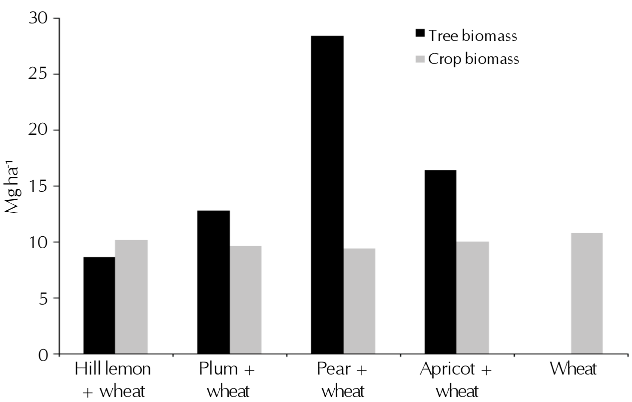


**Figure 1: Aboveground biomass (Mg ha$^{-1}$) of trees and crop in different land use systems**

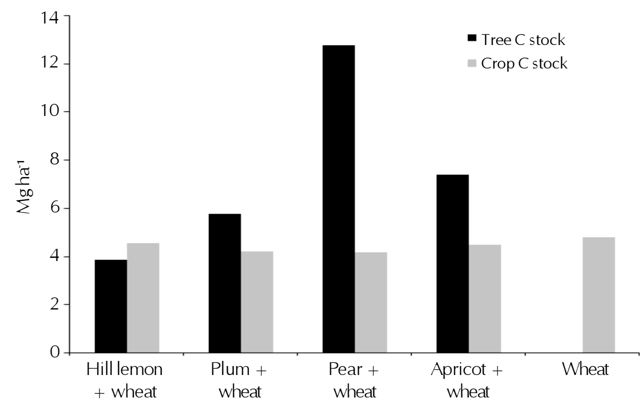


**Figure 2: Aboveground carbon stocks (Mg ha$^{-1}$) of trees and crop in different land use systems**

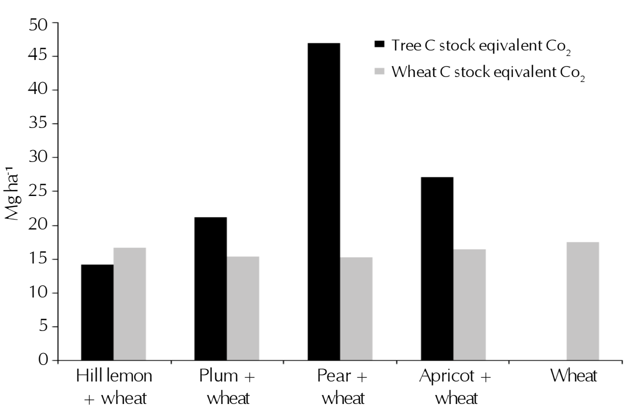


**Figure 3: Aboveground carbon stocks equivalent $Co_2$ (Mg ha$^{-1}$) of trees and crop in different land use systems.**

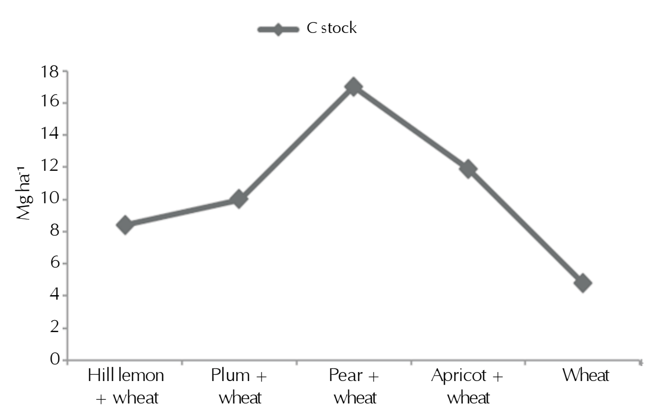


**Figure 4: Carbon stocks in relation to different fruit tree based land use systems**

ha$^{-1}$). Aboveground biomass accumulation rates (Table 1) also varied among the land use systems but it was not significant. Highest rate of biomass accumulation was found in the pear + wheat (12.0 Mg ha$^{-1}$ year$^{-1}$) followed by apricot + wheat (11.5 Mg ha$^{-1}$ year$^{1}$) > hill lemon + wheat (11.0 Mg ha$^{-1}$ year$^{1}$) > plum + wheat (10.8 Mg ha$^{-1}$ year$^{1}$) and lowest (10.7 Mg ha$^{-1}$ year$^{-1}$) rate of biomass accumulation was noted for the wheat monocropping. The contributions of tree and crop in aboveground biomass of different land use systems were calculated (Fig. 1). It is found that tree component contributed more than crop except in case of hill lemon + wheat in which crop contributed more than tree.

**Carbon Stocks**

The aboveground carbon stocks calculated for the 5 land use systems varied significantly (4.8–17.0 Mg C ha$^{-1}$; Table 2). The highest carbon stock was observed in the pear + wheat (17.0 Mg C ha$^{-1}$) followed by apricot + wheat (11.9 Mg C ha$^{-1}$) > plum + wheat (10.0 Mg C ha$^{-1}$) > hill lemon + wheat (8.4 Mg C ha$^{-1}$) whereas the lowest was in the wheat monocropping (4.8 Mg ha$^{-1}$). Aboveground carbon accumulation rates (Table 2) also varied among the land use systems but it was not significant. Highest rate of carbon accumulation was found in the pear + wheat (5.34 Mg C ha$^{-1}$ year$^{-1}$) followed by apricot + wheat (5.16 Mg C ha$^{-1}$ year$^{1}$) > hill lemon + wheat (4.90 Mg C ha$^{-1}$ year$^{1}$) > wheat (4.79 Mg C ha$^{-1}$ year$^{1}$) and lowest (4.72 Mg C ha$^{-1}$ year$^{-1}$) rate of carbon accumulation was noted for the plum + wheat. The contributions of tree and crop in aboveground carbon stock of different land use systems were calculated (Fig. 2).

**Carbon Stocks Equivalent Carbon Dioxide**

The aboveground carbon stocks equivalent carbon dioxide calculated for the 5 land use systems varied significantly (17.6-62.3 Mg $Co_2$ ha$^{-1}$; Table 3). The highest carbon stock equivalent carbon dioxide was observed in the pear + wheat (62.3 Mg $Co_2$ ha$^{-1}$) followed by apricot + wheat (43.6 Mg $Co_2$ ha$^{-1}$) > plum + wheat (36.5 Mg $Co_2$ ha$^{-1}$) > hill lemon + wheat (30.9 Mg $Co_2$ ha$^{-1}$) whereas the lowest was in the wheat monocropping (17.6 Mg $Co_2$ ha$^{-1}$). Aboveground carbon dioxide accumulation rates (Table 3) also varied among the land use systems but it was not significant. Highest rate of carbon dioxide accumulation was found in the pear + wheat (19.6 Mg ha$^{-1}$ year$^{-1}$) followed by apricot + wheat (18.9 Mg ha$^{-1}$ year$^{1}$) > hill lemon + wheat (18.0 Mg ha$^{-1}$ year$^{1}$) > wheat (17.6 Mg ha$^{-1}$ year$^{1}$) and lowest (17.3 Mg ha$^{-1}$ year$^{-1}$) rate of carbon dioxide accumulation was noted for the plum + wheat. The contributions of tree and crop in aboveground carbon stock equivalent carbon dioxide of different land use systems were calculated (Fig. 3). It is found that tree component contributed more than crop except in case of hill lemon + wheat in which crop contributed more than tree.

**Land Use Systems In Relation to Carbon Stock**

The tree species in each plot of the sampled land use system was plotted against carbon stock. In general, aboveground carbon stocks were varied in different land use systems with different tree species (Fig. 4). The pear + wheat, apricot + wheat, plum + wheat, hill lemon + wheat, were found to contain a fairly high carbon stocks due to tree species. Conversely, the land use systems without tree species had low carbon stocks *i.e.* wheat monocropping. Pearson correlation matrix (Table 4) revealed significant and positive relationship of tree biomass with, total biomass, total carbon and total carbon dioxide mitigation. Wheat biomass did not show any significant positive relationship with any of the parameters.

## DISCUSSION

Geographical region, plant species and age are the major determinants of biomass, carbon stock and carbon accumulation rate in vegetation (VanNoordwizk *et al.,* 1997; Dash and Behera, 2013; Liu *et al.,* 2015). There is a tendency that biomass, carbon stock and $CO_2$ assimilation is varied in the presence of tree and with diverse tree species in different land use system. Land use systems such as pear + wheat, apricot + wheat, plum + wheat and hill lemon + wheat, showed more carbon accumulation rates in comparison to wheat monoculture. This study has shown that fruit tree based land use systems in Indian Himalaya have high carbon accumulation rates in aboveground biomass due to presence of diverse fruit tree species in land use systems. Tree-crop systems sequestered carbon at a rate higher than those containing only annual crops, which accumulated limited carbon. Therefore, significant quantities of carbon can be sequestered by moving away from only annual crops to tree based systems like agroforestry and forest plantations. This is consistent with the findings of Tomich *et al.* (2002) and Yadav and Bisht (2014). Annual crops will only accumulate carbon through the roots and retention of crop residues, whereas the tree crops will accumulate carbon through roots, litter, and aboveground biomass. The carbon accumulation rates found at Indian Himalaya are higher than those reported by Pandey (2002) 2-4 Mg ha$^{-1}$ year$^{-1}$ for agroforestry. Montagnini and Nair (2004) reported carbon accumulation in tropical smallholder agroforestry to be in the range of 1.5-3.5 Mg ha$^{-1}$ year$^{-1}$. Vegetation biomass and carbon in present result is in accord with the result reported by Tiwari and Singh (1987), Sharma *et al.* (2010), Kanime *et al.* (2013), Sharma *et al.* (2014) for adjoining Himalayan forest ranges. This difference in biomass production in different trees is may be related to their leaf area index and canopy architecture. Singh (2005) and Sharma *et al.* (2014) demonstrated the usefulness of tree species in improving the carbon stock. Arora *et al.* (2014) reported aboveground carbon stocks in *P. deltoids* increased from 0.5 Mg ha$^{-1}$ at 1 year to 90.1 Mg ha$^{-1}$ at 11 years which is higher than this study and carbon sequestration rate in mature plantations (7–11 years) varied from 5.8 to 6.5 Mg C ha$^{-1}$ per year. It is found that tree component contributed more than crop except in case of hill lemon + wheat in which crop contributed more than tree. Gera *et al.* (2006) reported 115, 64 and 56 Mg ha$^{-1}$ carbon sequestration potential under poplar block, poplar boundary and *Eucalyptus* boundary plantations, respectively under irrigated agro ecosystem on farmer's fields.

The results on carbon stock and carbon accumulation rates found in this study must be interpreted with caution, because the carbon stock and the carbon accumulation rates are dependent on the age of the plants, plant density, soil fertility of the site, rainfall and other factors. In addition to the accumulation of high average carbon stock, agroforestry systems have several advantages over monocultures including crops for household consumption. Agroforestry also may provide a viable combination of carbon storage with minimal negative effects on food production (Pandey, 2002; Yadav and Bisht, 2014). High and long term biomass accumulation with early generation of income from annual and semi-perennial intercrops is a characteristic feature of agroforestry systems. In addition, they allow for long term accumulation of capital in large sized trees and would provide more complete canopy cover than certain tree crop monocultures (Schroth *et al.,* 2002). There is less risk in practicing agroforestry than monocropping with respect to climatic disasters such as floods and drought, market fluctuations and pest/disease attacks. It has been reported that agroforestry systems increase food security and provide additional income to farmers (Magcale-Macandog *et al.,* 2010).

The results showed that agroforestry accumulated higher carbon stocks than agriculture alone. The landscape in Indian Himalaya is a mosaic of different land use systems. Furthermore, there is heterogeneity within each land use system depending on species diversity landscape characteristics and soil quality. Integrated forest management including land use planning focused agroforestry applications and selective plantation forestry may help to sequester carbon and meet the needs of local people. This paper shows that fruit tree based land use systems in Indian Himalaya have higher potential for carbon stock and carbon accumulation in aboveground biomass. For instance, tree-crop systems pear

+ wheat, apricot + wheat, plum + wheat and hill lemon + wheat sequestered higher carbon than those containing monocropping of wheat, which has limited accumulation of carbon. In general carbon accumulation rates varied with diverse tree species in land use systems with high carbon accumulation. Fruit tree based land use systems contained the highest stock of carbon in their biomass. A nearly similar trend was found for rate of carbon dioxide mitigation. Pearson correlation matrix revealed significant and positive relationship of tree biomass with total biomass, total carbon stock and of carbon dioxide mitigation. Cultivating agricultural crops with fruit trees plantation, therefore, may be an attractive option for storage of atmospheric $Co_2$ in the Indian Himalaya.

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