Modelling Carbon Sequestration Potential of *Eucalyptus grandis* Forest Plantations in Intermediate Zone of Sri Lanka

M.M.S.N. Premetilake[1], R.R. Ratnayake[2*], G.A.D. Perera[3] and S.A.Kulasooriya[2]

[1]*Uva Wellassa University, Badulla, Sri Lanka*
[2]*National Institute of Fundamental Studies, Hantana Road, Kandy, Sri Lanka*
[3]*Department of Botany, University of Peradeniya, Peradeniya, Sri Lanka*

Abstract

Many parameters of ecosystems, control carbon sequestration process and multiple associations between these could be used in prediction of carbon sequestration potential of the ecosystem. In this study, an effort is made to develop models in order to elucidate the control of carbon sequestration in Eucalyptus grandis forest plantations in intermediate zone of Sri Lanka. E. grandis plantations in Passara, Badulla district, Sri Lanka, were selected for this study. Above ground measurements were taken and litter and soil samples were collected from each of six plots established in each site. Litter dry mass, soil pH and moisture content, microbial biomass carbon, water soluble carbon, total organic carbon (TOC), stable carbon (SC), Permanganate oxidizable carbon were measured using standard methods. Principle Factor Analysis and multiple regression were used to quantify the relationships among the trees and soil variables. According to the analysis SC in the forests were governed mainly by Stand age and TOC in soil (R2 =0.98). Therefore, sequestration of stable carbon in E. grandis plantations is more sensitive to stand age and total organic carbon content.

Keywords: *Carbon sequestration, Eucalyptus grandis, forest plantations, modelling*

1. Introduction

With the concerns on enhanced greenhouse effect, the world has turned towards many approaches to reduce increased CO_2 concentrations in the atmosphere. Forest plantations play an important role in this reduction process by storing carbon in long lived pools [1]- [3]. However, many parameters of the ecosystem control a range of forest processes including carbon sequestration [4]. The multiple associations between these parameters and carbon sequestration can assist in identifying relationships between each other which would enable the prediction of ecosystem processes through models. Further these models would enhance the ability of assessing carbon stocks rapidly and effortlessly with minimum costs. Nevertheless, models that can predict carbon stocks in Sri Lankan Eucalyptus forest plantations are not yet been formulated. Therefore, studies are required to assess and model carbon pools of these forest plantations and their association with various parameters of the ecosystem. In this study, an effort is

made to develop models in order to elucidate the control of carbon sequestration in *E. grandis* forest plantations in intermediate zone of Sri Lanka. Here we focus mainly on modelling stable carbon fraction of soil, because it is the representative fraction for carbon sequestration characterization [5].

2. Materials and Methods

2.1. Study area

The study was conducted at *E. grandis* forest plantations located in Passara, Badulla district, Sri Lanka (5° 54' N – 9° 52' N latitudes and 79° 39' E - 81° 53' E longitudes) which belongs to up country intermediate zone (IM2) [6] (*Figure 1*). A typical tropical monsoon climate occurs in this area with an annual mean precipitation of 2245 mm [7] and the temperature varies between 19 °C and 23 °C. The soil is typical Haplohumults, acidic, non-calcareous, fine loamy and isohyperthermic soils.

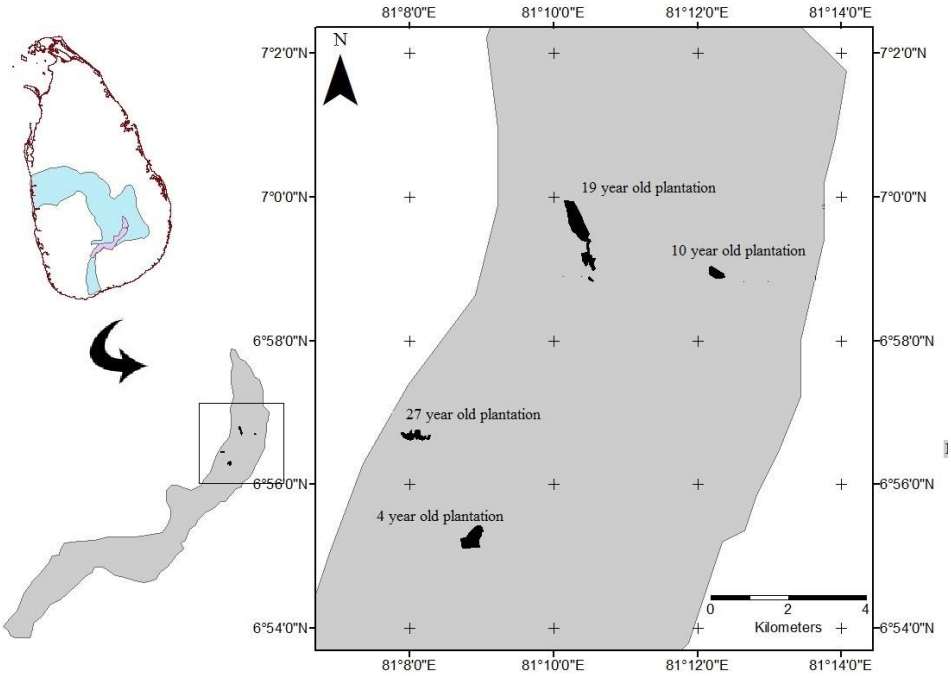


Figure 1. Map of Study Sites

2.2. Site description

E. grandis forest plantations of ages 4, 10, 19 and 27 years that were established in the same agro ecological zone (IM 2) were selected for this study. All selected sites were located within a radius of 8.5 km and spread over natural rugged topography with a modest slope (<4-6%).

Before the formation of forest plantations, the areas were mid elevation grasslands which mostly covered with *Cymbopogon nardus* (L.) Rendle. There were around 32-40 trees in each plot which varied with the age. Thinning of forest stands was carried out usually at, 3-4 years, 7-8 years, 13 years, 18 years and 25 years after plantation formation. However, no thinning measures were carried out in the selected forest plantations during the study period.

2.3. Experimental design

Stands fluctuating in age from 4 -27 years were used to form a chronosequence assuming that sites only vary in age with no systematic bias caused by confounding biotic or abiotic factors. The similarity of sites in silvicultural treatments, topography and the immediacy of vegetation plots were used in creating a situation for detecting variations in soil and vegetation following afforestation using a chronosequence design.

Six 20 m x 20 m plots were formed in each selected plantation forest, which were again divided in to four 10 m x 10 m subplots. The plots were demarcated at least 10 m away from fences and footpaths to avoid potential edge effects. Moreover, topography and slope and were also considered to reduce microclimatic disparities among the plots and the field sites.

2.4. Aboveground measurements and calculations

The heights of the trees in each plot (2/3 of all trees: whose diameter at breast height was greater than 10 cm) were measured using a Suunto clinometer 20 m away from the tree, assuming that the tree grows at a right angle to the ground [8]. The Diameter at Breast height (Dbh) of trees (at 1.3 m height) whose heights were taken, were measured at breast height using a diameter tape [8]. The ground-measured crown width for each tree was measured by taking the arithmetic mean of the horizontal crown diameter measured on the north-south axis and again on the east-west axis [9]. Number of trees (diameter >10 cm) in each plot were counted and tree density per site was calculated. The basal area (BA) was calculated from measurements of the diameter (Dbh in cm) for each measured tree in each plot using the following equation [8].

$$BA = \pi(DBH)^2 / 40000 \quad (1)$$

2.5. Litter sampling and measurement of litter dry mass

Litter on the forest floor were randomly sampled from a 1 m^2 quadrat at 4 locations within each plot at each location. Sampled plant litter was dried at 65°C to constant weight and the final dry mass was measured using an electronic balance (TP-214, Denver).

2.6. Soil sampling and sample preparation

Soil samples were collected in each sub plot as three soil samples from three randomly selected points in using a hand auger (50 mm diameter). These were pooled to have one composite sample. Moreover, soil samples were taken at 0-15 cm (upper soil layer) and 15-30 cm (lower soil layer) depths. A total of 72 composite soil samples were collected from each site. The selected points were 0.5 m and more than 5 m away from the nearest tree and away from each other respectively. In the laboratory, the collected soil samples were sieved using a 2 mm sieve to eliminate stones and roots. Soil pH and soil moisture content were measured using standard protocols as follows. Remaining soil were air dried and ground using M 20, IKA, WERKE® grinder before further analyses.

2.7. Soil analysis

Soil Moisture was determined by oven drying the samples at 105°C to a constant weight. Soil pH was measured using a bench pH meter (Cyberscan Eutech pH 510) with a soil to water ratio 1 :2.5. particle size analysis was done using the protocol described by [10] and clay, sand and silt percentages were calculated. Microbial biomass carbon (MBC) was measured using the chloroform fumigation and extraction method [11]. After fumigation MBC was extracted using 0.5 M K_2SO_4 and quantified by using a CHN analyser (Elemental analyser, Perkin-Elmer 2400 series II). Permanganate oxidizable carbon was determined by the method described by [12]. Water soluble organic carbon (WSC) was estimated by titration method using acidified ferrous ammonium sulphate [13]. Total labile carbon fraction was calculated by adding MBC, $KMnO_4$ oxidizable carbon and WSC together. Soil Total Organic Carbon (TOC) content was measured using dry combustion method with CHN analyser (Perkin-Elmer 2400 series II). Soil Stable Carbon (SC) was calculated from the variance between total organic carbon and labile carbon fraction.

2.8. Soil and Plantation Forest Relationships

Carbon pools and various forest aboveground and soil parameters were pooled and analyzed for detecting grouping of variables responsible for SC fraction using Principal Factor Analysis (PFA). Then factor plots were assembled to identify highly correlated variables clustering on the plot. After applying Varimax rotation to rotate the factor structure, the correlated variables were used in multiple regression analysis using MaxR to select the variables to enter the equation. To indicate the relationships of the variables, diagrammatical models were created.

3. Results and Discussion

The Factor plot revealed that Stand age, crown width, tree Dbh, Total Organic Carbon and Soil moisture content affects more to the Stable carbon fraction (*Figure 2*). Multiple regression analysis of the variables generated the following relationship.

$$SC = -15.74 - 0.70AG + 1.77TC + 0.02AG^2 - 0.02TC^2$$ (2)

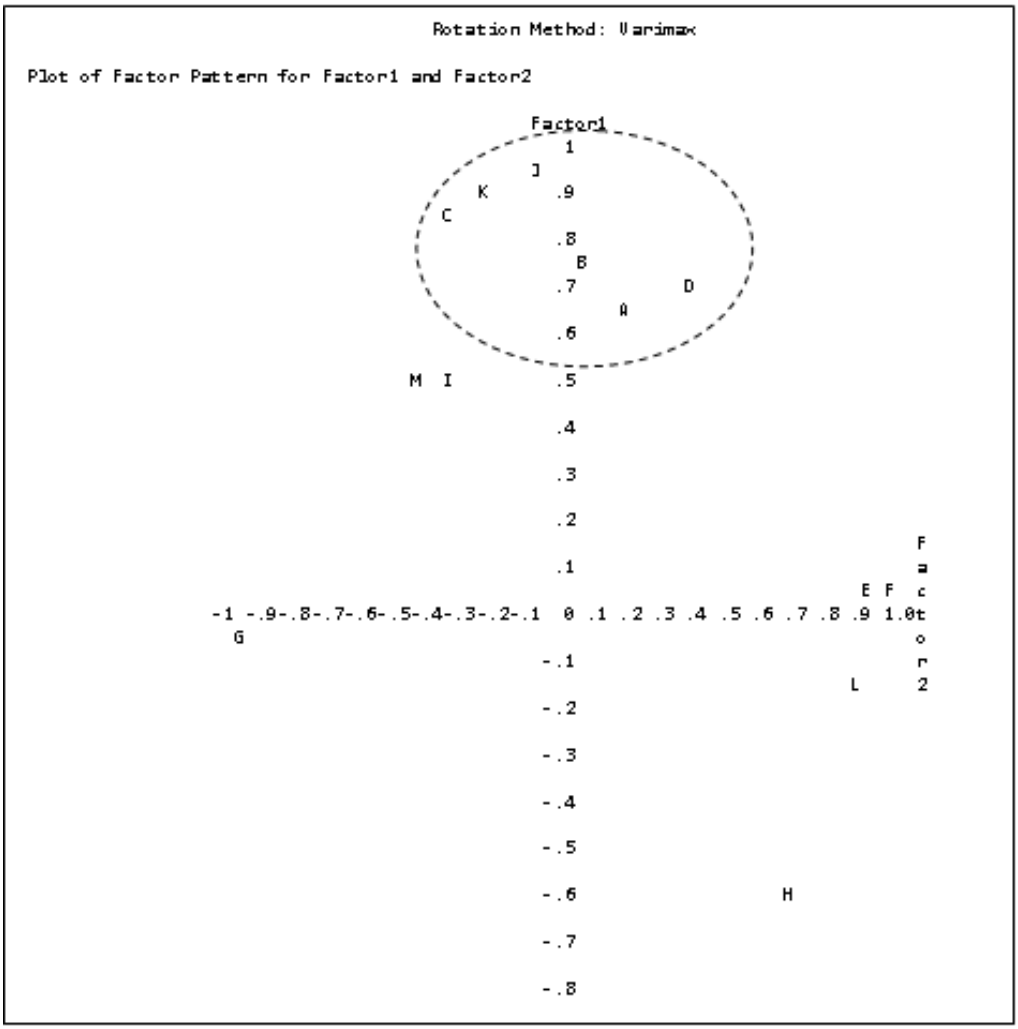
$R^2 = 0.98$

where AG and TC are stand age and total organic carbon respectively. This relationship designates that the stable carbon stock is controlled by stand age and total organic carbon content at the time of evaluation for *E. grandis* forest plantations in intermediate zone of Sri Lanka. In the studied *E. grandis* forest plantations, stable carbon content in soil varied significantly with stand age (Mix model ANOVA, p = 0.000). Although SC content showed increasing trend with increasing stand age there was no significant relationship ($p > 0.05$).

Numerous studies, together with chronosequence, have undeniably advocated that carbon accumulates in the forest floor as the stand ages [14], [15]. Further it has been found that masses of aggregates in soil increase with stand development of forest plantations [16] which ultimately results in increased stable carbon fraction (*Figure 3*). The main reason for increased aggregates could be due to associations of carbon with soil particles, especially clay and silt sized particles. These aggregates reduce accessibility of soil enzymes and microbes to organic matter, lowering the carbon turnover rates, thus increasing stable carbon fraction [17].

Moreover, the results of the present study revealed that there is a highly significant correlation between stable carbon fraction and total organic carbon pool (Correlation coefficients for upper and lower soil layers, 0.958 and 0.943, p = 0.000).

Generally organic carbon content in soil exhibits strong positive correlation to organic matter content in soil [18]. Further, it has been found that soil organic matter content is strongly correlated with aggregate stability [19]. This is because soil organic matter stabilizes aggregates against disruptive processes by increasing cohesion of aggregates through the binding of mineral particles by organic polymers or through physical enmeshment of particles by fine roots or fungi [20], [21]. Moreover, organic matter may decrease the wettability of aggregates slowing their rates of wetting and thus the extent of slaking [22]. These stable aggregates lower the carbon turnover rates, thus increasing stable carbon fraction in soil.



A = Stable carbon, B = Total organic carbon, C = Stand age, D = Soil moisture content, E = Clay content, F = Silt content, G = Sand content, H = Soil pH, I = Litter dry mass, J = Mean Tree Dbh, K = Mean Tree crown width, L = Basal area, M = Mean Tree height

Figure 2. Factor Plot Variables Responsible for Stable Carbon Fraction of the *E. Grandis* Forest Plantations. Highly Correlated Variables Clustered on the Plot Are Encircled with A Dotted Circle.

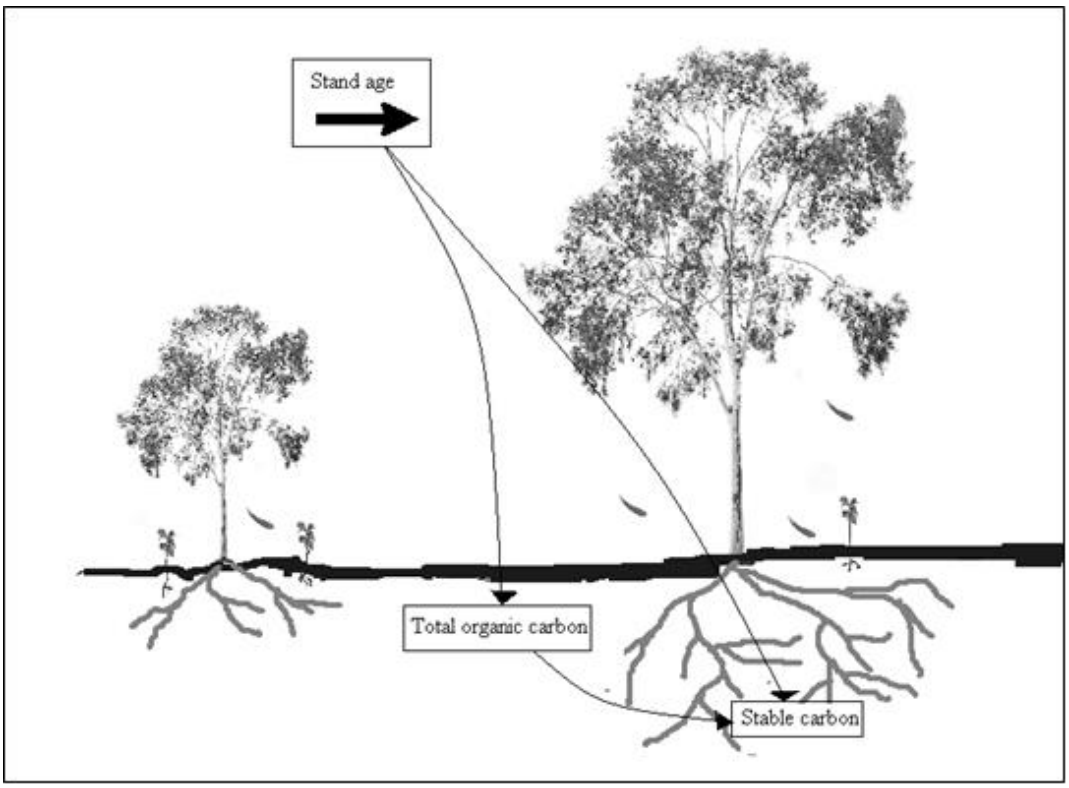


Figure 3. Diagrammatic Representation of Factors Controlling Stable Carbon Fraction in *E. Grandis* Forest Plantations in Intermediate Zone of Sri Lanka.

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