Carbon Stock Assessment for a Forest-to-coffee Conversion Landscape in Malang (East Java) and Sumber-Jaya (Lampung, Indonesia)

Kurniatun Hairiah[1)], Jonni Arifin[1)], Berlian[1)], Cahyo Prayogo[1)] and Meine van Noordwijk[2)]

■ Abstract

Assessment of aboveground C stock were made in upland coffee production areas near Malang (East Java) and in Sumber Jaya in West Lampung (Sumatra, Indonesia). The aboveground C stock of monocultural and multistrata coffee based system were compared with that of remnant natural forest and plantation forestry. For the various systems we found general agreement between the two sites. For the remnant natural forest in Sumberjaya we derived an estimate of aboveground tree C stock (195 Mg ha^{-1}) that was slightly above the value for a near-mature *Pinus* stand in Malang (175 Mg ha^{-1}). For the monocultural coffee systems we estimated aboveground tree C stocks of 7 Mg ha^{-1} in Sumberjaya, while this land cover type was not found in Malang. For simple shade coffee systems the values agreed well between sites (23 and 19 Mg ha^{-1} for Sumberjaya and Malang, respectively). The Malang version of the multistrata systems had a higher aboveground tree C stock than those in Sumber jaya (49 and 34 Mg ha^{-1}, respectively), related to the presence of the larger fraction of 'forest' trees in the plots. Annual aboveground C stock accumulation rates of mixed coffee system was found to be about 1.9 Mg ha^{-1} yr^{-1}, nearly double the value (1.0 Mg ha^{-1} yr^{-}1) found for coffee monoculture system. A ratio of C_{org} and the C_{ref} value that can be expected for forest soils of the same texture and pH, sampled at the same elevation and soil type, can be used as a ***'sustainability indicator'***. A value of the C_{org} /C_{ref} ratio of 1 mean a "fertile soil" similar to that found in the forest, smaller values indicate partial loss of the soil C stocks and related loss of soil fertility. Conversion of (remnant) forest to coffee based systems reduced the C_{org}/C_{ref} ratio from 0.8 to 0.5, equivalent with a loss of soil C of about 57 Mg C ha^{-1}.

■ Introduction

Clearing forest for new agricultural land is usually based on the slash-and-burning technique which causes an immediate release of carbon (C) to the atmosphere, whereas in other clearing techniques the C loss would be more gradual. The C initially held in trees and other vegetation included in necromass is released through burning (in the form of

[1)] Brawijaya University, Faculty of Agriculture, Malang, Indonesia.
[2)] International Centre for Research in Agroforestry (ICRAF) SE Asia, P.O.Box 161, Bogor 16001, Indonesia.

smoke) or decomposition of above and below ground plant material left in the soil at the time of clearing. Even if the gross and net primary productivity (NPP) of the new agricultural land is as high as it was in the forest, less of the crop production accumulates as litter, and a considerable part of it is harvested and subsequently consumed or respired away from the land where it was grown. This makes the 'net ecosystem productivity' (NEP) much lower. The reduction in litter input is not initially balanced by a reduction in soil respiration, leading to a decline in soil C stocks. In fact, the respiratory release is often enhanced by the cultivation itself, which exposes more of the organic matter to microbial activity and thus causes a net release of nutrients to the crops (and weeds). As a result, some of the C originally held in forest soil is released to the atmosphere after clearing. The C stocks maintained in aboveground biomass, however, do differ between forest and a cropped field, as does the rate of litterfall, leading to differences in soil organic matter (SOM) in soils.

Opening land for agricultural land reduced total C from tree biomass by about 66 % when slashing and burning were involved, but by only 21 % without burning (Prayogo, 2001). The aboveground C stock of the logged-over forest was only 38 % that of the undisturbed rainforest. Mature agroforest (jungle rubber) system produced about 104 Mg C ha^{-1}, but only 15% and 60% of which was estimated in 5 years old rubber and monoculture oilpalm plantation respectively (Hairiah and Sitompul, 2000). The cassava monoculture system, *Imperata* and *Chromolaena* fallow systems have a maximum C stock of about 1.7, 1.9 and 4.0 Mg ha^{-1} respectively.

Soil organic matter is considered to be a key characteristic in judging the sustainability of land use systems. Yet, total soil organic matter content is not a very sensitive indicator as it changes relatively slowly under different management regimes, and often has a high spatial variability linked to variability in soil texture, pH and elevation. Van Noordwijk et al. (1997) suggested to use a ratio of the measured C_{org} and a reference C_{org}, C_{org}/C_{ref} value for forest soils of the same texture and pH as a ***'sustainability indicator'***. If the value of the C_{org}/C_{ref} ratio is 1, this means the soil is similar to that of a forest, and/or is a "fertile soil"; values towards 0 mean "infertile soil".

A better understanding of the relations between C stocks and land use practices is required in the context of the global C balance. The impacts of the ongoing processes of land use change need to be assessed and efforts to store more C in terrestrial ecosystems need to be evaluated, in terms of their ability to slow down the rate of increase of atmospheric CO_2. While tree-based agricultural options are generally seen as a 'mitigation option' that can at least partially reduce the current net C emissions to the atmosphere from the use of fossil fuel and land conversion, there is considerable variation within the broad class of 'agroforestry' systems, but a shortage of quantitative studies. Through a comparison of coffee-based production systems in two sites in Indonesia we aim to add to the understanding of the potential for increasing C stocks in profitable land use practices under smallholder management.

■ Material and Methods

Measurements of aboveground C-stock were performed in two places i.e. Ngantang District (about 700 m a.s.l.; Malang, East Java) and in Sumber Jaya subdistrict, W.Lampung, Sumatra (850 m a.s.l).

The measurement of C stock in Malang were done in a *Pinus merkusii* woodlot (about 30 years) belong to Departement of forestry compared to shaded coffee and multistrata coffee. The coffee plots were established in 1980 by opening a natural fores. The plot gets a very little input and are pruned twice a year. In the shaded coffee systems *Gliricidia sepium* and banana were used as shade trees; while in the multistrata coffee system more trees species were planted such as Mahogany (*Swietenia mahogany*), Sengon (*Paraserienthes falcataria*), banana, papaya, durian, jack fruit (*Artocarpus heterophyllus*), avocado(*Persea Americana* Miller) etc. Three replicate fields were measured for each system.

In the Sumberjaya site, the measurements were done in the (a) remnant Natural Forest as a control, (b) Shaded coffee systems: *Gliricidia, Erythrina* and or *Leucaena* as shade trees (c) Multistrata coffee: *Gliricidia, Erythrina* and or *Leucaena* and others such as fruit trees or timber trees as shade tree. The plots were selected to represent three slope classes: (1) flat (0-10° slope), (2) Medium (10-30°) and steep (>30°). The coffee based plots were selected from the fields available that were cleared from forest at least 7 years old, so they represent established coffee based systems. The age of the coffee plants was also at least 15 years. Three replicate fields were sampled for each class.

Measurement of tree biomass

Methods for quantifying tree biomass were used as specified in the ASB (The Alternatives to Slash and Burn) protocol (Palm *et al.*, 1996; Hairiah *et al.*, 2002). For the vegetation and soil sampling area was based on a 40 x 5 m^2 transect. Two transects were made in each plot one uphill (top) and another downhill (bottom). The uphill transect was made at a distance from the top of the hill of about 10% of the slope length, and all transects were made along the contour.

Usually tree biomass (forest) is estimated by the 'generic' allometric equation developed by Brown (1997) which is not suitable to be used to estimate trees biomass of pruned coffee. The pruned coffee has different tree branching pattern than other forest trees, it formed more site branches. An allometric equation for coffee and other trees which has different branching patterns was developped based on destructive sampling. About ten trees of different size were cut, measured for stem diameter and height and weighed freshly and subsampled for dry weight calculations.

To avoid the need for measuring wood density ρ for every individual tree, a database of literature values was developed, recording lower bound, upper bound and medium values. Currently the database holds entries for 2800 tree species and will be shortly made available via www.icraf.cgiar/sea. Wood density can be classified as light (density less then

0.6 Mg m^{-3}), medium (between 0.6 to 0.75 Mg m^{-3}), heavy (0.75 to 0.9 Mg m^{-3}) and very heavy (more than 0.9 Mg m^{-3}) (Anonymous, 1981)

Understorey and herb layer vegetation were measured in ten 0.25 m^2 quadrat samples, total fresh weight was measured and subsamples were collected for determining dry matter content. Diameter and length of dead wood was measured within the 40 * 5 m^2 transect and converted to volume on the basis of a cylindrical form; three apparent density classes were used.

Surface litter (including wood < 5 cm diameter) of each land use was measured i.e. (a) litter thickness (mm) by pressing the litter layer and measured its thickness from the surface of the mineral soil, (b) Litter biomass (g/0.25 m^2) was collected down to the surface of the mineral soil in ten 0.25 m^2 samples and sub samples were taken for dry matter content.

Soil samples were collected (composite from 10 sample points) for the 0-5, 5-10, 10-20 cm depth zone below the litter layer, for analysis of texture (sand, silt, clay), pH (1N KCl), pH(H2O), C_{org} (Walkey and Black), N_{tot} (Kjeldahl).

A dimensionless ***'C saturation deficit'***, C_{satdef} was calculated as the difference between the current total C or C_{org} content and and the amount that would be expected for a forest soil, C_{ref}, with a long history of large litter inputs, for the same type of soil.

$$\mathbf{C_{satdef} = (C_{ref} - C_{org}) / C_{ref} = 1 - (C_{org} / C_{ref})}$$

Where, C_{org}/C_{ref} = soil organic carbon content relative to that for forest soils of the same texture and pH, C_{ref} = a reference soil C level representative of forest soil.

The equation for $C_{org,,ref}$ for upland soils in Sumatra (excluding peat and wetland soils as well as recent volcanic andisols) is:

$$\mathbf{C_{ref(adjusted)} = (Z_{sample}/ 7.5)^{-0.42} \exp(1.333 + 0.00994 * \%Clay + 0.00699 * \%Silt - 0.156 * pH_{KCl} + 0.000427 * Elevation)}$$

Where, Z_{sample} is the soil depth i.e. 0-5 cm, 5-15 cm. The elevation of the study area is about 850 m above sea level.

■ Results

Allometric equations for pruned coffee, bamboo and banana

Compared to the 'generic' Brown (1997) allometric equation, use of tree-specific allometrics that include estimates of wood density tend to lead to lower biomass estimates (Figure 1), especially in the low-to-medium biomasss categories. The developped allometric equation based on destructive sampling in Malang was used further to estimate prunned coffee biomass in Sumberjaya.

For pruned coffee, bamboo and banana separate allometric equations were used; for coffee was $W = 0.281D^{2.06}$, the power of which agrees with the Ketterings et al. (2001) equation, as c = 0.08 ($H = 1.79\ D^{0.08}$). For banana biomass an allometric equation based on pseudostem diameter was derived by Joni (2001) as : $W = 0.030\ D^{2.13}$. For the giant bamboo (*Dendrocalamus asper* (Schultes f.) Backer ex Heyne) Priyadarsini (1998) derived : $0.131\ D^{2.28}$.

Aboveground C-stock

For the Malang site, the aboveground C stock of the pinus woodlot was estimated, using a D and H equation, to be around 175 Mg ha^{-1}. A multistrata coffee system have a maximum C stock of about 49 Mg $ha^{-1}$and for shaded coffee system was about 19 Mg ha^{-1} only.

For the Sumberjaya site, the average aboveground tree biomass in the multistrata coffee system was about 74 Mg ha^{-1}(estimated C stock 34 Mg ha^{-1}), about 51 Mg ha^{-1} of shaded coffee system (estimated C stock 23 Mg ha^{-1}), and only 16 Mg ha^{-1} for coffee monoculture system (estimated C stock 7 Mg ha^{-1}). Under natural forest, the average aboveground tree biomass was about 435 Mg ha^{-1}, with an estimated C stock of 195 Mg ha^{-1}.

Time-averaged C-stock

Time averaged C-stock under forest, monoculture and multistrata coffee in Sumberjaya had been reported by Van Noordwijk *et al* (2002), The data for soil C, root biomass and aboveground biomass of trees, necromass, litter layer and understorey or herb layer, were combined to derive time-averaged C stocks (above a soil depth of 0.3 m) for the first 25 years of monoculture and multistrata coffee of 52 and 82 Mg C ha^{-1}, that are considerably below that of the remnant forest (262 Mg C ha^{-1}) or the young secondary forest (remnant of 'shifting cultivation'), at 96. Mg C ha^{-1} (Figure 2). From this study, for 15 years mix coffee systems (shaded and multistrata systems) provided aboveground biomass about 34 Mg C ha^{-1}

The average annual increase in C-stock of mixed coffee systems is about 1.9 Mg ha^{-1} yr^{-1} and that for coffee monoculture systems is only about 1.0 Mg ha^{-1} yr^{-1}.

Soil Organic Matter

The ratio C_{org}/C_{ref} of four land-uses tested in Sumber Jaya is shown in Figure 3. There is no major difference between the C_{org}/C_{ref} ratios for the 0-5 cm and 5-15 cm layers for the forest soil, suggesting that the sample depth correction in the C_{ref} equation is appropriate. The average C_{org}/C_{ref} ratio under forest condition was about 0.73, suggesting that the soil carbon status of this forest has declined from the undisturbed condition. . An increase of the land slope tends to reduce the C_{org}/C_{ref} for all land uses, but the effect was smaller than expected. The C_{org}/C_{ref} ratio of the coffee production systems was about half that of the remnant forest. The Multistrata coffee systems apparently maintains only slightly higher soil C levels than the coffee monocultures and simple shaded coffee. No consistent difference between the latter two was found, as may be expected from the higher N content and more rapid decomposition of the legume tree litter in this systems compared to coffee.

Discussion

For the various systems we found general agreement between the two sites. For the remnant natural forest in Sumberjaya we derived an estimate of aboveground tree C stock (195 Mg ha^{-1}) that was slightly above the value for a near-mature *Pinus* stand in Malang (175 Mg ha^{-1}). For the monocultural coffee systems we estimated aboveground tree C stocks of 7 Mg ha^{-1} in Sumberjaya, while this land cover type was not found in Malang. For simple shade coffee systems the values agreed well between sites (23 and 19 Mg ha^{-1} for Sumberjaya and Malang, respectively). The Malang version of the multistrata systems had a higher aboveground tree C stock than those in Sumber jaya (49 and 34 Mg ha^{-1}, respectively), related to the presence of the larger fraction of 'forest' trees in the plots.

The annual C accumulation rate of the coffee-based systems (1 and 1.9 Mg C ha^{-1} yr^{-1}) is well below the value (2.5 Mg C ha^{-1} yr^{-1}) for the jungle rubber agroforestry systems in Jambi about 2.5 ha^{-1} yr^{-1} (Tomich et al, 2000). The lower annual increment in combination with shorter life-spans of the system, leads to substantially lower time-averaged C stock estimates.

Acknowledgement

This financial support provided by APN (Asian Pasific Network) for study in Malang site, and ACIAR for Sumberjaya site through the ASB Project (Phase 3). The authors also wish to thank to Ir. Subekti Rahayu for her help on statistical analysis, to Ir Rudi Harto Widodo and Ir. Pratiknyo Purnomosidhi for their technical assistant.

References

Arifin, J., 2001. Estimasi cadangan karbon pada berbagai system penggunaan lahan di kecamatan Ngantang, Malang. Student thesis, Soil Science Department, Universitas Brawijaya, Malang, Indonesia. 59 pp

Brown S. 1997. Estimating biomass change of tropical forest, a primer. FAO Forestry Paper 134, FAO, Rome.

Hairiah K and Sitompul SM, 2000. Assesment and simulation of aboveground and belowground Carbon dynamics. APN/IC-SEA, Bogor.

Hairiah,K., Sitompul, SM, van Noordwijk, M. and Palm, C.A., 2001. Methods for sampling carbon stocks above and below ground. ASB_LN 4B. In: Van Noordwijk, M, Williams, S.E. and Verbist, B. (Eds.) 2001.Towards integrated natural resource management in forest margins of the humid tropics: local action and global concerns. ASB-Lecture Notes 1 – 12. International Centre for Research in Agroforestry (ICRAF), Bogor, Indonesia. Also available from: http://www.icraf.cgiar.org/sea/Training/Materials/ASB-TM/ASB-ICRAFSEA-LN.htm

Ketterings QM, Coe R, van Noordwijk M, Ambagau Y and Palm CA. 2001. Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests. Forest Ecology and Management 120, 199-209.

Priyadarshini, R., 1998. Estimasi modal C (C stock), masukan bahan organic dan hubungannya dengan populasi cacing tanah pada system wanatani. MSc thesis Brawijaya University, Malang. 76 pp

Tomich, T.P., Van Noordwijk, M., Budidarsono, S., Gillison, A., Kusumanto, T., Mudiyarso, D., Stolle, F. and Fagi, A.M., 1998. Alternatives to Slash-and-Burn in Indonesia. Summary Report & Synthesis of Phase II. ASB-Indonesia and ICRAF-S.E. Asia

Van Noordwijk M, Rahayu S, Hairiah, Wulan, Y.C., Farida, Verbist B, 2002. Carbon stock assessment for a forest-to-coffee conversion landscape in Sumber-Jaya (Lampung, Indonesia): from allometric equations to land use change analysis. J. Sc. China (special issue on Impacts of land use change on the terrestrial carbon cycle in the Asia Pacific region) (***in press***).

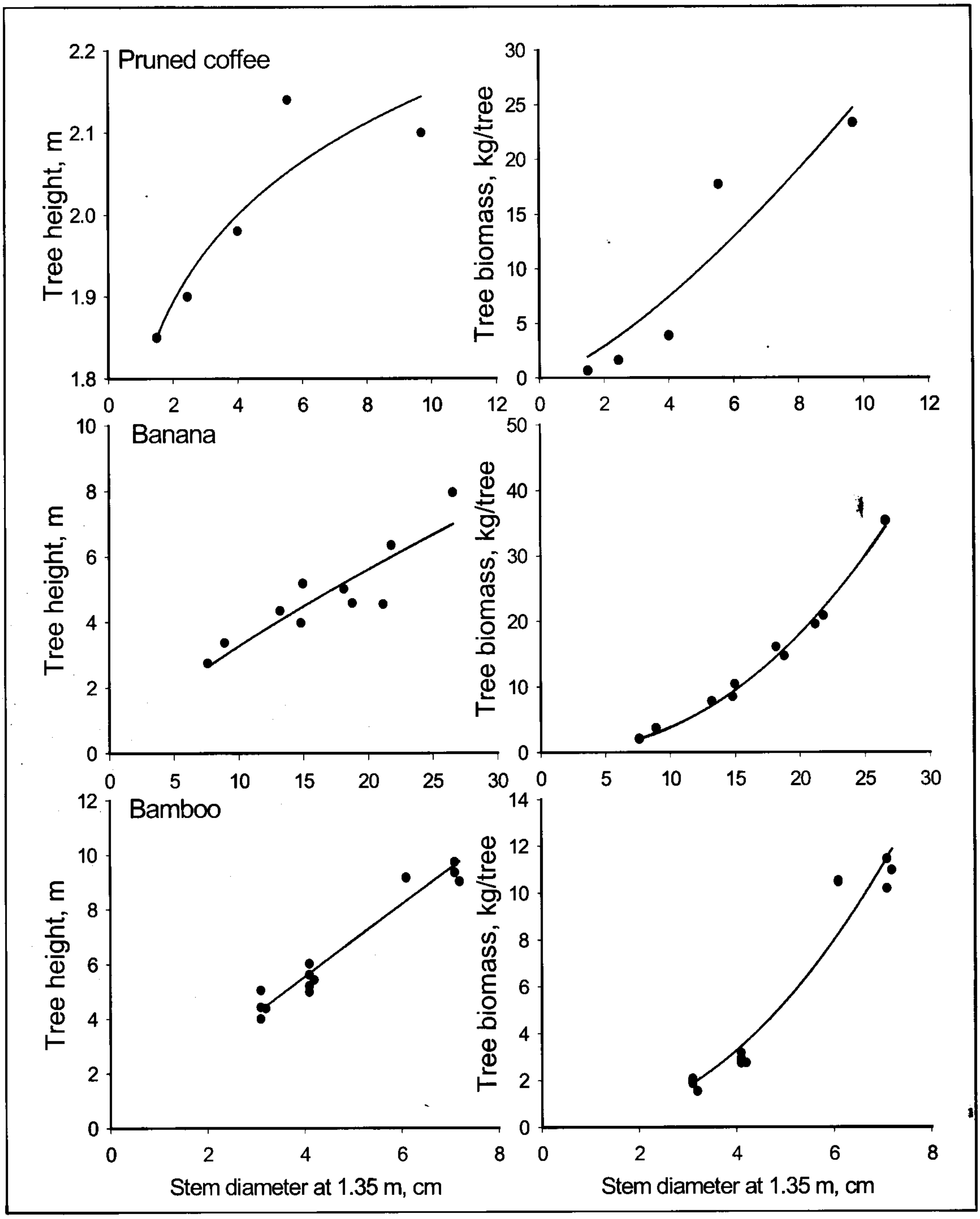

Figure 1 Allometric relationships between (pseudo)stem diameter and plant height or biomass (dry weight) for pruned coffee and banana (Arifin, 2001) and bamboo (Priyadarsini, 1998).

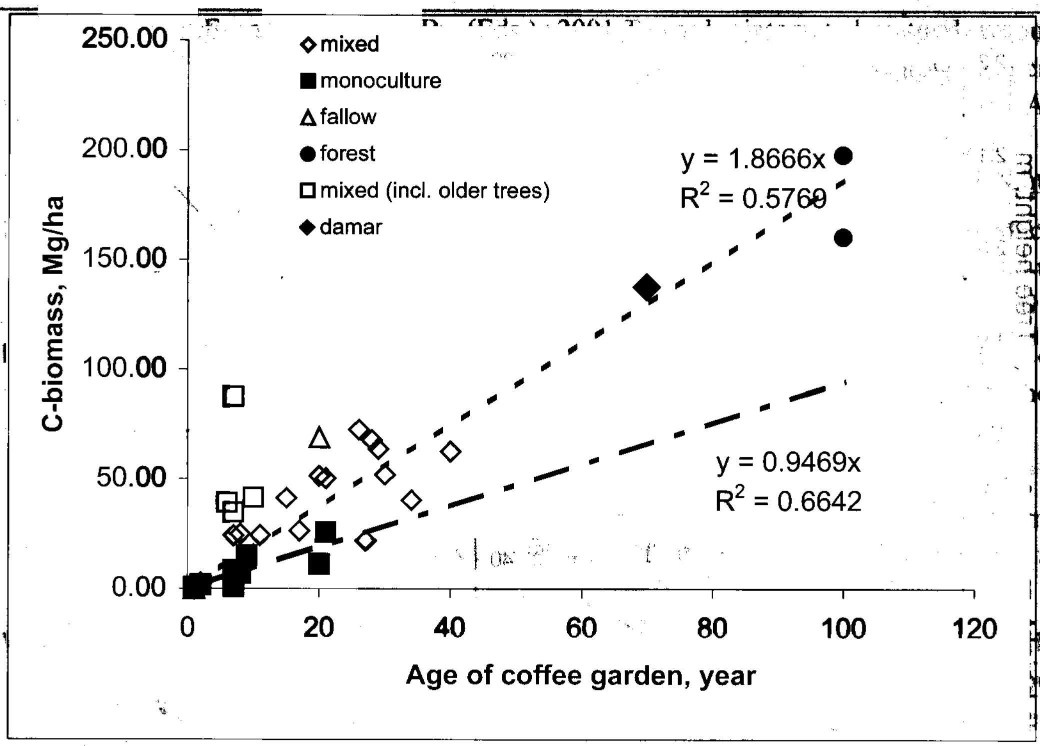

Figure 2 Relationship between aboveground C stock and age of coffee gardens (presumably since last clear-felling or slash-and-burn land clearing, but note that for some of the shade coffee gardens the age of the coffee plants is used as X-axis as the age of the garden is unknown) (Van Noordwijk et al, 2002).

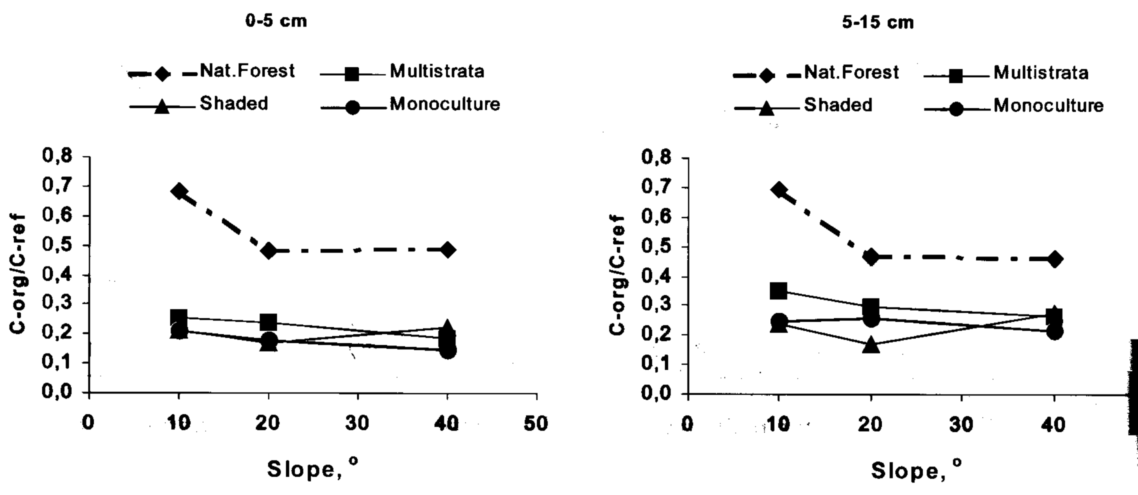

Figure 3 The ratio of C_{org}/C_{ref} of different land use types in Sumber Jaya (Bodong)