Preliminary assessment on above ground carbon stock of agroforestry and monoculture crop systems in peatlands

M Siarudin*, Y Indrajaya and A Hani

Research and Development Institute for Agroforestry Technology, Jl. Raya Ciamis-Banjar km 4, Ciamis, Jawa Barat

*Corresponding author’s e-mail address: msiarudin@yahoo.com

Abstract. Peatlands can be used for crop cultivation with various combination patterns both agroforestry and monoculture systems. Utilization of these lands not only produces high economic value products, but also contributes in providing environmental services, including carbon sequestration. This study aims to measure aboveground carbon stock of agroforestry and agricultural monoculture systems in Rasau Jaya, Kubu Raya Regency, West Kalimantan Province. The agroforestry system observed is divided based on the level of peat depth, which are 0-2 m and 3-4 m. The pattern of agroforestry at a depth of 0-2 m is a combination of timber and non timber tree species and agricultural crops, while the pattern of agroforestry at a depth of 3-4 m is a combination of timber and non-timber tree species and plantation crops. Timber tree species are Pulai (Alstonia pneumatohara) and Gerunggang (Cratoxylon arborescens Bl); the non-timber tree species is jelutung (Dyera costulata); and plantation crop species are Jengkol (Archidendron pauciflorum) and Pinang (Areca catechu); and the agricultural crops are peanuts, cayenne pepper, tomatoes, bitter melon and eggplant. Observations were also conducted on the monoculture pattern, including the eggplant, chili, bitter melon and tomato. The components of measured carbon stocks are plant biomass (trees and lower plants), wooden necromasses, non-woody necromasses, and wild plant biomass. The measurement results show a shallow peat agroforestry system (0-2 m) with a combination of one year old trees and agricultural crops contributing to carbon stock of 0.8 tons/ha. Deep peat agroforestry systems (3-4 m) with a combination of timber trees, non-timber trees and plantation crops contribute to carbon stocks of 3 tons/ha. While the monoculture system of agricultural crops produce an average carbon stock of 1.1 tons/ha. Contribution of tree component in the agroforestry system are still relatively small, which is 2.6% of total carbon stock. However, it is estimated that the carbon stocks will continue to increase with increasing age.

Keywords: agroforestry, carbon, monoculture, peatlands

1. Introduction

Tropical peatland has been widely recognized as one of the carbon rich ecosystems. With totally covering 11% of global peatlands[1], the tropical peatlands contribute about 15% of global peat carbon[2]. Indonesia alone comprises about 21 Mha peatlands area[3] with carbon stock estimated about 72 Gton C[4].

Eventhough consider as sub-optimal land, peatlands has become one of the resources for agricultural cultivations. The development of peatlands for agriculture on the other hand, can lead to carbon degradation due to deforestation, peat drainage and sometimes worsened by wildfires for land clearing activities[5]. Land cover change and the loss of trees become the major driver of above-ground C loss[6],
Over 25%, the change of virgin peatland forest into intensive agriculture contributed to 63% of total tropical peatland C loss [8].

Many studies had discussed biomass and carbon in peatlands. Some studies focused on how land-use changes affect the peatland carbon [7-9], reviewing the tropical peatland carbon fluxes [10-12], relating the peatland carbon to smallholder farmers [13, 14], discussing the drivers of peatland carbon loss [15] or particularly focusing on fire-driven carbon loss [16, 17]. However, studies on peat carbon which are specifically associated with agroforestry and agricultural monoculture land use patterns are still limited. Additional tree planted in agroforestry system increase the carbon stored in biomass. Agroforestry may produce food and wood for local communities and at the same time conserving and recovering ecosystem [18]. Harun and Yuwati [19] reported that agroforestry may sustain the production function and environmental protection of peatlands in Central Kalimantan.

This study is aimed at measuring aboveground carbon stock of agroforestry and agricultural monoculture systems in Rasau Jaya, Kubu Raya Regency, West Kalimantan Province. This paper is a preliminary research at demonstration plots that are still 1 year old from planting. This study is expected to increase understanding of how the process of developing agroforestry and agricultural monoculture on peatlands affects the dynamics of carbon stocks.

2. Materials and Methods

2.1. Research Site

Research activities were carried out on peat land in Rasau Jaya II Village, Rasau Jaya District, Kubu Raya District, West Kalimantan Province, Indonesia. The observation location is divided based on the depth of the peat, which is the depth of peat from 0-2 m (shallow peat) and 3-4 m (deep peat). Geographically, the study sites were located at 0°15'13.0"S and 109°24'33.0" E (shallow peat); and 0°14'43.3"S and 109°22'35.9" E (deep peat).

2.2. Procedure of Data Collection and Data Analysis

The observation was targeted to agroforestry and agricultural monoculture patterns. Above-ground carbon stocks measurement was carried out through measurements of tree growth, as well as biomass produced from crops and weeds. The components of carbon stocks measured were: trees, plants/understorey, woody necromass, necromass not woody (litter) [20, 21]. Tree plants at the demonstration plot were 1 year old and have an average diameter of less than 5 cm, so destructive sampling was not applied. The tree biomass estimation was carried out using a tree volume approach multiplied by the wood density. Tree volume was calculated using tree diameter and height data, taking into account the tree shape factor 0.6 [22]. This number is a tree form factor that applies to tree species in general which is based on Indonesian National Standard (SNI) No 7724-2011, considering the tree form factors of tree species present in this study were not yet available. While the density value of wood species was based on Global Wood Density Data Base data [23].

Carbon stock in crops, weeds and necromass were measured using the RaCsa (Rapid Carbon Stock Appraisal) method [24], with a plot of 0.5 m x 0.5 m. However, in certain agricultural crop species, a plot approach of 2.5 m x 2.5 m is used (such as in peanut plants), or an individual sample approach (such as in chili, eggplant, bitter melon, and tomato) because of the use of 0.5 m x 0.5 m plot cannot represent. The kiln dry weight of agricultural / understorey plant samples then were measured the in the laboratory, as the biomass weight. Carbon stock was calculated at 0.47 of the biomass weight [25].

As a basis for estimating the number of plants in agroforestry demonstration plots, calculation of plant population density is carried out in one particular area. Calculations are based on observing the spacing of crops in the field, as well as interviews with sharecroppers. Based on observations and interviews, farmers planted crops by making raised beds 70-80 cm wide. The beds are made in a 6 m alley between rows of tree plants (plant spacing of 6 x 4 m). Between beds are separated by a trench with a width of 40 cm. If on a 1m wide tree line should not be disturbed for planting crops, then there are 4 beds in a 6 m alley.
Table 1. Cropping patterns of crops as a basis for calculating biomass

| Species     | Plant spacing | Population (N/ha) | Remarks                                      |
|-------------|---------------|-------------------|----------------------------------------------|
| Peanut      | 20 x 20 cm    | 200,000           | 6 m beds between tree lines                  |
| Tomato      | 70 x 40 cm    | 32,000            | 70 cm beds, 40 cm canal between beds         |
| Chili       | 40 x 40 cm    | 48,000            | 80 cm beds, 40 cm canal between beds         |
| Eggplant    | 80 x 60 cm    | 21,333            | 80 cm beds, 40 cm canal between beds         |
| Bitter melon| 100 x 110 cm  | 6,400             | 70 cm beds, 40 cm canal between beds         |

Estimation of carbon stocks in peat agroforestry demonstration plots was carried out to 3 cropping patterns designed in the experimental design. These patterns are:

- Pattern 1: Agroforestry with timber tree species 50% + NTFP 20% + plantation species 30%
- Pattern 2: Agroforestry with timber tree species 30% + NTFP 20% + plantation species 50%
- Pattern 3: Agroforestry with timber tree species 40% + NTFP 20% + plantation species 40%

The timber tree species are Pulai (*Alstonia pneumatohara*) and Gerunggang (*Cratoxylon arborescens* Bl); the non-timber forest product (NTFP) species is Jelutung (*Dyera costulata*); and plantation species are Jengkol (*Archidendron pauciflorum*) and Pinang (*Areca catechu*).

3. Results and Discussion

Carbon stocks in crops, weeds, and necromass at agricultural sites vary from 0.4 - 3 tons/ha with an average of 1.1 tons/ha, which is equal to 3 tons/ha. The carbon stocks in this system are weeds (wild grass) and necromass because there are no cultivated crops. Based on the data in Table 2, the high carbon stock in this system comes from non-woody necromass (litter) which reaches 1.8 tons/ha. Likewise weeds and necromass woody with carbon stock are 0.6 and 0.5 tons/ha respectively, indicating the highest value compared to other land cover systems. The absence of agricultural cultivation is thought to cause litter and necromass to accumulate because there is no intensive land clearing activity. This information is in accordance with the study by Astiani, Mujiman and Rafiastanto [6] that necromass significantly contributes to biomass stocks in agriculture and shrub areas.

Crops in shallow peat agroforestry demonstration plots show carbon stocks that vary from 0.4 to 1 ton/ha. Whereas the monoculture crop system varies from 0.9 to 1.3 tons/ha. Both of these land-use systems have almost the same carbon stock average in the components of agricultural crops, which are 0.5 and 0.6 tons/ha, respectively. In general, the monoculture of agricultural carbon stock in this study is lower than the value stated by Hergoualc’h and Verchot [8] that time-averaged C stock in mixed cropland and shrubland is 15.7 Mt/ha in each rotation. This is due to more intensive land cleaning activities in agricultural crops so that less biomass is left.

The carbon stocks in wild plants and necromasses between agricultural crops appear to be higher in agricultural monocultures. Thus, agricultural cultivation in agroforestry demonstration plots, as well as agricultural monoculture, produces relatively the same carbon stock, considering that tree plants in the demonstration plots are still small and have not had much influence on the productivity (biomass) of crops. The difference between agroforestry and monoculture demonstration plots is mostly due to land maintenance activities (weed cleaning and necromass) which have an impact on the variation of biomass on the land at the time the measurements are made.
Table 2. Carbon stocks in agricultural crops, wild plants and necromass

| No. | Land use system       | Location                 | Carbon of agricultural crops (ton/ha) | Carbon of weeds and necromass (ton/ha) | Total   |
|-----|-----------------------|--------------------------|---------------------------------------|----------------------------------------|---------|
|     |                       |                          | Fruit | Stem + leaves | Root | Total | W | NWN | WN | Total |
| 1   | Wild grasses/weeds    | Deep peat agroforestry   |       |              | 0.6  | 1.8   | 0.5 |    |    | 3.0   |
|     |                       |                          |       |              |      |       |     | 0.1 |    | 3.0   |
| 2   | Peanut                | Shallow peat agroforestry| 0.2   | 0.3           | 0.7  | 0.2   | 0.1 |    |    | 0.3   |
|     |                       |                          |       |              |      |       |     | 0.3 |    | 1.0   |
| 3   | Curly chili           | Shallow peat agroforestry| 0.2   | 0.2           | 0.5  | 0.2   | 0.1 |    |    | 0.3   |
|     |                       |                          |       |              |      |       |     | 0.3 |    | 0.9   |
| 4   | Tomato                | Shallow peat agroforestry| 0.2   | 0.2           | 0.5  | 0.2   | 0.1 |    |    | 0.3   |
|     |                       |                          |       |              |      |       |     | 0.3 |    | 0.8   |
| 5   | Bitter melon          | Shallow peat agroforestry| 0.1   | 0.1           | 0.1  | 0.2   | 0.1 |    |    | 0.3   |
|     |                       |                          |       |              |      |       |     | 0.3 |    | 0.4   |
| 6   | Eggplant              | Shallow peat agroforestry| 0.2   | 0.2           | 0.5  | 0.2   | 0.1 |    |    | 0.3   |
|     |                       |                          |       |              |      |       |     | 0.3 |    | 0.8   |
| 7   | Cayenne pepper        | Monoculture of agricultural crop| 0.0  | 0.2           | 0.3  | 0.1   | 0.3 | 0.1 |    | 0.5   |
|     |                       |                          |       |              |      |       |     | 0.5 |    | 0.9   |
| 8   | Chili pong            | Monoculture of agricultural crop| 0.1  | 0.2           | 0.6  | 0.1   | 0.3 | 0.1 |    | 0.5   |
|     |                       |                          |       |              |      |       |     | 0.5 |    | 1.1   |
| 9   | Curly chili           | Monoculture of agricultural crop| 0.1  | 0.2           | 0.4  | 0.1   | 0.3 | 0.1 |    | 0.5   |
|     |                       |                          |       |              |      |       |     | 0.5 |    | 1.0   |
| 10  | Tomato                | Monoculture of agricultural crop| 0.5  | 0.4           | 1.0  | 0.2   |    |    |    | 0.2   |
|     |                       |                          |       |              |      |       |     | 1.3 |    | 1.5   |
|     |                       |                          |       |              |      |       |     |     |    | 0.6   |

Average

|                       | Deep peat agroforestry |       |              | 0.6  | 1.8   | 0.5 |    |    | 3.0   |
|                       | Shallow peat agroforestry| 0.2  | 0.2           | 0.1  | 0.5  | 0.2 | 0.1 |    | 0.3   |
|                       | Monoculture of agricultural crop| 0.2  | 0.2           | 0.3  | 0.1  | 0.6 | 0.2 | 0.2 | 0.1   |

All

|                       | 0.2   | 0.2   | 0.2   | 0.1  | 0.5  | 0.2 | 0.3 | 0.1 | 0.6   |

Remarks: W = Weeds; NWN = Non woody necromass/litter; WN = Woody necromass

Tree plants in the agroforestry demonstration plot are still 1 year old and have an average biomass content of 93.9 gr/tree in shallow peat agroforestry demonstration plots, and 210.5 gr/tree in deep peat agroforestry demonstration plots. The highest biomass was found in Jelutung species on deep peat agroforestry land, which reached 400 gr/tree. While the lowest biomass is found in the Pulai species on shallow peat agroforestry land. This variation is closely related to the growth of the plant species itself. This is due to the calculation of the biomass content estimated by the tree volume approach and wood density (Table 3).

The total biomass and carbon stock content is estimated by calculating the number of plants in one hectare. Based on the results of calculations, the total carbon stock in deep peat agroforestry demonstration plots has a higher average because the number of plants is doubled (spacing of 3 m x 4 m) compared to shallow peat agroforestry (spacing of 6 m x 4 m). The tree carbon stock in shallow peat agroforestry is only 0.02 tons / ha, whereas in deep peat agroforestry it reaches 0.08 tons/ha. However, carbon stocks in these trees still do not describe the total carbon stock in each agroforestry pattern because they have not taken into account understorey and necromass.
Table 3. Carbon of tree plants in agroforestry plots

| No | Species                        | H (cm) | D (cm) | V (cm³) | WD (gr/cm³) | Biomass (gr/tree) | Population density (n/ha) | Total biomass (ton/ha) | Carbon (ton/ha) |
|----|--------------------------------|--------|--------|---------|-------------|-------------------|--------------------------|------------------------|-----------------|
|    | Shallow peat agroforestry      |        |        |         |             |                   |                          |                        |                 |
| 1  | Pulai (Alstonia scholaris)     | 83.4   | 2.4    | 183.7   | 0.35        | 64.3              | 417                      | 0.03                   | 0.01            |
| 2  | Jelutung (Dyera costulata)     | 127.6  | 3.3    | 541.1   | 0.34        | 184.0             | 417                      | 0.08                   | 0.04            |
| 3  | Jengkol (Archidendron pauciflorum) | 98.3   | 1.5    | 83.9    | 0.4         | 33.6              | 417                      | 0.01                   | 0.01            |
|    | Deep peat agroforestry         |        |        |         |             |                   |                          |                        |                 |
| 1  | Pulai (Alstonia pneumatohara)  | 101.6  | 3.7    | 539.3   | 0.35        | 188.7             | 833                      | 0.16                   | 0.07            |
| 2  | Gerunggang (Cratoxylon arborescens Bl) | 114.2  | 2.7    | 336.8   | 0.49        | 165.0             | 833                      | 0.14                   | 0.06            |
| 3  | Jelutung (Dyera costulata)     | 147.1  | 4.6    | 1,201.8 | 0.34        | 408.6             | 833                      | 0.34                   | 0.16            |
| 4  | Jengkol (Archidendron pauciflorum) | 93.3   | 3.5    | 454.1   | 0.4         | 181.6             | 833                      | 0.15                   | 0.07            |
| 5  | Pinang (Areca catechu)         | 68.3   | 2.5    | 164.5   | 0.66        | 108.6             | 833                      | 0.09                   | 0.04            |

Remarks: H = Stem height; D = Stem diameter; V = Volume; WD = Wood density

Estimates of carbon stocks that combine the components of trees and crops, weeds and necromass are presented graphically in Figure 1 and Figure 2. The average carbon stock in shallow peat agroforestry fields is 0.8 tons/ha with a range of 0.43-1.06 tons/ha. Based on comparisons among components, tree carbon stocks only accounted for 2.3 %, while the rest came from agricultural, weeds, and necromassic components. Therefore, the variation of carbon among the cropping patterns in shallow peat demonstration plots is more influenced by variations in carbon in agricultural crops/understorey. This can be seen in Figure 1, where the cropping pattern with peanut plants consistently shows the highest carbon stock in the three types of tree crop variations (pulai, jelutung and jengkol). Conversely, the lowest carbon stock is found in cropping patterns with bitter melon plants. As presented in Table 3, the bitter melon plant system shows the lowest carbon stock (0.3 ton/ha) and peanut plants show the highest carbon stock (1 ton/ha) in shallow peat agroforestry.

Figure 1. Carbon stock in shallow peat agroforestry system
Carbon stocks in deep peat agroforestry are relatively not varied in scenario 3 of the cropping pattern, which is around 0.52 tons/ha. As in the design of planting patterns, the three patterns combine timber tree species + NTFP species + plantation species with 3 variations in the percentage of each species. Relatively equivalent carbon stock data is due to the 5 species planted being small (young) so that the percentage variation per species does not have much effect, as long as the total number of trees per ha is the same.

![Figure 2. Carbon stock in deep peat agroforestry system](image)

Comparison among components in the deep peat agroforestry demonstration plot also shows a small contribution of tree carbon stock, which is 2.6 %, and the rest comes from the components of crops/understorey and necromass. The small contribution of trees to carbon stocks in the two demonstration plots is due to trees that are still young so that the aggregate of biomass per hectare is still much smaller than that of crops, weeds necromass. This is different from forest land with mature trees, the contribution of trees to carbon stocks will be more dominant. According to Astiani, Mujiman and Rafiastanto [6] only in small amount (3 %) is the carbon sequestered in groundstorey while about 87 % are stored in living trees.

This study shows that carbon stocks in crops/understorey plants contribute significantly to the carbon stock of the agroforestry system, especially in the early growth of trees. Although crops will be harvested, but the biomass left behind in the land (leaves, stems, roots) will become carbon deposits that play a role in the cycle of biomass/carbon in the land.

4. Conclusions and Recommendations

4.1. Conclusion
The shallow peat agroforestry system (0-2 m) with a combination of one-year-old trees and crops contributes to carbon stock of 0.8 tons/ha. The pattern of jelutong+peanut, pulai+peanut, and jengkol+peanut shows the top three carbon stock, exceeding 1 tons/ha. Deep peat agroforestry systems (3-4 m) with a combination of timber trees, non-timber trees and plantation crops contribute to carbon stocks of 3 tons/ha. While the monoculture system of crops produces an average carbon stock of 1.1 tons/ha. Contribution of tree component in the agroforestry system is still relatively small, which is 2.6 % of total carbon stock. However, it is estimated that the percentage will continue to increase with increasing age.
4.2. Recommendations

Further observations are needed to evaluate carbon stocks in agroforestry cropping patterns compared to agricultural monocultures and natural peat ecosystems. Agroforestry planting patterns with a more mature tree age will illustrate a fair comparison regarding carbon stocks with agricultural monocultures and natural ecosystems of peat. This is necessary considering that agroforestry with a combination of trees and crops can be an alternative for land management by cultivating seasonal crops without reducing a lot of carbon stocks.

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