ABOVE-GROUND CARBON POOLS OF *CITRUS* ACREAGE IN PAKISTAN

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ABSTRACT

Estimation of above-ground biomass (AGB) is important for forest resource inventory, natural resource management and environmental services such as estimation of carbon sequestration. Objective of this study was to estimate AGB of *citrus* trees using a non-destructivemethod and quantify carbon pools of *citrus* acreage in Pakistan. One hundred trees of different age were selected at three various locations in Faisalabad Division to achieve the study objective. Measurements of tree height, breast height diameter, wood density and green volume were made using standard methods. Regression equations were used to estimate AGB of *citrus* plants from above plant variables. Total carbon sequestered by *citrus* cultivation in Pakistan was estimated to be 1176 tons from the data of *citrus* acreage in Pakistan with an average density of 40 plants ha^{-1}. Field implications of this research include estimation of environmental services of forestation and managing agro-ecosystems. Total amount of carbon sequestered by *citrus* orchards of various ages can be estimated by the relationships established in this study. These research results may be used as baseline information for future studies and planning and management of carbon budgets in Pakistan.

Key words: Plant biomass, carbon sequestration, environmental services, plant variables, agro-forestry.

INTRODUCTION

Trees can store significant amounts of carbon in cellulose and lignin in the form of wood (Brown, 1997; Takimoto *et al.* 2008). Hence, calculation of the tree biomass can provide estimates of environmental services including carbon pooling in forests or orchards. Biomass is the living or dead organic material that constitutes both above- and below-ground parts of a tree, most of which is constituted above-ground. Living portion of a tree or a plant that is above from soil surface which includesstem, stump, branches, bark, seeds and foliage is known as above-ground biomass (ABG). The trees especially which have deep root systems store long-term higher amounts of carbon in their biomass. Whereas, all living roots not including fine roots (less than 2 mm in diameter) are called below-ground biomass.

Quantification of ABG of a tree can be done by destructive and/or non-destructive ways; the earlier involves tree harvesting (Stewart *et al.* 1992) and the later is adopted without cutting down a tree (Montes *et al.* 2000). Non-destructive methodsare mostly applicable for rare tree species or orchard trees (Brown 1997). In non-destructive methods, stem weight estimation is derived from wood density measurements using metal cores and/or sections of dead stems (Vann *et al.* 1998). Quantified biomass is measured either by fresh weight (Araujo *et al.* 1999) or by dry weight units (Aboal *et al.* 2005; Montagu *et al.* 2005; Saint-Andre *et al.* 2005; Ketterings *et al.* 2001).

Growing of trees have number of benefits such as; decreasing food insecurity issues, enhancing crop yields, improving resilience of agro ecosystems and CO_2 sequestration (Ajayi *et al.* 2011). Carbon sequestration is successful when carbon storage resulting from conservation practices exceeds carbon losses (Ibrahim *et al*. 2011; Ahmad *et al*. 2014; Smith *et al.* 2014; Zahra *et al*. 2016). Sequestration is possible through a range of processes, occurring naturally in plants. Recently, carbon sequestration and decreased emissions from circumvented deforestation have received more attention as a method to reduce the buildup of GHGs in the earth atmosphere (Sedjo and Sohngen 2012). Carbon sequestration happens in two major segments of the agroforestry systems; aboveground and below ground. The aboveground segment is described as specific plant parts (stem and leaves of herbaceous plants and trees), while the belowground segment contains roots and soil organisms, and carbon stored in various soil horizons. Due to net positive contribution of agroforestry to climate change system the system has become a carbon sink.

The potential value of using long-term data from tropical forest plots for studying changes in biomass was highlighted by a study of 68 pantropical sites by Phillips *et al.* (1998). Overthe period 1975–1996, in 40 sites across Amazonia, total AGB increased by 0.97±0.58 Mg ha^{-1} yr^{-1}, which is equivalent to 0.88±0.53 Mg $ha^{-1}yr^{-1}$ for trees that are 10 cmor more in diameter. This value was used to estimate a totalcarbon sink across Amazonia of 0.44±0.26 Gt C yr^{-1}.

Estimates of tree biomass can help in evaluating environmental services provided by forests or orchards in a country. Pakistan enjoys a distinguished position in *citrus* producing countries of the world. In Pakistan, *Citrus* is grown on an area of about 200 thousand hectares with an annual production of 2,438 thousand tones (Anonymous 2010). *Citrus* is an important component of an agro-forestry system in Pakistan. Literature search did not reveal any study on estimation of carbon sequestration potential of *Citrus* orchards in Pakistan. This data is imperative for carbon budgeting of agro-forestry and modeling environmental impacts of *Citrus* cultivation on our ecosystem. Such baseline information is needed for future studying, planning and management of carbon budgets of agro-forestry systems. Therefore, this study was planned to estimate ABG of a *Citrus* tree using a non-destructive method and to quantify carbon sequestration potential of *Citrus* acreage in Pakistan.

MATERIALS AND METHODS

Study area: Ten *Citrus* orchards; five in the Ayub Agricultural Research Institute, Faisalabad and five from distinct locations in Faisalabad district, were selected for *Citrus* plant biomass estimation. Faisalabad district (30.35 to 31.47° N, 72.01 to 73.40° E) constitutes plain lands in the northeast Punjab – Pakistan at an elevation of 183 m above mean sea level. The district covers more than 16,000 km^2 area. The area has arid climatic conditions with extreme maximum temperature, extreme minimum temperature, and mean daily precipitation values of 50°C, –2 °C, and 1.02 mm, respectively (Abbas 2013; Abbas *et al*. 2014).

Meter calibration: Thirty-five (35) objects (including buildings, pillars, doors, windows, gates, home refrigerators, picture frames fixed on walls, poles, bus-stop tops, and under constructions structures) of know height were used to calibrate Hega Altimeter and Suunto Clinometer. Calibration equations for each of the above instruments were established by plotting their reading against known readings (confirmed with measuring tape). Calibration equations were used to convert plant height readings taken with Hega Altimeter and Suunto Clinometer.

Data collection and analysis: One hundred *Citrus* plants of various age and size from the above mentioned ten distinct orchards in Faisalabad district were randomly selected to measure tree height, breast-height diameter, tree volume and stem density. Wood samples were packed in plastic bags, labeled and bought to the laboratory of the Department of Environmental Sciences and Engineering at the Government College University Faisalabad for further analysis. Above-ground biomass of a tree was calculated as (Rajput *et al*. 1996; Negi *et al.* 2003):

$$\text{AGB (g)} = \text{SG} \times V \quad (1)$$

Where SG is specific gravity (g m^3) and V is volume of biomass (m^3). Specific gravity was calculated as:

$$SG = W_d / V_g \quad (2)$$

where W_d and V_g stand for oven-dry volume and green volume of the wood samples, respectively. The value of W_d was achieved by drying (at 70 ºC for 48-72 hrs) the wood sample to its constant weight. The value of V_g was achieved by immersing the fresh wood samples into a water cylinder of know volume and recording the displaced volume of water as a result of log immersion.

Volume of biomass was calculated as (Grismer *et al.* 2000):

$$\text{V} = A_b \times H \times K_c \quad (3)$$

where A_b stands for basil area of a tree, H for a tree height and K_c for the crop coefficient – a ratio between ETc (crop evapotranspiration) and ETo (evapotranspiration from a reference grass); K_c values for mature *Citrus* groves range from 0.50 to 0.75 (Grismer *et al.* 2000). Basil area of tree was measured as:

$$A_b = \Pi \times r^2 \quad (4)$$

where Π (Pi) = 22/7 and r = tree radius (0.5 × breast-height diameter).

Tree height was measured with Haga Altimeter and Suunto Clinometer. These instruments were calibrated prior to their use by plotting their height measurements versus height values of known objects. Thirty-five objects of various heights were selected for height determination in triplicate by these instruments, a pole and a measuring tape. Calibration equation were established for each of these instruments and used for further data collection.

For estimation of biomass and carbon sequestration studies, the dry weight is more applicable because 50% of it is carbon (Montagu *et al.* 2005; Losi *et al.* 2003; Montagnini and Porras 1998). Mostly biomass estimation studies are focused on above-ground biomass (Aboal *et al.* 2005; Segura and Kanninen 2005; Kraenzel *et al.* 2003; Losi *et al.* 2003) because it accounts for the majority of the total accumulated biomass.

Amount of sequestered carbon (SC) by a tree (mg of C) was determined as (Howard 1965):

$$SC = 0.50 \times \text{OM} \quad (5)$$

where OM stands for organic matter (mg) that was determined by combustion method. For this purpose, wood samples were combusted to 350 ºC and loss on ignition was determined by Konen *et al.* (2002) method.

Literature also recommends targeting individual treesthrough the use of airborne laser lidar that provides the tool to reliably measure not onlytree height but also crown dimensions, thus improvingestimates of forest volume and biomass (Popescu*et al.* 2003). The current study could not use these advanced techniques due to resource constraints.

In order to quantify above-ground carbon pools of *Citrus* acreage in Pakistan, the values of Citrus acreage determined from literature survey and from the data collected from the Statistics Department of Pakistan and the Department of Agriculture Pakistan were multiplied with the calculated values of sequestered carbon (*SC*) per unit area.

$$\text{Total } SC_{AGB} = SC \times A \times T_n \quad (6)$$

where SC_{AGB} (Mg of C) is total sequestered carbon in above-ground biomass of *Citrus* acreage in Pakistan, *SC* is mean carbon sequestered per tree (Mg of C), *A* is *Citrus* acreage in Pakistan (ha), and T_n is number of *Citrus* trees per ha (~278) in Pakistan. The standard plant population in an orchard was calculated by keeping 6 m plant to plant and row to row distances using the following formula (Malik 1994):

$$\text{Plant Population} = \frac{(Area)}{(P \times P)(R \times R)}$$

$$\text{Plant Population} = \frac{(10000)}{(6)(6)} = 277.77 \text{ plant}$$

RESULTS AND DISCUSSION

Meter calibration: Figure 1 shows calibration equations established for Hega Altimeter and Suunto Clinometer.The equations were developed by plotting the values of exact tree height with help of a measuring tape (on x-axis) versus the values of the same tree height measured with Hega Altimeter and Suunto Clinometer (on y-axis). Based on the close to unity values of goodness of fit, *i.e*., R^2 (0.99) the coefficient of determination, for Hega Altimeter and Suunto Clinometer, these calibration equations were considered accurate to convert meter readings of tree heights.

Relationships of tree biomass with measured parameters: Table 1 shows minimum, maximum, mean and standard deviation of values of specific gravity, volume, height, diameter, and biomass of 100 citrus plants.

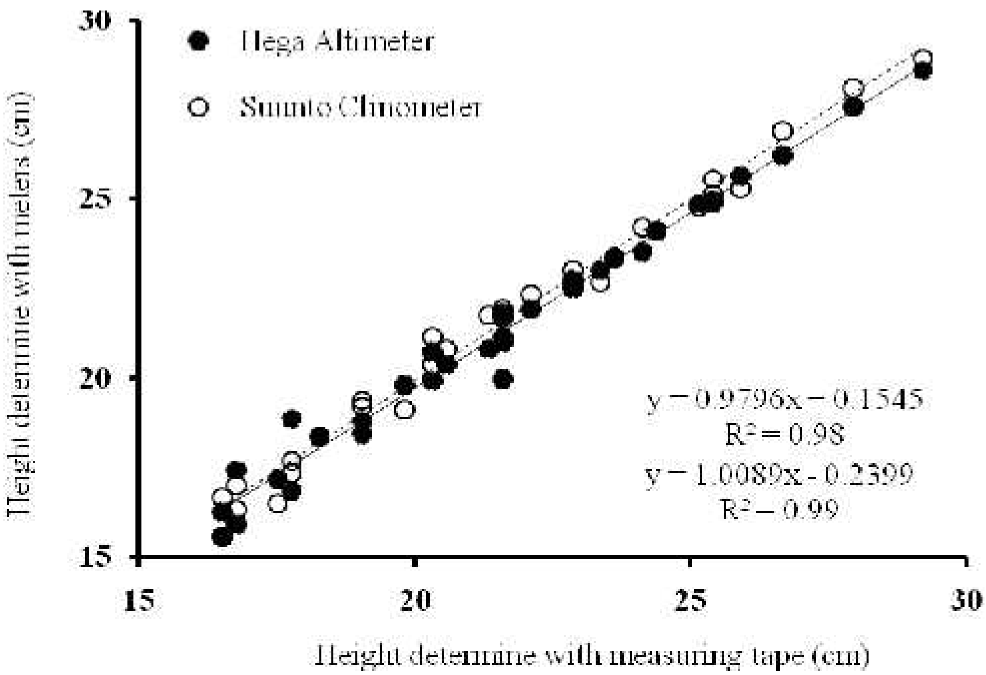

Figure 1. Calibration equations established for Hega Altimeter (solid line on closed circles) and Suunto Clinometer (dotted line on open circles) used to measure tree height

Table 1. Statistical values of the measured parameters of observed trees.

Parameter	Maximum value	Minimum value	Mean ± Standard deviation
Specific Gravity (g/cm^3)	0.96	0.45	0.70 ± 0.15
Volume (cm^3)	204458	52738	104391 ± 36599
Height (cm)	521	250	367 ± 62.80
Diameter (cm)	97.54	51.8	75.41 ± 11.20
Biomass (kg)	138	16.42	52.70 ± 26.30

These tree parameters showed relationships between them and the basil area (Table 2). There was a positive relationship between the specific gravity and biomass with R^2 = 0.48. The results reviled 1 g cm^{-1} change specific gravity caused 121 kg changes in plant biomass. Relationship between the tree volume and its biomasswas also positive and significant with R^2 = 0.67. Calculation showed that 1 cm^3change in tree volume caused 0.67 kg changes in plant biomass. A weakbut positive relationship between tree height and its biomass was observed with R^2 = 0.14. There was positive correlation between the basal area and biomass was observed with R^2 to 0.48 reflecting that 1 cm^2 change in tree basal area causes 0.0137 kg changes in tree biomass.

These results are in concurrence with the findings of Slik *et al*. (2010) who environmentally correlated tree biomass, basal area, wood specific gravity and stem density gradients in Borneo's tropical forests by combining these variables and AGB data from 83 locations in Borneo with an environmental database containing elevation, climate and soil variables. They reported that wood density, stem density, basal area and AGB respond significantly, but differentially, to the environment. AGB was only correlated with basal area, but not with stem density and community wood specific gravity.

Table 2. Relationships of various parameter of citrus tree with its above-ground biomass (ABG).

Parameter	Relationship	R^2	Change in biomass (kg) per unit change in tree parameters
Specific Gravity (g/cm^3)	ABG = 120.69 SG – 7.44	0.48	121
Volume (cm^3)	ABG = 0.0006 V – 9.03	0.67	0.67
Height (cm)	ABG = 0.158 H – 5.27	0.14	0.14
Basil area (cm^2)	ABG = 0.0137 A_b– 10.04	0.48	0.014

ABG = Above Ground Biomass; SG = Specific Gravity; H = Height; V = Volume; A_b = Basil Area

Figure 2 shows the relationship between tree volume and its basal area. A significant and positive relationship between the basal area volume reflected by R^2 = 0.73 showed that 1 cm^2 change in tree basal area causes 23.51 cm^3 change in tree volume. Similarly, Figure 3 shows the relationship between tree volume and its height. There is weak positive relationship between the tree height and its volume with R^2 = 0.22 showing that 1 cm change in tree height causes 27.08 cm^3 in tree volume.

Chave *et al*. (2005) developed relationships between aboveground biomass and the product of wood density, trunk cross-sectional area, andtotal height through using regression analysis. However, they concluded that based on an unprecedented dataset, these models should improve the qualityof tropical biomass estimates, and bring consensusabout the contribution of the tropical forest biome andtropical deforestation to the global carbon cycle and the estimation of tree volume from its height remains a challenge. The reason behind this challenge is that the predictive power of these models depends on how well they are validated using tree biomass dataobtained directly from destructive harvest experiments.

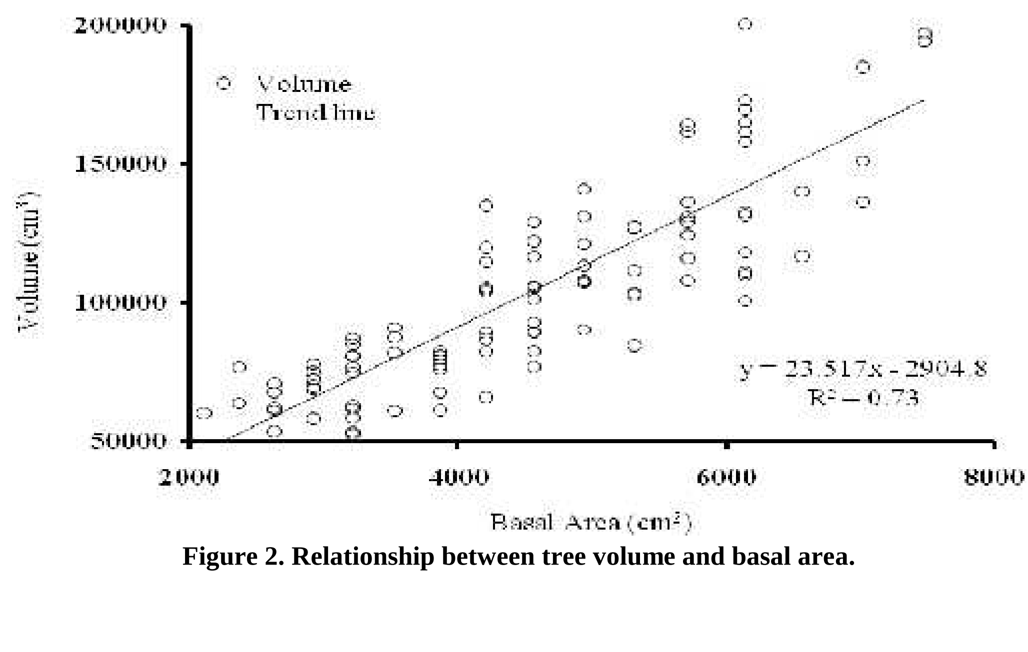

Figure 2. Relationship between tree volume and basal area.

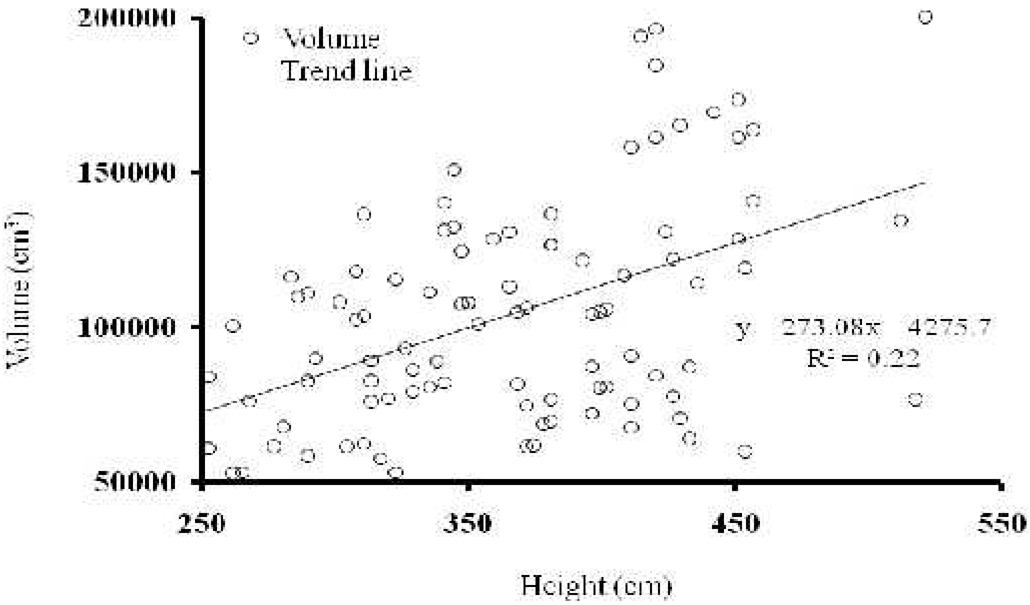

Figure 3. Relationship between tree volume and height.

Quantification of carbon pools of *Citrus* acreage in Pakistan: Literature showsthat citrus is grown in 199.4 thousand ha area of Pakistan. With recommended row to row and plant to plant spacing, forty trees are planted in one ha. Biomass of an average size tree is calculated to be 531.672 kg. Multiplying this value with total number of trees in total citrus acreage in Pakistan resulted in 4241 Mg of biomass. The above calculation showsthat 5.89 Mg of carbon is stored in one ha of citrus acreage in Pakistan.These results were concurredwith the findings of Magan *et al*. (2006) who reported that the weight of mature citrus tree ranges from 120 to 194 Mg with mean to be exactly 94 Mg $tree^{-1}$.

Advanced and sophisticated methods of tree volume and hence biomass / potentially sequestered carbon estimates include using remote sensing. The use of airborne lidar technology to measure forest biophysical characteristics has been rapidly increasing since in addition to providing a characterization ofground topography, lidar data give new knowledge about thecanopy surface and vegetation parameters, such as height, treedensity, and crown dimensions, which are critical for environmental modelling activities (Popescu *et al.*, 2003).

Conclusion: This study has produced baseline data and information for the above-ground biomass and organic carbon stocks of *citrus* in Pakistan. The study has shown that the net above ground biomass of a *citrus* plant of average age is in 199.4 ha of citrus acreage in Pakistan sequester 1175.7 tons of carbon. The study results may act as a baseline-information for future studies, planning and management of land and carbon budgets in Pakistan. This approach has the capability of being used as a regional, national or global scale for carbon sequestration estimation of *citrus*. However, the use of remote sensing can result in efficient way of estimation of carbon sequestration estimation of *citrus.*

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