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The Variation of Soil Nutrients and Microbial Biomass Carbon with Stand Age in *Eucalyptus grandis* Plantations in Sri Lanka

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Abstract:

Soil nutrients and microbial activity greatly influence plant development and yield in plantation forests. With the stand age these parameters may change and may affect the yield directly or indirectly. In the present study the relationships between soil macro nutrients (available N, available P, Ca, Mg, K) and microbial biomass carbon (MBC) with stand age of *Eucalyptus grandis* was studied in different plantation forest stands in the intermediate zone of Sri Lanka. All the studied nutrients negatively correlated with stand age of the plantation forests (Pearson correlation, $p < 0.05$) except for Ca and Mg. However, Ca and Mg concentrations in soil also declined with stand age and again increased rapidly towards the stand age of 28 years. MBC in soil also varied significantly with the stand age. The mean differences in MBC in upper and lower soil layers of 5-year-old plantation forest and 28-year-old plantation forests was 1408 mg kg^{-1} and 519 mg kg^{-1} respectively. Of all the nutrients only available N had shown a significant relationship with MBC content in soil (Pearson correlation: upper soil layer, -0.848, p =0.000; lower soil layer -0.706, p = 0.000). The decrease of soil nutrients could be due to the absorption of nutrients by the trees during their rapid growth and MBC reduction in soil could be due to the amplification of monoterpene secretion with forest/ plant age. The knowledge on these parameters would support in practicing various management practices to improve yields in plantation forests.

Keywords **—*Eucalyptus grandis*, Soil macronutrients, Microorganisms, Plantation age.**

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I. INTRODUCTION

Plantation forests covers around 200 million hectares throughout the world and they are increasing with about 1.2% relative rate of annual expansion due to rising demands for wood and timber and also to sequester carbon dioxide from the atmosphere [1],[2]. However, soil fertility affects significantly to obtain better yield from these forests [3]. Most of the plantation forests are established in degraded lands with low soil fertility and further successive rotations of trees remove nutrients from the sites [4],[5]. Moreover, some studies suggested that some plantation species such as Eucalyptus may also have negative effects on soil fertility specially soil nutrients and microorganisms with time [6],[7]. Several studies had been carried out to find how nutrients and microbial biomass carbon in Eucalyptus forest soil changes with time. Turner and Lambert have studied nutrient cycling in Australian Eucalyptus plantation forests [8], [9]. They reported that most of the nutrients accumulate in trees and reach peak near the time of crown closure and then decline. Further Leite et al. [10] reported that P, K, Ca and Mg concentrations in *E. grandis* plantation soil reduced with stand age of the plantation forest. Further microbial biomass in Eucalyptus plantation forest was compared with deciduous natural forest and regenerating forest in India [11] and reported that microbial biomass is comparatively lower in Eucalyptus soil. Cortez et al. [12] also reported a decline in microbial biomass with time in *E. grandis* plantation in Brazil. Both soil nutrients and microorganism are important for soil fertility [13]. However, studies on variation of both nutrients and microbial biomass with stand age in Eucalyptus plantation forests are limited. Since both parameters and their interrelationships are important for soil fertility, recognition and understanding of nutrient variation and microbial biomass in Eucalyptus plantation forests with stand age will consequently permit better economic and environmental benefits over successive harvest rotations.

Therefore, the present study the variation of major macronutrients and microbial biomass carbon with the age of *E. grandis* plantation forest. For the study four *E. grandis* plantations were selected with different stand age which were located in the same agro ecological zone, Passara , Sri Lanka.

II. MATERIALS AND METHODS

A. Study sites

This study was carried out in *Eucalyptus grandis* plantation forests in Passara, Badulla district, Sri Lanka (5º 54’ N - 9º 52’ N latitude and 79º 39’ E - 81º 53’ E longitude). The study area is representative of typical Haplohumults fine loamy, acidic, non-calcareous and isohyperthermic soils [14]. The topography is generally hilly to steeply dissect with sandy clay loam surface and subsurface soils. The annual temperature varied between 19˚C and 23˚C. The mean annual rainfall of the area was 2245 mm, mainly received during October to December [15]. Age 5, 10, 20 and 28 years old plantation forests of *E. grandis* belonging to the same agro ecological zone were selected for the study. The experiment was carried out in a randomized block design with three replications. Three plots of 20 m x 20 m each were demarcated in each site and further divided into 4 equal sub-plots. After removing the surface litter layer of random chosen positions, 60 soil core samples (pooled in to 12 samples) were collected per plot at two depths (0-15cm and 15-30cm).

B. Soil analysis

Microbial biomass carbon was extracted by using chloroform fumigation method and quantified using titration method [16]. Available N was determined adding up soil nitrate (NO^{3-}) and soil ammonium (NH^{4+}) concentrations. For determination of nitrate and ammonium colorimetric methods described by Cataldo et al. [17] and Lenore et al. [18] were used respectively. Soil available P was also determined by colorimetric method using spectrophotometer as described by Anderson and Ingram [16]. Soil Ca, Mg and K were extracted by modified Morgan extract and analysed using atomic absorption spectrophotometer (GBC 933 AA, Australia) [19].

C. Statistical analysis

Two-way analyses of variance (ANOVA) were used to study the effect of stand age and soil layer on macro nutrients and MBC.

III. RESULTS

The concentrations of studied soil nutrients significantly varied among studied forests and occasionally with the soil depth (Two way ANOVA: for forest age, $p = 0.000$ (Available N), 0.000 (Available P), 0.000 (Ca), 0.002 (Mg), 0.000 (K); for the soil depth, $p = 0.967$ (Available N), 0.000 (Available P), 0.000 (Ca), 0.399 (Mg), 0.024 (K);

interaction effect, p = 0.236 (Available N), 0.000 (Available P), 0.026 (Ca), 0.866 (Mg), 0.872 (K).

Concentration of soil nutrients had decreased stand age. Mean concentrations of available N decreased from 4.18 to 2.48 mg kg^{-1} in upper soil layer while it decreased from 4.53 to 2.30 mg kg^{-1}. There was a significant negative correlation between stand age and the available N (Pearson correlation -0.645, $p < 0.05$). However, by 28 years of age the concentration of soil available N seems to stabilize (Fig. 01). Available P also decreased from 0.72 to 0.16 mg kg^{-1} and 1.10 to 0.17 mg kg^{-1} in two layers respectively (Fig. 1) and showed significant relationship with stand age (Pearson correlation -0.742, $p < 0.05$). Soil K also decreased when the plantation got older in both soil layers and displayed a significant relationship with stand age (Pearson correlation -0.6490, $p < 0.05$). But after 20 years the concentration of K in soil appeared to be stable. Although soil Ca concentration and Mg concentration had declined in the first 20 years, there is an apparent increase afterwards (Fig. 2). However, there was no significant correlation between Ca and Mg concentrations with stand age ($p > 0.05$). Soil MBC concentration was low at the beginning. Then when the plantation got older MBC in soil had increased and later it had started to decrease again (Fig. 3). The mean differences in MBC in upper and lower soil layers of 5-year-old plantation forest and 28-year-old plantation forests was 1408 mg kg^{-1} and 519 mg kg^{-1} respectively. However, of all the nutrients only available N had shown a significant relationship with MBC content in soil (Pearson correlation: upper soil layer, -0.848, p =0.000; lower soil layer -0.706, p = 0.000).

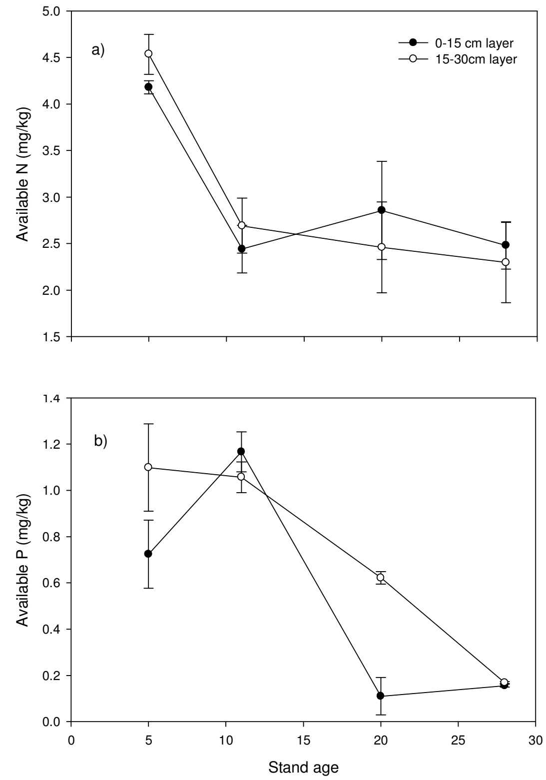

Fig.1 Variation of soil a) available N b) available P in *Eucalyptus grandis* plantation forest with stand age

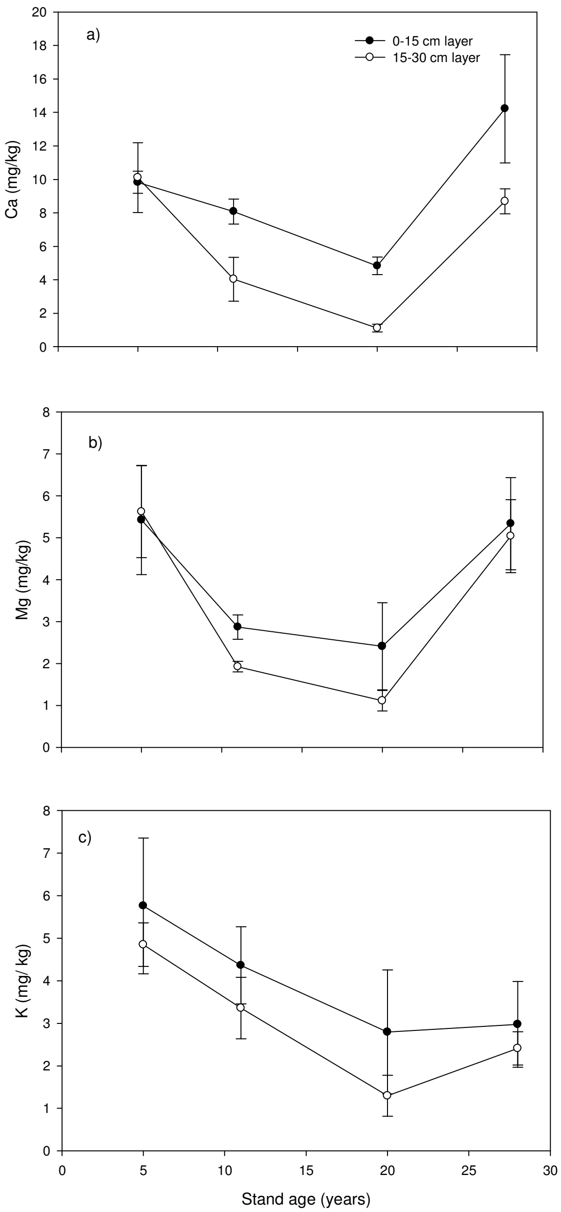

Fig. 2 Variation of soil a) Ca b) Mg c) K in *Eucalyptus grandis* plantation forest with stand age

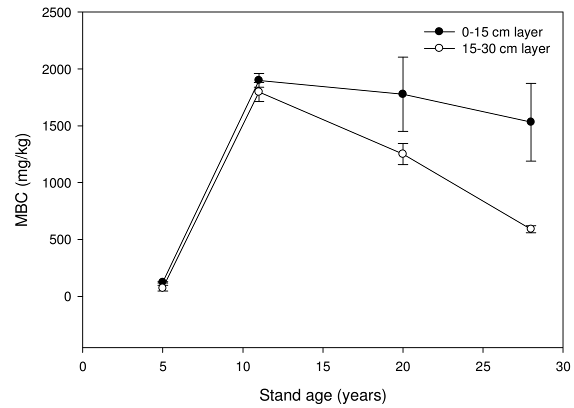

Fig. 3 Variation of soil Microbial Biomss Carbon (MBC) in*Eucalyptus grandis* plantation forest with stand age

IV. DISCUSSION

Plantation of *E. grandis* caused concentrations of soil nutrients in both soil layer to decline specially in the first 20 years. Although available N concentrations in soil were comparatively higher than our values, similar decline pattern with stand age was observed by Frederick et al. [20], in *E. regnans* plantation in New Zealand. The available phosphorus in the present study displayed a negative relationship with increasing stand age. However, Zhang et al. [1] reported that there is no relationship between the two parameters in a study of *E. grandis* forest plantation in south-western China. Our results revealed that the available Ca, Mg and K had decreased initially up to about 20 years. This agrees with the findings of Turner and Lambert [9] that nutrients in soil deplete with the age of the temperate plantation forest. Leite et al. [10] also observed reduction in Ca, Mg and K concentrations in forest floor with increasing forest age, when they studied nutrients in soils of plantations of 0.25 years to 6.75 years.

As soil is the only provider of nutrients to the plants when there is no added fertilizer, the available nutrients may have been used for plant growth and development. Since Eucalyptus is known to be a fast growing species, their nutrient could be comparatively higher. The intensification of the biochemical nutrient cycling with aging of the forest obviously had decreased the nutrients in soil. Another possibility would be decrease of nutrient levels in litter. After a certain time, due to the nutrient availability reduction in soil during the growth cycle the concentration of these nutrients in the materials that make up the litter also could decrease. Therefore, the proportion of the components with higher nutrient concentrations in the forest floor composition could decrease with age [10].

According to Turner and Lambert (2008), nutrient uptake reduces when the trees mature. So excess amounts of these macro nutrients may accumulate in soil, resulting stable level of most of the studied nutrients in soil. So the cycling of nutrients could affect for changes in nutrients in soil.

Similar to soil nutrients, soil microorganisms also play a major role in fertility of soil which is measured as MBC. Nevertheless, disturbances to the soil affects microbial biomass carbon directly. The initial disturbance at the time of establishment leads to a decline of organic carbon in surface soil as seen in the youngest site. The decline usually continues for a period of about five years [8]. There was a rapid increase in MBC up to 11 years and then a decrease, possibly due to the increased monoterpene content in the soil that inhibits microbial growth. Monoterpene released by Eucalyptus litter is one of the major inhibitors that limit microbial growth in soil [21]. Further it is reported that the secretions from older trees are higher than those from the younger trees [22], which could explain the decline in MBC in the present study.

It has been found that availability of soil nutrients directly or indirectly could affects microbial population in soil [13]. However only available N concentration in soil had shown a significant relationship with MBC in soil in the present study. Yan et al. [23] reported that soil N directly increase soil microbial population. So the negative relationship obtained in the present study for available N and MBC could be due to the usage of available N by the microorganisms. Although the other nutrients don not correlate with MBC, they may have indirectly affected the MBC content soil. However further studies are required to clarify this matter.

V. CONCLUSION

The study showed that macro nutrients in soil decrease with the stand age of the plantation and seems to stabilize or increase again. Microbial biomass carbon content of soil increased rapidly in the beginning and later declined. However, MBC in the oldest forest was higher than the youngest. The MBC in soil didn't show a strong relationship towards the nutrients levels in *E. grandis* plantation forests, except for available N. We can suggest that by applying fertilizers in different level of cycle of plantation forest could replenish the declined soil nutrient levels leading to a better harvest.

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