CARBON STOCK IN FOREST PLANTATIONS - A CASE STUDY IN LUOT MOUNTAIN

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SUMMARY

In this paper the relationship between trunk biomass and diameter-at-breast-height (DBH), which developed by Chave et al. (2005) is applied to estimate trunk biomass then trunk carbon stock in different forest kinds. Even though this approach uses only DBH and forest density to estimate trunk biomass, the results are not significant different with in comparing with the method of using DBH and height. The average difference is 12.3%. The carbon stock in forest soil is also estimated in order to understand the two carbon sequestration pools capacity. The carbon stock in forest soil is estimated by using soil sample from three soil horizons of 0 - 10 cm; 10 - 20 cm and 20 - 30 cm. The results show that the average of trunk carbon stock is 23.04 tons/ha and varied by forest kinds. Even though using only DBH and forest density to estimate forest biomass and then carbon stock but the accuracy is acceptable. The carbon stock in forest soil increases with depth. Total amount of carbon stock in forest soil is accounted for 20.88% in comparing with total amount trunk carbon stock. The total amount of forest carbon stock in these two pools is then mapped using kringing algorithm in order to estimate for any interested location inside forest area. The estimated carbon stock in the study site is classified into three categories of low stock, moderate stock, and high stock.

Keywords: Carbon pool, carbon sequestration, carbon stock, diameter-at-breast-height (DBH), trunk biomass.

I. INTRODUCTION

Carbon stock is defined as the amount of carbon in a “pool”, meaning a system which has the capability to perform collect or produce carbon (FAO, 2005). Forest plays an important role as one of the main carbon pool (UNFCCC, 1998). Several approaches to estimate forest carbon have been reported (Shi and Liu, 2017) such as estimation of forest carbon at individual tree (G. Matthew, 1993; Y. Isagi et al., 1993), stand level (Qi et al., 2015; S. Brown, 1997) or large-scale (Whittaker et al., 1963; Shi. L., 2014; Zhang et al., 2016). Carbon may store in reservoirs through physiochemical and biological processes. Carbon pool depend upon the vegetation of an entire country or land area, carbon pools consist of living biomass including above and belowground biomass, dead organic matter including dead wood and litter, and soil carbon including soils organic matter (Grafll et al., 1998). It is reported that global forest store more than 485 Gt (1 Gt = 1 billion tons) of carbon, 260 Gt in the biomass (53%), 37 Gt in dead wood and litter (8%), and 189 Gt in soil (39%) (FAO, 2015). Forest carbon stocks now in the world are decreasing due to loss of forest biomass by deforestation and land use change and forest litter where destruction by fire reducing organic matter in forest soil. Carbon stocks in forest biomass in the whole world decreased by an estimated 0.22 Gt annually during the period 2011 - 2015 (FAO, 2014).

Several studies concerning how to estimate carbon stock or forest biomass in the forest of tropic region have been reported. Laurance et al. (1999) in their research on assessment the relationship between soil features and aboveground biomass of tropical forest in Arizona had measured all trees with diameter-at-breast-height (DBH) greater than 10 cm to estimate biomass and then using correction factor to estimate biomass of smaller tree (< 10 cm) in 65 plots with 1 ha in size. Biomass estimates varied more than two-fold, from 231 to 492 metric tons ha^{-1}, with a mean of 356 ± 47 tons ha^{-1}. This report also found that there is a positive relationship between biomass and some soil features such total N, total exchangeable bases, K^+... (Laurance et al., 1999). In the same research area, Nascimento and Laurance (2002) found that there is no relationship between large tree (DBH > 10 cm) and other biomass component such lianas, seedlings, litter... There also is no relationship among large-tree biomass and other living parts (Nascimento and Laurance, 2002).

Luot forest is a specific purpose forest inside the Vietnam National University of Forestry (VNUF). This forest is currently using as students practice site. The aim of this study is to estimate carbon stock in this forest to contribute to improve understanding of forest value in the context of broadly applying payment for forest ecosystem service (PFES).

II. RESEARCH METHODOLOGY

2.1. Study site

Luot mountain locates inside Vietnam National University of Forestry (VNUF) main campus in Xuan Mai town, Chuong My district, Ha Noi with the longitude and latitude is 105°34'11"E and 20°54'43" N, respectively. The total area of Luot is approximately 130 ha of which about 67 hectares covered by many tree species such *Pinus massoniana, Acacia auriculiformis* and more than 300 indigenous plant species.

Seven main forest kinds were classified base on three main mature species named *Pinus massoniana, Acacia auriculiformis, Eucalyptus urophylla*. The area of these kinds of forest varies from 0.13 ha to 6.19 ha (range is 6.06 ha) where *Pinus massoniana* and *Acacia auriculiformis* are the dominant species.

2.2. Method

Forest carbon stock is considered as parts of tree biomass, which could be found in the following carbon pools such living parts, dead wood, litter, root, and soil organic. In this study, we just emphasize on carbon stock in trunks of mature species and in forest soil organic.

2.2.1. Sample plot establishment

Inherited map of Luot Mountain was divided into different forest kinds base on main dominant mature species of which, 20 sample plots were randomly setup inside forest covered area with size of 500 m^2 (25 x 20 m) with respect scatter distribution and forest kinds (Figure 1).

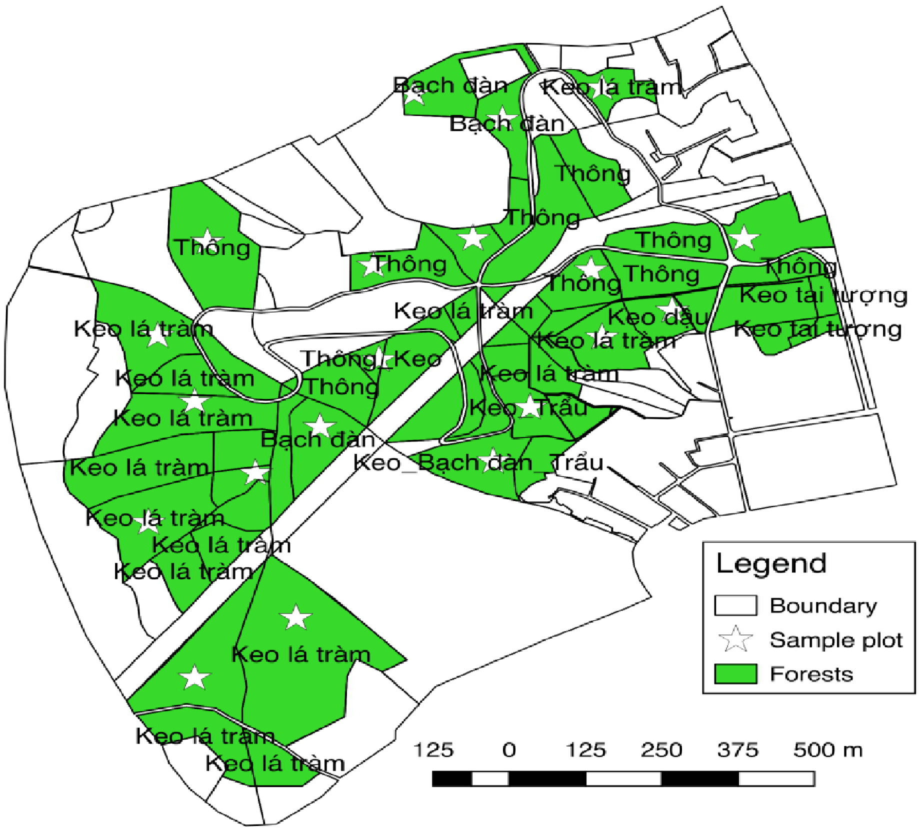

Figure 1. Sample plots location

These sample plots are generated using stratified random sampling method with respect to forest kinds

2.2.2. Data collection and treatment

Trunk carbon stock

All mature trees with diameter-at-breast-height (DBH) greater than 10 cm inside each sample plot were carefully measured using appropriate equipment. Trunk biomass is estimated using the allometric model generated by Chave et al. (2005) as the following equation (Chave et al., 2005).

Trunk biomass = wood density (in g/cm^3) x exp (-1.499 + 2.148ln(DBH) + 0.207(ln(DBH))^2 - 0.0281(ln(DBH))^3)   (1)

Where average wood density used for Asia equal 0.57 g/cm^3 (Reyes et al., 1992). This regression model was tested for secondary and old-growth forests, for different forest types such as dry, moist and wet forests for lowland and montane forests and for mangrove forests, as well (Chave et al., 2005).

Trunk carbon stock is then calculated following (Goslee et al., 2012):

$$C_p = DM * CF \qquad (2)$$

Where C_p is carbon stock (t C ha^{-1}), DM is trunk biomass (t ha^{-1}), CF = 0.47 (Grais and Casarim, 2013) is carbon fraction (t C t^{-1}matter) for woody material. The total trunk carbon is then estimated by multiplying with the stand density.

Carbon stock in forest soil

In this study, only carbon in soil is considered. Three soil samples are collected in each sample plot from different three depth layers 0 - 10 cm, 10 - 20 cm and 20 - 30 cm, respectively. The soil samples are collected in the middle of each sample plot. To calculate carbon stock in forest soil, the Walkey and Black titration method is applied then percentage of carbon in soil samples is generated by the below equation:

$$C = N \times \frac{V_0 - V_1}{a} \times 0.39 \times K \qquad (3)$$

Where: *C* is ratio of carbon in sample; *N* is the equivalent concentration of $FeSO_4$ solution; V_0, V_1 is the volume of $FeSO_4$ solution; *a* is the amount of samples taken of analysis; 0.39 is the coefficient; *K* is the conversion factor from air-dried samples to absolute dried samples and being calculate by:

$$K = \frac{100 - W}{100} \qquad (4)$$

Where: *W* is amount of water (%) contain in the soil sample which is calculated by:

$$W = \frac{W_1}{W_2} \times 100\ (\%) \qquad (5)$$

Where: W_1 is weight of air-dried soil sample; W_2 is weight of absolute dried soil sample.

Then carbon stock in soil sample is estimated by:

$$M_C = D \times BD \times C\ (g/cm2) \qquad (6)$$

Where: *Mc* is carbon sequestration in soil sample (g/cm^2); *D* is the depth of taken sample (cm); *BD* is the bulk density (g/cm^3); C is defined above.

The carbon sequestration in soil is converted into tone per hectare.

III. RESULTS

3.1. Trunk biomass distribution

Forest trunk biomass varies by different forest kinds (Table 1). The range of forest trunk biomass per hectare is 104.67 tons of which the lowest and highest values were accounted for 2.72 tons/ha and 107.39 tons/ha, respectively (data were not shown). Most forest kinds (75%) have biomass over 60 tons/ha while others (25%) reach around 29 tons/ha (Fig. 2).

Table 1. Total trunk biomass estimated by using Chave et al. (2015) equation and stand density
The data of minor species were not shown

	Forest kinds	Trunk biomass (tons/ha)	St. Error (%)
1	A.auriculiformis	45.26	4.49
2	Acacia mangium	65.55	19.22
3	Acacia_Eucalyptus	63.40	10.54
4	Eucalyptus	37.86	7.74
5	Pinus	50.63	6.48
6	Pinus_Acacia	68.03	14.55
7	Pinus_Eucalyptus	78.54	7.27

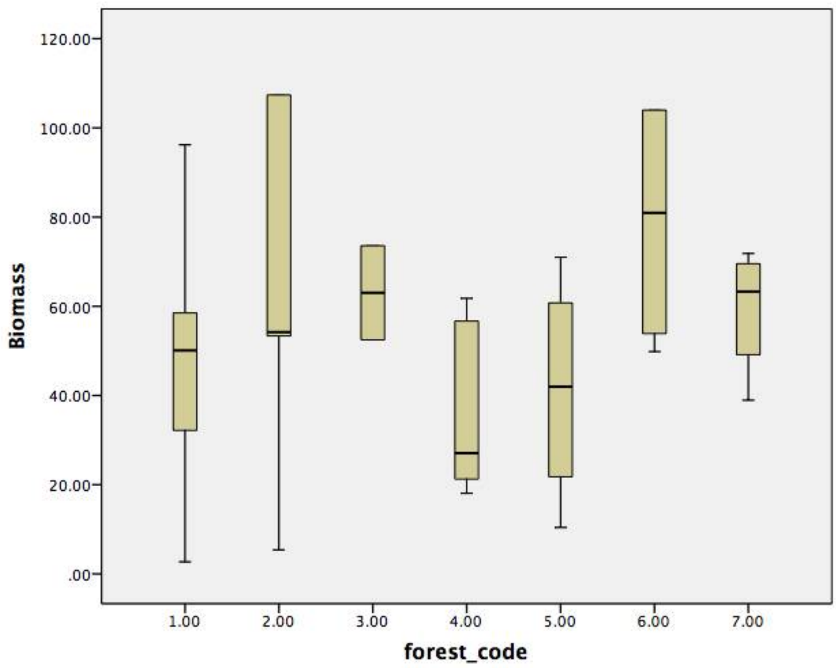

Figure 2. Trunk biomass by forest kinds

The code from 1 to 7 are Acacia auriculiformis, Acacia mangium, Acacia_Eucalyptus, Eucalyptus, Pinus, Pinus_Acacia, and Pinus_Eucalyptus, respectively

The median of each forest stands are different. The median and mean of trunk biomass in *Acacia_Eucalyptus, Pinus and Pinus_Acacia* stands are close together indicating that small variability among different biomass classes while the second and fourth forest stand have the median lower than the mean indicating that a large variability.

3.2. Carbon stock estimation

Trunk carbon stock

Trunk carbon stock varies by different forest kinds. Of which, carbon sequestration in the forest kind of *Pinus_Eucalyptus* is highest (39.70 tons/ha) while that value in the *Eucalyptus_Acacia_Vernicia* is smallest (8.98 tons/ha). The average carbon stock of Luot Mountain forest is 23.04 tons/ha (Fig. 3). *Pinus* and *Acacia* are the two main species, which contribute higher percentage of carbon sequestration then most other species. The trunk carbon stock was classified into three categories such as high stock, moderate stock, and low stock (Fig. 4).

The total amount carbon stock from tree trunks for 66.47 ha of forest in Luot Mountain is 13783.10 tons.

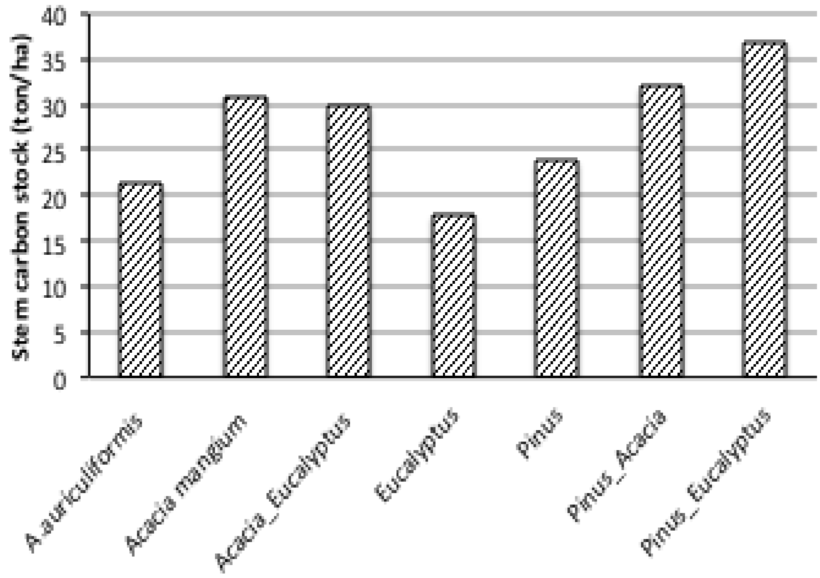

Figure 3. Trunk carbon stock (tons/ha) varies by main forest kinds

Data were generated from trunk biomass with coefficient of 0.47 (Grais and Casarim, 2013)

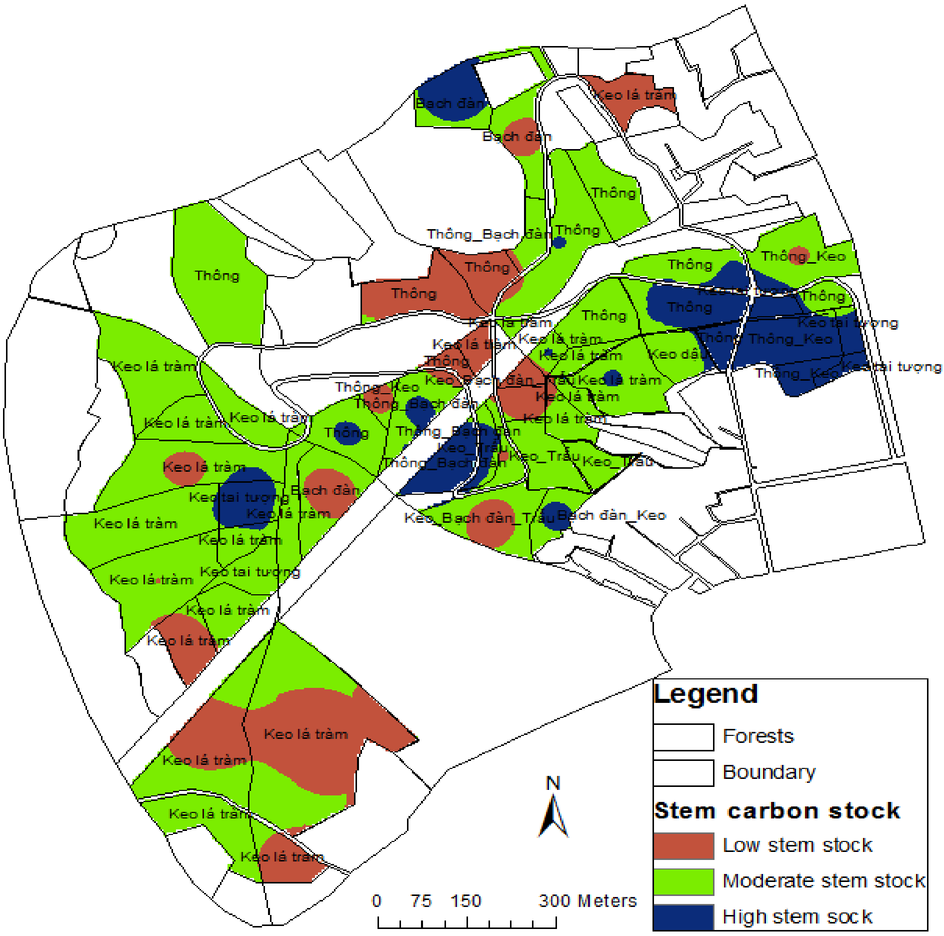

Figure 4. Trunk carbon stock distribution in the Luot Mountain was classified into three categories including high stock, moderate stock, and low stock

Carbon stock in forest soil organic

Carbon stock in forest soil organic varies by different depths and forest kinds. It is found that carbon stock in forest soil at Luot Mountain is higher in the forest kinds of Pine and lower in the forest type of Acacia and Eucalyptus. Most high stocks of carbon in soil are concentrate in the foothill locations. On average, these values have trend to increase from 10 cm (8.93 ± 1.30 tons/ha) to 30 cm (18.59 ± 2.72 tons/ha) of depth (Table 2). On average, the carbon stock in forest soil of three horizons is 43.65 tons/ha.

Table 2. Carbon stocked in different soil horizons
the data come from the average soil carbon stock of all forest kinds

	Carbon stock in different soil depth level (tons/ha)		
	10 cm	**20 cm**	**30 cm**
Mean	8.93	16.13	18.59
St. Deviation	6.27	11.32	13.05
St. Error (%)	1.30	2.36	2.72

IV. DISCUSSION

The result of this study provides total trunk biomass, which is one out of three aboveground forest biomass pool. In this study, only trees with diameter greater than 10 cm were measured. The results show that the average estimation of total trunk biomass is close with estimation from FAO for the Southeast Asia forests (85 tons/ha) (FAO, 2000) and Nascimento and Laurance (2002) when estimating above-ground biomass in central Amazonia forests (Nascimento and Laurance, 2002), and Vo Dai Hai (2012) with similar study output (51.91 - 93.04 tons/ha) on three Acacia plantations (Hai, 2012). These values are smaller than that in Africa (109 tons/ha) and South America (203 tons/ha). In the Luot Mountain, trunk biomass mostly concentrates from 60 tons/ha and over indicating that high carbon stock potential even though the average forest density is quite low (486 tree/ha). The highest standard error related to Acacia forests suggests the higher variation in DBH in comparing with other forest kinds. The results are also compliant with several reports on forest stand volume and biomass, which were estimated by both tree growth characters (DBH, height) and stand density, as well. For instance, when comparing with Dung and Truong (2005) report (Dung and Truong, 2005), the absolute difference value is less than 23%. Selecting and applying the appropriate allometric models are now preferred to the conventional approaches (Grais and Casarim, 2013). The method in this study was tested for several forest types as mentioned in the method section. Even though using only DBH as the input factor accompanied with forest density, the average bias from 0.5% to 6.5% is quite small after testing. Following the author’s suggestion, this model should improve the quality of tropical biomass estimates (Chave et al., 2005). In the case of this study, the average difference between applying Chave et al. (2005) model and the estimation method using DBH and height is 12.3%. It suggests that the simpler model would be apply effectively.

Total amount of carbon stock in forest soil of Luot is account for 20.88% (2901.41 tons/ha) in comparing with trunk carbon stock. This is smaller than that (36.86% - 95.60%) reported by Vo Dai Hai (2012) with the study on carbon sequestration capacity of Acacia plantations (Hai, 2012). The average soil carbon stock (43.65 tons/ha) is close to that value which reported by Schulp et al. (2008) when they did study on a specific temperate region (Schulp et al., 2008). However, in their report the stock of carbon in forest soil decreases with increasing soil depth. Interestingly, this is opposite trend in comparing with our study results. The difference would be explained by the ratio of decomposition of litter and other organic materials on the forest floor. In comparing with carbon stock in natural forest soil in the same region which is reported by Toai et al. (2016), our estimation is much smaller than their report number (171.59 ± 4.75 tons/ha) (Toai et al., 2016). This difference suggests that natural forest has higher capacity of storing carbon inside forest soil then plantation. Thus, under UN-REDD goals, the natural forests are highly encouraged in comparing with plantations.

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ƯỚC TÍNH LƯỢNG CÁC BON TRONG RỪNG TRỒNG NGHIÊN CỨU ĐIỂM TẠI NÚI LUỐT

Hà Quang Anh

Trường Đại học Lâm nghiệp

TÓM TẮT

Trong bài viết này tác giả lựa chọn phương trình mối liên hệ giữa sinh khối thân cây với đường kính ngang ngực (DBH) phát triển bởi Chave và cộng sự (2005) để ước tính lượng các bon trong thân cây của rừng trồng tại núi Luốt. Mặc dù chỉ sử dụng đường kính ngang ngực và đặc điểm về mật độ lâm phần song kết quả ước lượng tương đối chính xác so với đối chứng bằng phương pháp đo đếm ô tiêu chuẩn với sai lệch trung bình là 12,3%. Bên cạnh đó, lượng các bon trong đất của một số trạng thái rừng tại núi Luốt cũng được ước tính bằng phương pháp lấy mẫu theo tầng từ 0 - 10 cm, 10 - 20 cm và 20 - 30 cm tại các ô tiêu chuẩn. Kết quả cho thấy lượng các bon tích lũy trong thân cây trung bình là 23,04 tấn/ha, biến động theo trạng thái rừng. Lượng các bon tích lũy trong đất rừng tăng lên theo độ sâu của tầng đất. Tổng lượng các bon trong đất chiếm 20,88% so với lượng các bon trong thân cây. Tổng lược các bon ở hai bể chứa này đã được sử dụng để vẽ lên bản đồ phân bố trữ lượng các bon trong diện tích rừng che phủ thông qua thuật toán Kriging. Sản phẩm ước tính này cho phép phân chia trữ tổng trữ lượng các bon của hai bể chứa thành 3 nhóm: nhóm trữ lượng cao, nhóm trữ lượng trung bình và nhóm trữ lượng thấp.

Từ khóa: Bể chứa các bon, dự trữ các bon, đường kính ngang ngực (DBH), sinh khối thân cây, tích lũy các bon.

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