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Biomass, carbon stock under different production systems in the mid hills of Indian Himalaya

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Abstract: Pecan nut (*Carya illinoinensis)* forms an important component in the different production systems of Indian Himalaya, which provide extensive ecosystem services. In this context, biomass and carbon inventory in these production systems is essential. In this study we have estimated biomass and carbon allocation in different production systems in the mid hills of Indian Himalaya, at experimental farm Hawalbagh of Vivekananda Institute of Hill Agriculture, Almora, India. The maximum biomass (56.5 t ha^{-1}) and carbon stocks (25.3 t ha^{-1}) were recorded in wheat + pecan nut system followed by (53.2 and 23.9 t ha^{-1}) in lentil + pecan nut system while the minimum value of biomass and biomass C was recorded 2.75 and 1.17 t ha^{-1} in pure lentil production system. The Long lived carbon storage of pecan nut agroforestry plantation was 9.21 t C ha^{-1}. The contribution of pecan nut in carbon stock and carbon sequestration rate were recorded 22.8 t C ha^{-1} and 1.67 t C ha^{-1} year^{-1}, respectively. Furthermore, agroforestry systems produce timber, firewood, fruits and other products that will bring profit to peasants and reduce the release of carbon dioxide into the atmosphere.

Key words: Agroforestry, biomass, carbon stock, Himalaya, pecan nut, production system.

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Introduction

The global apprehension is that carbon management should be in forests to mitigate the increased concentration of green house gases in the atmosphere. A recent estimate indicates that tropical forests account for 247 Gt vegetation carbon, of which 193 Gt is stored as above ground (Saatchi *et al*. 2011). However, the worldwide forest cover is diminishing fast in view of great biotic stress, industrialization, urbanization, land use changes for developmental activities and conversion of forests to agricultural land. The importance of terrestrial vegetation as significant sinks of atmospheric carbon dioxide and its other derivatives is highlighted under Kyoto Protocol (Wani *et al*. 2010) to improve environmental conditions and check the processes of environmental degradation.

Biomass assessment is important for national development planning as well as for scientific studies of ecosystem productivity (Pandey *et al*. 2010). In the agroforestry systems the amount of carbon sequestrated is determined by the structure and function of systems which to a great extent, are determined by environmental and socio-economic factors. Biomass and carbon storage in agroforestry systems can also be influenced by tree species and system management (Albrecht & Kandji 2003; Pandey *et al*. 2010; Rajput *et al*. 2015). Globally, the estimated range between 40 and 150 t C ha^{-1} is the average quantity of carbon stored in the aboveground components of agroforestry systems (IPCC 2006). The potential role of agroforestry systems to work as a carbon sinks and to be

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incorporated into international carbon trading system has been ignored (Oelbermann *et al.* 2004). From both industrialized and developing countries in latest years, the significance of agroforestry system in CO_2 mitigation has turned out to be more broadly recognized.

Himalayan region has a long custom of agroforestry, based on people's needs and site-specific distinctiveness numerous native agroforestry systems have been developed over the years (Chinnamani 1993; Yadav & Bisht 2014a). Through improved growth of trees and shrubs, agroforestry practices have wide and promising potential to store carbon and remove atmospheric carbon dioxide. The vast potential of smallholder agroforestry system for C storage and sequestration remains underexploited and proper utilization, management and innovative policies can make this an effective carbon sink besides fulfilling the diverse needs of rural livelihoods (Nath & Das 2012; Yadav & Bisht 2013). Average sequestration potential has been estimated to be 25 t C ha^{-1} over 96 million ha of land in India in agroforestry (Sathaye & Ravindranath 1998) and 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). However information on carbon allocation in different management systems in this region is relatively scanty. Therefore, the present study was designed to estimate biomass and carbon allocation in different production systems in the mid hills of Central Himalaya.

Material and methods

Site descriptions

The study was conducted during 2012 - 13 at experimental farm Hawalbagh (29°36'N and 79°40'E, 1250 m amsl) of Vivekananda Institute of Hill Agriculture, Almora, India. The climate of this region is sub-temperate and temperature ranging between 32 °C during summer and the minimum temperature from below freezing during winter. Average annual precipitations ranged 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. The experimental site was neutral in pH (6.5), had 1.42% organic C, 231.0 kg ha^{-1} available N, 17.89 kg ha^{-1} P, and 132.5 kg ha^{-1} K in the 0–15 cm depth. The organic C content, available N, and available K decreased as the depth increased. The pH of the soil was measured by Beckman Glass electrode pH meter. Available N, P, and K contents were measured by micro-Kjeldahl (Jackson 1967), Olsen's method and Flame Photometric method (Jackson 1967), respectively.

Tree establishment and experimental design

Carya illinoinensis (Wangenh.) K. Koch (pecan nut) trees plantation were carried out at 6.0 m × 7.0 m spacing with a density of 238 trees per ha in mid hill situation. Pecan nut-crop intercropping patterns were designed during the planting and plots were arranged in East-West orientation. Intercropping is the intensive activity in an agro ecosystem, two crops wheat (*Triticum aestivum*) and Lentil (*Lens esculentum*) in rainfed system, the management measures were the same with normal practices of farmers, and no supplementary nutrients and water were provided intentionally. The data were analyzed with the help of OPSTAT (http://14.139.232.166/opstat/default.asp) in factorial randomized block design.

Pecan nut biomass

The pecan nut plantation was 11 year old and well managed under agroforestry system at the time of present study. Trees within plot for height and diameter at breast height was measured and recorded. In order to assess the tree biomass the regression equations developed by Ares *et al.* (2006) for pecan nut in silvopastures have been used. The equation to estimate wood volume of pecan nut tree as a function of DBH (m) and height (m) was: $V = 0.6134\ DBH^{1.7775}\ H$, where, V = wood volume (m^3), DBH = mean diameter at breast height (1.37 m) above the ground level (m) and H = height (m).

Crop biomass

Biomass of the crops was measured by placing a one-meter-square in the field at full maturity. Aboveground biomass of crops was measured by cutting, drying and weighing all the plant material within the square from five replicated plots. Fresh weights of aboveground components for each one-meter-square quadrate were determined in the field, and sub-samples for each component were collected for moisture and C analysis. From the biomass sampling measurement, crop biomass was expanded to an area basis in the field as a whole.

Carbon concentration analysis and C stock assessment

Most of the information for carbon estimation described in the literature suggests that carbon constitutes between 45 to 50% of dry matter and it can be estimated by simply taking a fraction of biomass as (Magnussen & Reed 2004): C = 0.45 × B, Where C is the carbon content and B is biomass. In the present study we followed the above equation to assess the carbon content in different components of pecan nut plantation. All plant materials were dried at 70 ± 1 °C in oven, grind and stored in airtight containers for chemical analysis. Carbon concentrations of plant samples were determined by liquid TOC Analyzer. The mass of carbon stored in crop compartments was estimated by multiplying their measured mass by the carbon concentrations. Then, carbon stocks in pecan nut trees as well as in crops were expand to an area basis. Total carbon stock in the each intercropping configuration was calculated as the sum of pecan nut trees and crops. CO_2 mitigation by different agroforestry systems was estimated by multiplying the values of carbon stock by factor of 3.66. Long-lived carbon storage, heat from biomass combustion and carbon storage from coal substitution was estimated by the formula (Wang & Feng 1995). Total amount of carbon sequestration in woody component was estimated by adding long lived carbon storage in wood products and the carbon storage due to substitution biomass for coal and expressed in t ha^{-1}.

Results and discussion

Biomass and carbon allocation

Tree density of 11-year-old *C. illinoinensis* plantation was 238 trees ha^{-1} and the total tree basal area was 6.11 m^2 ha^{-1}. The pecan nut plantation had a mean dbh (diameter at breast height) of 18.04 cm and wood volume 0.266 cubic meters. Chauhan *et al.* (2011) also reported a similar trend in growth of *P. deltoides* under agroforestry in the Indo- Gangetic plains. A single tree accounts for biomass (204.8 kg), biomass carbon stock (92.17 kg) and carbon dioxide equivalent carbon (338.3 kg) (Table 1). A similar trend was observed by Singh & Singh (1981) for dry tropical forests of India, Swamy & Puri (2005) for *Gmelina arborea* and Arora *et al.* (2014) for *Populus deltoids.* Carbon concentration in different content, which further varies with components of

Table 1. Mean DBH, wood volume, biomass, biomass carbon stock and CO_2 equivalent carbon per tree.

Parameters	Values
Height (m)	9.14
DBH (cm)	18.04
Wood volume (m^3)	0.266
Biomass (kg)	204.82
Biomass C (kg)	92.17
C equivalent CO_2 (kg)	338.26

the trees, viz., stem, branch, leaf etc. (Negi *et al.* 2003). Carbon concentration in aboveground components varied from 41.7–44.6%. In wheat crop, carbon concentration of 42.7% and 44.6% was observed in grain and straw with pecan nut and 42.4% and 43.13% in pure crop, respectively.

In lentil crop, carbon concentration was recorded 44.0% and 44.3% was observed in grain and straw with pecan nut 43.5% and 41.7% in pure lentil crop, respectively. The carbon concentrations of live plants are related to the chemical composition and this chemical composition is a function of various components, type of plant, geographical location, climate and soil conditions (Romberger *et al.* 2004) and therefore all these characteristics must be taken into account.

Biomass production

The data in Table 2 shows the variation in biomass level for different management systems, viz., lentil + pecan nut, wheat + pecan nut in agroforestry systems and lentil and wheat as a pure crop. The maximum biomass was recorded (56.5 t ha^{-1}) in wheat + pecan nut system followed by (53.2 t ha^{-1}) in lentil + pecan nut system, while the minimum value of biomass was recorded 2.75 t ha^{-1} in lentil as a pure lentil system. The present estimates of aboveground biomass are in the range of those reported by Raizada and Srivastava (1989), Lodhiyal *et al.* (1995), Yadava (2010) and Kanime *et al.* (2013), and Pandey *et al.* (1987) for *Populus deltoides* and *Eucalyptus* species, respectively. The variations in tree biomass as compared to other studies are attributed to a number of factors, such as growth conditions, site quality, age, density, structure, and management practices (Goswami *et al.* 2013; Kanime *et al.* 2013; Oelbermann *et al.* 2004; Swamy & Puri 2005) and its interaction with below ground crops have also

Table 2. Above ground biomass production of different management systems.

Systems	No. of trees ha^{-1}	Age of trees (years)	Above ground biomass (t ha^{-1})		
			Trees	Crops	Total
Pecan nut + Lentil	238	11	50.71	2.52	53.23
Pecan nut + Wheat	238	11	50.71	5.75	56.46
Lentil	-	-	-	2.75	2.75
Wheat	-	-	-	5.84	5.84
LSD					1.57

contributed towards increasing height and diameter at breast height of pecan nut trees. The highest biomass in pecan nut + wheat system can be attributed to higher aboveground biomass of wheat in comparison to lentil. Swamy *et al.* (2003) reported that in nutrient rich soil, more of biomass is allocated to aboveground parts. Lowest biomass in lentil as a pure crop system can be attributed due to lesser biomass of lentil.

The Biomass of wheat crop was recorded maximum in wheat as a pure crop system (5.84 t ha^{-1}) followed by pecan nut + wheat system (5.75 t ha^{-1}) and biomass of lentil was recorded higher in pure lentil system (2.75 t ha^{-1}) followed by pecan nut + lentil system (2.52 t ha^{-1}). The maximum aboveground biomass was recorded (56.5 t ha^{-1}) in pecan nut + wheat system followed by pecan nut + lentil system (53.2 t ha^{-1}), while the minimum value of (2.75 t ha^{-1}) above ground biomass was recorded in lentil as a pure lentil system. The results are in conformity with the findings of Devagiri *et al.* (2013). The reason for reduction in crop biomass in agroforestry system may be due to the competition between trees and crop for the sharing of resources, viz., light, water and nutrients hence causing reduction in dry matter accumulation. Reduction in biomass of wheat below tree canopy has also been recorded by Dhillon *et al.* (1998).

Carbon stock and carbon dioxide mitigation through biomass

Aboveground biomass carbon stocks (t ha^{-1}) in different systems are given in Table 3. The maximum carbon stock was observed in pecan nut + wheat system (25.30 t ha^{-1}), followed by pecan nut + lentil system (23.92 t ha^{-1}) and minimum was recorded (1.17 t ha^{-1}) in lentil system as a pure crop. Among different components, tree showed maximum carbon dioxide mitigation potential (Table 4). Maximum carbon dioxide mitigation (92.5 t ha^{-1}) recorded in pecan nut + wheat system followed by pecan nut + lentil system (87.78 t ha^{-1}). Whereas, minimum carbon dioxide mitigation (4.29 t ha^{-1}) was recorded in lentil system as a pure crop. The maximum carbon dioxide mitigation in wheat crop was in wheat system (9.17 t ha^{-1}) as a pure crop closely followed by pecan nut + wheat system (9.13 t ha^{-1}). Carbon stocks are dependent on the higher tree density and carbon concentration in different components.

Carbon storage in plant can be high in complex agroforestry systems and productivity depends on several factors such as age, structure and way how the systems are managed (Oelbermann *et al.* 2004; Swamy & Puri 2005). The results are comparable with the findings of Albrecht & Kandji (2003), Rizvi *et al.* (2011), Wani *et al.* (2010), Yadav & Bisht (2014b), reported that agroforestry can store carbon in the range of 12–228 Mg ha^{-1}. Gera *et al.* (2011) attributed that the variations in the carbon sequestration potential relates to the mean annual increment, which varied with site, age, density, and plantation, as well as the quality of planting stock. Carbon dioxide (CO_2) mitigation by aboveground parts varied from 4.07 in lentil with pecan nut to 83.71 t ha^{-1} in pecan nut biomass. Total above ground CO_2 mitigation recorded maximum for pecan nut + wheat system (92.85 t ha^{-1}), followed by pecan nut + lentil system (87.78 t ha^{-1}). Minimum CO_2 equivalent carbon was recorded 4.29 t ha^{-1} in lentil system as a pure crop. Carbon dioxide mitigation by plant is directly related to biomass production of the different plant components. Higher mitigation value of pecan nut + wheat system and pecan nut + lentil system can be attributed to more biomass and more carbon stock in agroforestry system as compare to sole agriculture system.

Carbon sequestration by tree

Large C stock does not necessarily mean a large C sequestration potential. Carbon stock refers to the absolute quantity of C held at the time of inventory, whereas C sequestration refers to the process of removing carbon from the atmosphere and depositing it in a reservoir (Takimoto *et al.* 2008). Long lived carbon storage in stem and carbon storage from coal substitution through branches and twigs/leaves was also calculated (Table 5). The long lived carbon storage,

Table 3. Above ground biomass carbon stock under different management systems.

Systems	Above ground biomass C (t ha^{-1})		
	Trees	Crops	Total
Pecan nut + Lentil	22.81	1.11	23.92
Pecan nut + Wheat	22.81	2.49	25.30
Lentil	-	1.17	1.17
Wheat	-	2.50	2.50
LSD			0.22

Table 4. Above ground carbon dioxide mitigation by different management systems.

Systems	Above ground biomass CO_2 (t ha^{-1})		
	Trees	Crops	Total
Pecan nut + Lentil	83.71	4.07	87.78
Pecan nut + Wheat	83.71	9.13	92.85
Lentil	-	4.29	4.29
Wheat	-	9.17	9.17
LSD			0.81

Table 5. Biomass production and carbon sequestration in pecan nut tree.

Parameters	**Values**
Biomass (t ha^{-1})	48.75
C storage (t ha^{-1})	21.93
Long lived C storage (t ha^{-1})	9.21
Heat from biomass combustion (× 10^{10})	54.42
C storage from coal substitution (t C ha^{-1})	9.14
Total carbon sequestration (t C ha^{-1})	18.35
C sequestration (t C ha^{-1})	1.67

heat from biomass combustion and carbon storage from coal substitute was observed in pecan nut and the values were 9.21 C ha^{-1}, 544.2 × 10^9 and 9.14 t C ha^{-1}, respectively. The carbon sequestration was recorded 18.53 t C ha^{-1} and 1.67 t C ha^{-1} year^{-1} by pecan nut tree. Tree stem sequesters the carbon for longer time after felling as compared to the carbon stored in leaves and branch biomass (Gera *et al.* 2011; Kaul *et al.* 2010; Rana *et al.* 1989; Wang & Feng 1995).

Conclusions

In the situation of increasing atmospheric level of carbon dioxide and continued accelerative rate of deforestation, finding low cost methodologies to sequester increased level of atmospheric carbon into terrestrial ecosystems is a major strategy of most of the developing countries. In the Indian Central Himalayan region where people's dependence on forest resources is high, agroforestry systems can play an important role in environmental and ecological sustainability. Agroforestry systems in this region can reduce the pressure on natural forests by providing the much needed fuel and fodder requirements of the peoples and can reduce a significant amount of atmospheric carbon through carbon sequestration in the standing biomass. In the present study, biomass and carbon storage in cropping system alone and 11-year-old pecan nut agroforestry plantations ranged from 2.75 to 50.71 t ha^{-1} and 1.17 to 22.81 t C ha^{-1}, respectively, however, production systems also influence crop carbon stocks. Our results indicated that the carbon storage in pecan nut with crop was more than that in pure cropping system alone. Our study reveals that a considerable amount of carbon is allocated in *C. illinoinensis* agroforestry plantation, which acts as an additional carbon sink in the region, as large scale Pecan nut plantations exits in the mid hills of central Himalaya.

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