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Carbon storage and sequestration potential of aboveground biomass of African oil palm (*Elaeis guineensis* Jacq.) in three plantation sites in Visayas and Mindanao, Philippines

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ABSTRACT. Despite its potential role in mitigating climate change, there is very limited study on assessing carbon storage and sequestration of African oil palm (*Elaeis guineensis* Jacq.) in the Philippines. To address this gap, the ability of African oil palm to store carbon was studied by sampling four palms each from 6-, 10-, 15-, 17.5-, and 30-year-old plantations in three study sites in Visayas and Mindanao and compared with the biomass and carbon densities of grasslands in Visayas. Results showed that biomass densities of African oil palms in Bohol and Sultan Kudarat were 68.06 Mg ha^{-1} and 61.18 Mg ha^{-1}, respectively. The biomass mean annual increment (MAI) of African oil palm in Bohol is 7.63 Mg $ha^{-1}yr^{-1}$ while that for Sultan Kudarat was 2.95 Mg $ha^{-1}yr^{-1}$. Across all ages and sites, African oil palms have average biomass density of 63.93 Mg ha^{-1} and biomass MAI of 4.82 Mg $ha^{-1}yr^{-1}$. The trunk contributes the largest percent (59%) to its total biomass. Considering all the oil palms in both sites , the average carbon density of African oil palms studied was 28.77 Mg ha^{-1} and carbon MAI of 2.17 Mg $ha^{-1}yr^{-1}$. Biomass and carbon densities of grasslands were 23.69 Mg ha^{-1} and 10.66 Mg ha^{-1}, respectively. Using carbon densities of African oil palm and grassland, carbon storage potential of the two ecosystems were projected. Results showed that a hectare of grassland when planted with African oil palm can store 39.90 Mg–102.90 Mg of carbon after 30 years. If the same area is left to be covered with grassland however, carbon storage remains constant at 10.66 Mg from year 1 to year 30 because grassland has zero rate of sequestration. Considering the potential of African oil palm to contribute to climate change mitigation, it is suggested that the government encourage development of grasslands and open barren lands into African oil palm plantation through provision of technical assistance, low interest loans, and tax incentives.

Keywords: biomass density, carbon density, climate change, climate change mitigation

INTRODUCTION

Global warming of 1°C was reached in 2017 and is estimated to increase to 1.5°C between 2030 and 2052 (IPCC 2018). Significant risks associated with global warming will occur and have great impacts on the poor and most vulnerable sectors of society. The Philippines, being located at the Pacific Ring of Fire, is one of the most vulnerable countries in the world. Based on the World Risk Index, the Philippines consistently occupied third place as the country with the highest risk of hazards from 2012 to 2016 (Heintze *et al.* 2018). From 1998–2017, there were about 307 climatic events that occurred in the Philippines leading to annual average death toll of 867 and total loss of USD 2.9 M (Eckstein *et al.* 2019).

In recognition of its responsibility to cooperate with the global community in combatting climate change and addressing its adverse impacts, the Philippine government together with 192 countries submitted its Intended Nationally Determined Contributions (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC). The INDC indicates post-2020 climate actions that a country would take under a new international climate agreement (CCC 2015). Specifically, the Philippine INDC plans to achieve 70% emissions reduction by 2030 relative to its business-as-usual scenario for 2000–2030. However, emissions reduction commitment is dependent on the financial support, technology transfer, and capacity building that will be extended to the Philippines. Since change in land use is the second largest source of carbon emissions, reduction can be achieved by slowing down deforestation and forest degradation (IPCC 2013). Aside from reducing emissions, carbon absorption capacity of the country can be increased by developing grasslands and open barren areas into tree/oil palm plantations.

African oil palm was first introduced in the Philippines in 1950s by Menzi Agricultural Corporation when it developed a 280 ha plantation in Basilan, Zamboanga (Nozawa 2011).

Since then, several companies/entities developed African oil palm plantations in different parts of Mindanao, and in the provinces of Bohol and Palawan. African oil palm became popular in the country because of the enactment of the Biofuels Act in 2006 (Manyama *et al.* 2009). The Act stipulates that by 2011, diesel and gasoline should be blended by as much as 2% biodiesel blend and 10% bioethanol blend, respectively (Stromberg *et al.* 2011). Aside from the Biofuels Act, African oil palm became popular because of its vast utility such as cooking, animal feeds, cosmetics, as well as soap and detergent production and the potential socio-economic benefits that farmers can reap when they get engaged in African oil palm farming. Along with other countries in Asia such as India, China, Pakistan, and Bangladesh, the Philippines is one of the major importers of oil palm (Maluin *et al.* 2020). As of 2012, about 54,748 ha of land is covered with African oil palm (Batugal 2014).

Several scientists studied the potential of oil palm in storing carbon in Indonesia and Malaysia: Palm *et al*. 2005, Tomich *et al.* 2002, Murdiyarso *et al.* 2002, Khasanah *et al.* 2015, Henson 2003, Kho & Jepsen 2015, and Besar *et al.* 2020. In the Philippines, there is very limited study conducted to assess the carbon storage potential of African oil palm. This study, which seeks to determine the amount of carbon stored in two major islands of the Philippines, Visayas and Mindanao, was conducted to fill such gap.

METHODOLOGY

Study sites

The study was conducted in three municipalities: Sagbayan and Carmen in Bohol (representing the Visayas region) and Isulan in Sultan Kudarat (representing Mindanao region). These sites are areas of top three African oil palm growers in the Philippines (**Figure 1**). Sagbayan is a fourth-class municipality located in the central part of Bohol. It has a total area of 9,675 ha, which is almost equally divided into timberland (4,940 ha) and alienable and disposable land (4,735 ha). Soils of Sagbayan are a mix of Batuan-Faraon Complex, Sevilla Clay, and Inabanga Clay. Climate in Sagbayan belongs to Climatic Type IV, characterized by evenly distributed rainfall throughout the year (Bantayan *et al.* 2010).

Carmen is an interior town located near the center of Bohol. It is a second-class municipality and hosts the Chocolate Hills, the famous tourist destination in the island. The municipality has a total area of 24,804 ha, which comprise mostly of alienable and disposable land (17,626 ha or 71%) and timberland (7,178 ha or 29%). Soils of Carmen are of Batuan-Faraon Clay, Ubay Clay, Ubay Clay Loam, Bantog Clay, and Calape Clay Loam. Similar to Sagbayan, Carmen belongs to Climatic Type IV (Bantayan *et al.* 2010).

In Mindanao, Isulan is a first-class municipality of Sultan Kudarat. It is centrally located and accessible to all neighboring towns and some municipalities of neighboring provinces of Maguindanao, South Cotabato, and Davao del Sur. From Isulan's total area of 43,864 ha, about 11,522 ha or 26% are timberland and the remaining 32,342 ha or 74% are alienable and disposable lands. With a generally flat terrain, around 2,478 ha are devoted to oil palm plantations involving 93 growers.

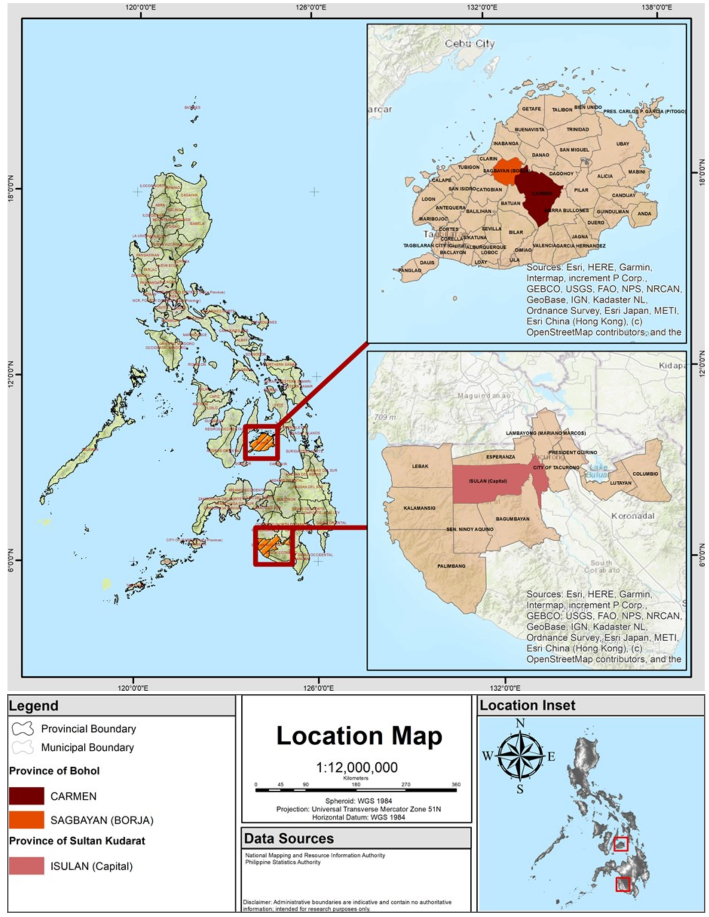

Figure 1. Location map of the municipalities of Sagbayan and Carmen in Bohol and Isulan in Sultan Kudarat, Philippines.

Isulan soil is composed of mountain soils undifferentiated and Dadiangas loamy soil. The municipality belongs to Climatic Type IV characterized by evenly distributed rainfall throughout the year.

Sampling method

African oil palm

This study followed the procedure used by Syahrinudin (2005) and Pulhin *et al*. (2014) in measuring carbon stored/density of oil palm in Indonesia and Philippines, respectively. Twenty African oil palms or four palms per age (**Figure 2**) were harvested to assess the amount of carbon stored in the plant. Five age groups were considered in the study: 6-, 10-, 15-, 17.5-, and 30-year-old palms. The 6- and 10-year-old African oil palm plantations are located in Sagbayan and Carmen, Bohol, while the 15-, 17.5- and 30-year-old plantations are situated in Isulan, Sultan Kudarat.

African oil palms were felled using a chainsaw. The total length or height of each palm felled was measured using a meter tape. All fronds were removed, leaving the frond butts attached to each trunk. Since it was difficult to weigh the whole trunk at one time, it was subdivided into small parts and numbered/coded when recording the characteristics of each trunk. In each subdivided trunk, weight, length, and diameter at both ends were measured. Weights were in kilogram while lengths and

Figure 2. Oil palm plantation in Mindanao, Philippines (Photo by Edwino S. Fernando).

diameters were expressed in meter and centimeter, respectively. From each subdivided trunk, a 1 kg sample was placed in a labeled plastic bag and taken to the University of the Philippines Los Baños (UPLB) for oven drying and analysis. A small portion from each log was taken to ensure that all trunk sections were represented in the collected sample for air and oven drying.

Similar to the trunk, the fronds were subdivided and recorded for weighing convenience. A 1 kg sample of the fronds was placed in a labeled bag and set aside for air and oven drying. A small portion from each frond was collected to ensure that all frond sections were represented in the collected sample.

Fruits and flowers of the African oil palm were also collected and separated from the butts. Weights of the fruits and flowers were separately obtained and recorded. About a kilogram each of the fruits and flowers were taken for air and oven drying.

Air drying of all samples was done for one week to minimize the time spent for oven drying. Air dried samples were placed in labeled paper bags and taken to the laboratory for oven drying. The samples were oven dried at 85°C for three days or until the weights of the samples became constant (Hairiah *et al.* 2001).

Biomass values for the trunk, fronds, leaves, flower, fruit, and roots were calculated using the following formula by Hairiah *et al.* (2001):

$$ODW = TFW - (TFW * (SFW - SODW))/SFW$$

where,

ODW = total oven dry weight
TFW = total fresh weight
SFW = sample fresh weight
SODW = sample oven-dry weight

Total biomass of the African oil palms was estimated by summing the biomass values derived from each plant part: trunk, fronds, leaves, flower, fruit, and frond base. Biomass of the African oil palm roots was not obtained as measuring this carbon pool is labor intensive and costly. Likewise, contribution of this carbon pool to the total biomass is not significant as studies show that majority of the biomass is contributed by the trunk, fronds, and fruits (Khalid *et al.* 1999b; Aholoukpe *et al.* 2013, Pulhin *et al.* 2014).

Carbon stored in each plant part was obtained by multiplying the biomass with percent carbon. Due to fund limitations to do carbon analysis, this study used 45% carbon (Lasco & Pulhin 2000), which is the average carbon content of different tree species in the Philippines. Similar to biomass, total carbon stored in the whole African oil palm plant is derived by adding the carbon stored in each of the plant parts.

Grassland

To determine the potential carbon that an area covered with grass can sequester if converted into African oil palm plantation, both biomass and carbon of a grassland in Carmen, Bohol were assessed (**Figure 3**).

Due to budget limitations, no grassland samples were obtained from Isulan, Sultan Kudarat. Ten sample plots measuring 2m x 2m were randomly laid out. Each sample plot was 10 m apart. Inside each of the 2m x 2m sample plot, all grasses were harvested excluding the roots. Total fresh weight of the harvested grasses in each sample plot was taken and recorded. A sub sample of 300 g in each sample plot was set aside for air and oven drying. Oven drying of the samples was done at 85°C for three days or until the samples attain its oven dry weight (Hairiah *et al.* 2001). Thus, a total of 10 sub samples weighing 300 g each were collected.

Biomass density (Mg ha^{-1}) of the grasslands was determined using the same formula for calculating the biomass of oil palm parts described earlier. Carbon density was derived by multiplying biomass with percent carbon, 45% (Lasco & Pulhin 2000).

RESULTS AND DISCUSSION

African oil palm

Biomass. Table 1 shows the biomass of the individual African oil palm by age. Highest biomass obtained in the 6-year-old plantation was 0.21 Mg (Palm 2) while the lowest value was 0.15 Mg (Palm 4). The average biomass of the four African oil palms belonging to this age was 0.18 Mg.

For the 10-year-old plantation, biomass ranged from 0.70–1.06 Mg or an average of 0.83 Mg. Biomass of this group was about

Figure 3. Grassland in Bohol, Philippines (Photo by Edwino S. Fernando).

five times bigger than that of the 6-year-old African oil palms. Based on biomass, oil palms of this group can be arranged in the following order: Palm 1 > Palm 2 > Palm 3 > Palm 4.

In the 15-year-old plantation, Palms 2 and 3 have the same biomass values, which also turned out to be the smallest when compared with the biomass of the remaining African oil palms. Palm 4 closely followed Palms 2 and 3, while Palm 1 has the highest biomass.

The 17.5-year-old African oil palms have an average biomass of 0.36 Mg. African oil palms belonging to this group have biomass values ranging from 0.23 to 0.49 Mg. Results show that African oil palms belonging to the same age group vary greatly in biomass. For instance, biomass of Palm 1 was twice as much as that of Palms 3 and 4.

As regards the 30-year-old plantation, biomass of the African oil palms ranged from 0.59 to 0.76 Mg or an average of 0.65 Mg. Based on biomass value, the African oil palms can be arranged as follows: Palm 3 > Palm 1 > Palm 4 > Palm 2.

In terms of MAI of the biomass, results showed that the growth rate of 15-, 17.5-, and 30- year-old plantations was 0.02 Mg $ha^{-1}yr^{-1}$. The 6-year-old African oil palm has slightly bigger growth rate of 0.03 Mg $ha^{-1}yr^{-1}$, while the 10-year-old African oil palm has the biggest rate of 0.08 Mg $ha^{-1}yr^{-1}$.

Both 6- and 10-year-old African oil palms were grown in Sagbayan and Carmen, Bohol while the remaining African oil palms were sampled from plantations in Isulan, Sultan Kudarat. Comparing the two regions, it can be deduced that African oil palms grown in Bohol have higher biomass than those grown in Sultan Kudarat. Considering that the group of 10-year-old African oil palms were not the oldest among those sampled, the higher biomass density of this group of African oil palms compared to the 15-, 17.5-, and 30-year-old ones was likely due to the more favorable site condition. While no survey on the amount of fertilizers used in each plantation was done, a potential reason for the good growth of the 10-year-old oil palms was the application of commercial fertilizer and pesticides. Results indicate that good site conditions and sufficient inputs are essential to ensure good growth in African oil palm plantations.

On the average, biomass of African oil palms sampled in Bohol was 0.50 Mg while 0.45 Mg for those in Sultan Kudarat. Since a hectare of oil palm contains 135 individual palms (Nozawa 2011), the biomass densities of oil palms in Bohol and Sultan Kudarat were 68.06 Mg ha^{-1} and 61.18 Mg ha^{-1}, respectively.

Across all ages and sites, African oil palms have biomass of 0.47 Mg or an average density of 63.93 Mg ha^{-1}. The 6-year-old African oil palm has the lowest biomass density while the 10-year -old African oil palm has the highest. **Table 2** shows the remaining plantations and ranking in terms of biomass density: 30-year- old (ranked 2nd), 15-year-old (ranked 3rd), and 17.5-year-old (ranked 4th).

Table 2. Biomass density of African oil palm per age.

Age	Biomass density (Mg ha^{-1})
6	24.62
10	111.51
15	48.50
17.5	47.35
30	87.70
Average	63.93
Range	24.62 – 111.51
Std Dev	34.96

Average biomass MAI of African oil palms in Bohol is 0.06 Mg $palm^{-1}$ yr^{-1} while those plantations in Sultan Kudarat have MAI of 0.02 Mg $palm^{-1}yr^{-1}$. When all biomass values were averaged across all ages and sites, the MAI of African oil palms was 0.04 Mg $palm^{-1}$ yr^{-1}. On a per hectare basis, biomass MAI of African oil palm in Bohol and Sultan Kudarat were 7.63 Mg ha^{-1} yr^{-1} and 2.95 Mg ha^{-1} yr^{-1}, respectively while biomass MAI across all ages and sites was 4.82 Mg ha^{-1} yr^{-1}. The value derived from Bohol was within the range of values of the aboveground biomass MAI (6.39–7.99 Mg ha^{-1} yr^{-1}) derived in drained peatland in Malaysia (Lewis *et al.* 2020) while the biomass density values derived from Isulan, Sultan Kudarat and from African oil palms sampled across all ages and sites were of lower values.

Percent distribution of different plant parts to total biomass

Figure 4 shows the contribution of the different plant parts to total biomass of the African oil palm at different plantation ages. Percent contribution of the different plant parts vary across ages. For instance, in the 6-year-old African oil palm, the trunk constituted around 37% (0.07 Mg) of the total biomass. Frond

Table 1. Biomass (Mg) of individual African oil palm at different ages.

Palm number	Sample age (years)				
	6	10	15	17.5	30
1	0.20	1.06	0.53	0.49	0.66
2	0.21	0.82	0.27	0.41	0.59
3	0.17	0.72	0.27	0.27	0.76
4	0.15	0.70	0.36	0.23	0.60
Range	0.15 – 0.21	0.70 – 1.06	0.27 – 0.53	0.23 – 0.49	0.59 – 0.76
Average	0.18	0.83	0.36	0.35	0.65
MAI	0.03	0.08	0.02	0.02	0.02
Std Dev	0.03	0.17	0.12	0.12	0.08

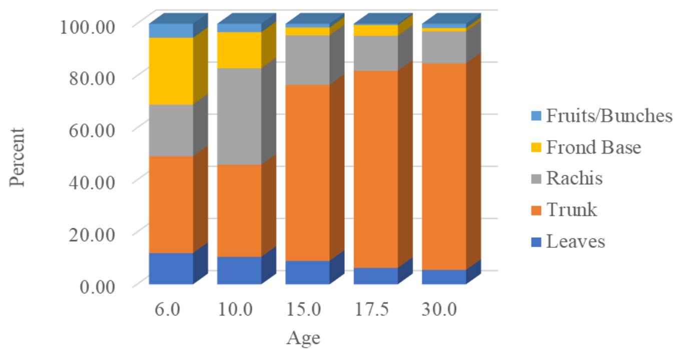

Figure 4. Percent distribution of the different parts in the total biomass of African oil palm.

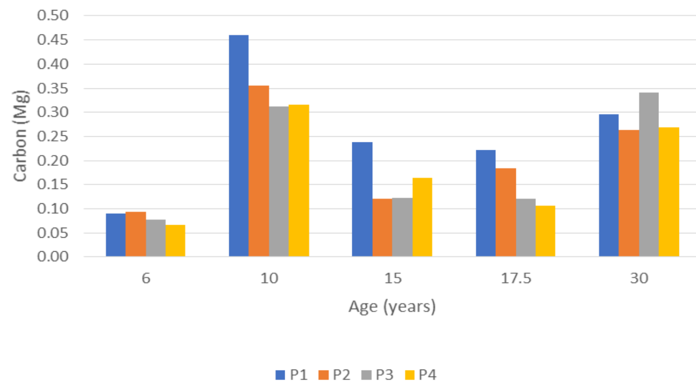

Figure 5. Carbon stored per palm per age of African oil palm.

base contributed 26% (0.05 Mg) while the rachis gave 20% (0.04 Mg) of the total plant biomass. Leaves and fruits/bunches shared 12% (0.02 Mg) and 5% (0.01 Mg), respectively.

In the 10-year-old African oil palm, the rachis comprised the biggest chunk of the total biomass. Percent contribution of rachis in the total biomass of the African oil palm was 37% or 0.31 Mg. Rachis was closely followed by the trunk, which comprised 35% (0.29 Mg) of the biomass. Frond bases' share in the total biomass of the 10-year-old plantation was 14% (0.11 Mg), while leaves and fruits/bunches have contribution of 10% (0.09 Mg) and 3% (0.03 Mg), respectively.

For the 15-year-old African oil palm, more than half of the total biomass was contributed by the trunk with 68% share or 0.24 Mg. Rachis ranked second contributing 19% or 0.07 Mg while leaves constituted 9% or 0.03 Mg. Frond base and fruits/bunches have small shares as 3% of the total biomass came from the former while 1% was given by the latter.

As regards the 17.5-year-old plantation, the different plant parts followed the same order as that of the 15-year-old plantation in terms of percent contribution to the total biomass: trunk > rachis > leaves > frond base > fruits/bunches. The bulk of the total biomass was contributed by the trunk as it comprised 75% or 0.27 Mg of the total biomass. Rachis contributed 13% or 0.05 Mg while the leaves comprised 6% or 0.02 Mg of the total biomass. Frond base with a biomass of 0.01 Mg contributed about 4% of the total biomass while fruits/bunches have less than 1% share or 0.002 Mg.

For the 30-year-old plantation, the trunk gets the biggest share as it contributed 79% or 0.51 Mg of the total biomass. The remaining 21% was shared by rachis (12% or 0.08 Mg), leaves (6% or 0.04 Mg), fruits/bunches (2% or 0.01 Mg), and frond base (1% or 0.01 Mg).

Across all ages, results showed that the trunk comprised the largest percentage of the total biomass of oil palm. The results obtained concurred with the findings of Migolet *et al.* (2020) where the trunk comprises 73% of the total aboveground biomass of oil palm in Congo.

Carbon. Carbon data of individual African oil palms per age are shown in **Figure 5**. Similar to the trend observed in biomass, Palm 4 has the lowest amount of carbon while Palms 1 and 2 contained the highest amount in the 6-year-old African oil palm. The amount of carbon for this age ranged from 0.07–0.9 Mg or an average of 0.08 Mg. Compared with study results of Pulhin *et al.* (2014), carbon stored in the 6-year-old African oil palm from this study was a little bit higher. Pulhin *et al.* (2014) reported that 6-year-old African oil palm contains 0.06 Mg of carbon.

For the 10-year-old plantation, carbon stored by African oil palms ranged from 0.31–0.46 Mg or an average of 0.36 Mg. Using amount of carbon as the metric, oil palms are in the following order: Palm 1 > Palm 2 > Palm 4 > Palm 3.

In the 15-year-old plantation, the most amount of carbon (0.24 Mg) was found in Palm 1 followed by Palm 4 (0.16 Mg). Palm 2 and 3 both contained 0.12 Mg carbon in the biomass. The average amount of carbon stored for this plantation was 0.16 Mg.

Similar to the 15-year-old plantation, the 17.5-year-old palm has an average carbon stored of 0.16 Mg with maximum and minimum carbon values of 0.11 Mg and 0.22 Mg, respectively. Among the palms sampled, Palm 1 contained the highest amount of carbon while Palm 4 has the least amount.

For the 30-year-old plantation, Palm 3 occupied the highest rank in terms of amount of carbon stored followed by Palm 1. Palm 4 ranked 3rd while Palm 2 ranked 4th. Carbon stored values ranged from 0.26–0.34 Mg or an average of 0.29 Mg. Comparing both samples, obtained carbon data followed a similar trend observed in biomass: 10-year-old > 30-year-old > 15-year-old > 17.5-year-old > 6-year-old.

Average carbon stored per palm in Bohol and Sultan Kudarat were 0.23 Mg and 0.20 Mg, respectively while across all ages and sites, African oil palms stored 0.21 Mg of carbon. Since there are 135 trees per hectare of oil palm plantation (Nozawa 2011), the carbon densities derived were 30.63 Mg ha^{-1} (Bohol), and 27.53 Mg ha^{-1} (Sultan Kudarat). Across all ages and sites, carbon density of African oil palm ranged from 11.08–50.18 Mg ha^{-1} or an average of 28.77 Mg ha^{-1}. Similar to the trend observed in biomass density, 10-year-old plantation had the highest carbon density followed by the 30-year-old stand. The 15-year-old plantation occupied the third rank while the 17.5-year-old and 6-year-old plantations were in the fourth and fifth ranks, respectively (**Table 3**).

The values obtained in this study were way below the average carbon density values derived from oil palm plantations in

Table 3. Carbon density of African oil palm per age.

Age	Carbon Density (Mg ha^{-1})
6	11.08
10	50.18
15	21.82
17.5	21.31
30	39.47
Average	28.77
Range	11.07 – 50.18
Std Dev	15.73

neighboring countries such as Indonesia and Malaysia. Studies in Indonesia reveal carbon densities of 48 Mg ha^{-1} (Palm *et al.* 2005), 90 Mg ha^{-1} (Tomich *et al.* 2002), 91 Mg ha^{-1} (Murdiyarso *et al.* 2002), 37.76–42.07 Mg ha^{-1} (Khasanah *et al.* 2015) while in Malaysia reported values are 36 Mg ha^{-1} (Henson 2003), 2 to 60 Mg ha^{-1} (Kho & Jepsen 2015) and 60.30 Mg ha^{-1} for 6-year-old plantation and 76.44 Mg ha^{-1} for 16-year -old oil palm plantations (Besar *et al.* 2020).

In terms of carbon MAI, the 10-year-old African oil palm plantation has the biggest carbon accumulation rate of 0.04 Mg $palm^{-1}yr^{-1}$. The remaining African oil palm plantations have carbon MAI of 0.01 Mg $palm^{-1}yr^{-1}$. The average MAIs of the African oil palm plantations studied in Bohol and Sultan Kudarat were 0.03 Mg $palm^{-1}yr^{-1}$and 0.01 Mg $palm^{-1}yr^{-1}$, respectively. On a per hectare basis, MAI of African oil palms in Bohol was 3.43 Mg ha^{-1} yr^{-1} and 1.33 Mg $ha^{-1}yr^{-1}$ for Sultan Kudarat. Across all ages and sites, African oil palms have MAI of 0.02 Mg $palm^{-1}yr^{-1}$ or 2.17 Mg $ha^{-1}yr^{-1}$.

Grassland

Biomass. Biomass densities of the grass samples collected from Carmen in Bohol varied greatly (**Table 4**). Plots 1 and 10 have very low biomass densities while Plot 6 has extremely high biomass value. Biomass density ranged from 6.88 Mg ha^{-1} to 58.80 Mg ha^{-1}. On the average, biomass density of the grass sampled was 23.69 Mg ha^{-1}. Compared with studies conducted in the Philippines, the low biomass density values derived from this study were comparable with the values derived by Brakas & Aune (2011), Villamor *et al.* (2010), and Decipulo *et al.* (2009). Brakas and Aune in their study on grassland in Mindanao reported biomass density of 6.4 Mg ha^{-1}. Villamor *et al.* (2010) in their investigation of grassland in Ikalahan Forest Reserve, Nueva Vizcaya found that such ecosystem has biomass density of 9.11 Mg ha^{-1}. Decipulo *et al.* (2009) derived biomass density of 6 Mg ha^{-1} from grasslands in Manupali Watershed in Mindanao.

High biomass density values particularly in Plots 4–8, were comparable with the values derived by Lasco & Pulhin (2003); where biomass density of *Sacharrum sp.* and *Imperata sp.* in Leyte showed values of 29.11 Mg ha^{-1} and 18.89 Mg ha^{-1}, respectively.

Carbon. In terms of carbon, results of the analysis showed that grasslands in Carmen, Bohol have an average density of 10.66 Mg ha^{-1}. Since carbon density is derived by multiplying the biomass density with the percent carbon, carbon density follows the same trend as that of the biomass density values where values have large variation. Among the plots studied, Plot 6 has the highest carbon density value while Plot 10 has the lowest. Carbon density of the grasslands sampled ranged from 3.09 Mg ha^{-1} to 26.46 Mg ha^{-1} (**Table 4**).

Table 4. Biomass and carbon density of grassland in Bohol, Philippines.

Plot Number	Biomass Density (Mg ha^{-1})	Carbon Density (Mg ha^{-1})
1	9.60	4.32
2	17.05	7.67
3	17.45	7.85
4	25.39	11.42
5	31.75	14.29
6	58.80	26.46
7	23.21	10.44
8	28.35	12.76
9	18.40	8.28
10	6.88	3.10
Range	6.88 – 58.80	3.10 – 26.46
Average	23.69	10.66
Std Dev	14.59	6.56

Carbon storage and sequestration potential of African oil palm

Using the carbon densities of African oil palm plantations and grasslands as well as the mean annual increments of oil palm derived from the study, the potential carbon that can be stored were estimated if one hectare of grassland is converted into an African oil palm plantation. As part of this study's limitation, carbon emissions associated with establishment of African oil palm plantation was not included in the estimate as the paper intends to give the readers an idea of the potential of African oil palm in sequestering carbon from the atmosphere.

Since this study derived three values each for carbon densities and carbon MAIs, the carbon stored in a hectare of land if developed into African oil palm plantation was projected for 30 years under three scenarios. The first scenario used the carbon MAI (3.43 Mg $ha^{-1}yr^{-1}$) of African oil palm plantation in Sagbayan and Carmen, Bohol, while both the second and third scenarios used the carbon MAI (1.33 Mg $ha^{-1}yr^{-1}$) of the African oil palm plantation in Isulan, Sultan Kudarat and 2.17 Mg $ha^{-1}yr^{-1}$, for all African oil palms sampled across ages regardless of sites, respectively.

Using the carbon MAI value derived from plantations in Sagbayan and Carmen, Bohol, the developed area initially contains 3.43 Mg at year 1. As the African oil palms grow, it continues to sequester carbon from the atmosphere. Carbon storage capacity of the area rapidly increased through time until it reached 102.90 Mg at the 30^{th} year. Carbon storage value after 30 years is 30 times bigger than the carbon during African oil palm establishment (**Figure 6**). The table further shows the carbon projection for 30 years using the carbon density and MAI derived from African oil palms studied in Isulan, Sultan Kudarat. Starting with 1.33 Mg of carbon at year 1, the area slowly increased its carbon storage capacity through time. At Year 30, the area accumulates a total of 39.90 Mg of carbon.

Using the average carbon MAI of all African oil palms across ages and sites, carbon stored in the area at Year 1 is 2.17 Mg. Similar to Scenarios 1 and 2 discussed earlier, carbon in the area will continue to accumulate until it reaches 65.10 Mg at Year 30 (**Figure 6**).

In contrast, carbon storage of the area did not increase through time if such remains to be covered with grassland. From Year 1 to Year 30, carbon stocks in the area was at a constant value of 10.66 Mg because grassland has zero sequestration as it is burned every year (**Figure 6**).

Results of the carbon projections show that it is better to convert grasslands into oil palm plantations as the latter increases the carbon storage capacity of an area as oil palms grow and store carbon in their biomass. When managed well, oil palm plantation can increase its capacity to absorb more carbon from the atmosphere and play a big role in climate change mitigation.

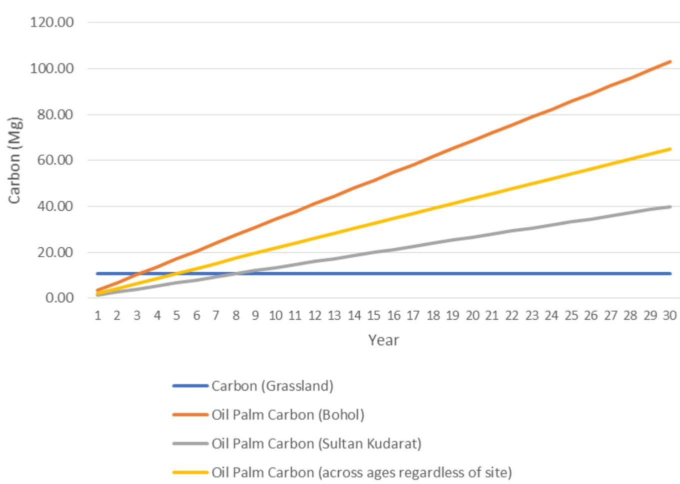

Figure 6. Potential carbon benefits of a grassland when planted with African oil palm.

CONCLUSION

Oil palm plantations have the potential to contribute to climate change mitigation as it can absorb more carbon dioxide from the atmosphere than grasslands. A hectare of grassland when planted with oil palm can store substantial carbon regardless of the carbon MAI value used (Sultan Kudarat, Bohol or the average of all oil palms sampled in both sites). With rates of sequestration of 1.33 Mg $ha^{-1}yr^{-1}$ (Sultan Kudarat carbon MAI), 2. 17 Mg $ha^{-1}yr^{-1}$ (using average carbon MAI of all oil palms sampled) and 3.43 Mg $ha^{-1}yr^{-1}$ (Bohol carbon MAI), oil palms sequestered more carbon from the atmosphere as it matures. By the time the oil palm plantation reaches the age of 30, it contributes 39.90 Mg (based on Sultan Kudarat values), 65.10 (based on average of all oil palms), and 102.90 Mg (based on Bohol values) of carbon in the area. On the other hand, if the same site is left covered with grassland, carbon storage remains constant at 10.66 Mg from Year 1 to Year 30.

Aside from carbon, oil palm plantations also provide socio–economic benefits to the farmers (Lifianthia & Husina 2012; Alwarritzi *et al.* 2016). Studies conducted in Indonesia to determine the impact of growing oil palm to the farmers' socio–economic condition show that farmers gain higher profit from oil palm planted in suboptimal land compared when such areas are planted to rice, corn, and soybean (Lifianthia & Husina 2012). Likewise, Alwarritzi *et al.* (2016) reported that oil palm plantations help reduce the problem of lack of job opportunity and poverty in Indonesia. In India, Sati & Vangchhia (2017) found that income from oil palm plantation is 50% higher than income derived from cereal farming. In the Philippines, annual net income reported by the oil palm growers amount to PhP 80, 916 (1 USD = PhP 48.00) (Nozawa 2011).

Considering the carbon benefits and the associated socio–economic benefits of growing oil palm, the Philippine government should encourage small farmers to develop existing grasslands and open areas into African oil palm plantations.

In the future, this study suggests for sampling to be done in the grasslands of Isulan, Sultan Kudarat. The carbon stored in such ecosystem can be determined, as well as the carbon benefits, if developed into an oil palm plantation. Also, socio–economic study of oil palm plantations can be done to determine the benefits that farmers can reap from such venture.

LITERATURE CITED

Aholoukpe, H., Dubos, B., Flori, A., Deleporte, P., Amadji, G., Jean-Luc, C., & Didier, B. (2013) Estimating aboveground biomass of oil palm: Allometric equations for estimating frond biomass. *Forest Ecology and Management* 292: 122–129.

Alwarritzi, W., Nanseki, T., & Chomei, Y. (2016) Impact of oil palm expansion on farmers' crop income and poverty reduction in Indonesia: An application of propensity score matching. *Journal of Agricultural Science* 8(1): 119–131.

Bantayan N.C., Calderon, M.M., Pulhin, F.B., Predo, C.D., & Barruga, R.A.C. (2010) *How to Make Burning of Chocolate Hills of Bohol, Philippines Carbon Neutral.* Terminal Report. Institute of Renewable Natural Resources, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna. 66p.

Batugal, P. (2014) Philippine Palm Oil Industry Road Map (2014 – 2023). Retrieved on August 10, 2020 <www.mpoc.org. my/ upload/POTS_Philippine_Palm_Oil_Industry_Road_ Map .pdf>. 38p.

Besar, N.A., Suardi, H., Phua, M.H., James, D., Mokhtar, M.B., & Ahmed, M.F. (2020) Carbon stock and sequestration potential of an agroforestry system in Sabah, Malaysia. *Forests* 11(2): 210.

Brakas, S.G. & Aune, J.B. (2011) Biomass and Carbon Accumulation in Land Use Systems of Claveria, the Philippines. pp. 163–175. *In:* Kumar, B.M. & Nair, P.K.R. (eds.). *Carbon Sequestration Potential of Agroforestry Systems: Opportunities and Challenges.* vol. 8, Advances in Agroforestry. Dordrecht, Heidelberg, London, New York: Springer.

Climate Change Commission. (2015) *Philippines: Intended Nationally Determined Contribution.* Retrieved at <www4. unfccc.int/submissions/indc/Submission%20Pages submissions.aspx>.

Decipulo, M.S., Ambos, N., Gabule, D.T., Diana, R., Golosino, B., & Sioquim, C. (2009) *Carbon Stock Assessment of*

Manupali Watershed. Unpublished Terminal Report.

Hairiah, K.S., Sitompul, M., van Noordwijk, M., & Palm, C. (2001) *Methods for Sampling Carbon Stocks Above and Below Ground. International Centre for Research in Agroforestry.* Southeast Asian Regional Research Programme. Bogor, Indonesia. 32p.

Heintze, H.J., Kirch, L., Küppers, B., Mann, H., Mischo, F., Mucke, P., Pazdzierny, T., Prütz, R., Radtke, K., Strube, F., & Weller, D. (2018) *World Risk Report 2018.* Ruhr University Bochum – Institute for International Law of Peace and Armed Conflict (IFHV). Germany. 55p.

Eckstein, D., Hutfils, M.L., & Winges, M. (2019) *Global Climate RiskIndex 2019: Who Suffers Most from Extreme Weather Events? Weather-related Loss Events in 2017 and 1998 to 2017.* German Watch, Germany. 36p.

Henson, I.E. (2003) The Malaysian national average oil palm: Concept and evaluation. *Oil Palm Bulletin* 14: 15–27.

IPCC (2018) Summary for Policymakers. *In: Global Warming of 1.5° C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.* Masson-Delmotte, T.W.V., Zhai, P., Pörtner, H.O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M., & Waterfield, T. (eds.), World Meteorological Organization, Geneva, Technical Report 2018.

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., & Midgley, P.M. (eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 1535p.

Khasanah, N., van Noordwijk, M., & Ningsih, H. (2015) Aboveground carbon stocks in oil palm plantations and the threshold for carbon-neutral vegetation conversion on mineral soils. *Cogent Environmental Science* 1(1): 1119964. DOI: 10.1080/23311843.2015.1119964

Khalid H., Zin, Z., & Anderson, J.M. (1999) Quantification of oil palm biomass and nutrient value in a mature plantation. II. Belowground biomass. *Journal of Oil Palm Research* 2: 63–71.

Kho, L.K. & Jepsen, M.R. (2015) Carbon stock of oil palm plantations and tropical forests in Malaysia: A Review. *Singapore Journal of Tropical Geography* 36 (2): 249–266. DOI: 10.1111/sjtg.12100

Lasco, R.D. & Pulhin, F.B. (2000) Forest land use change in the Philippines and climate change mitigation. *Mitigation and Adaptation to Climate Change Journal* 5: 81–97.

Lewis, K., Rumpang, E., & Kho, L.K. (2020) An assessment of oil palm plantation aboveground biomass stocks on tropical peat using destructive and non-destructive methods. *Scientific Reports* 10(1): 1–12. DOI: 10.1038/s41598-020-58982-9

Lifianthia & Husina, L. (2012) Productivity and income performance comparison of smallholder oil palm plantation at dry land and wet land of South Sumatra, Indonesia. *APCBEE Procedia* 3: 270–275.

Maluin, F.N., Hussein, M.Z., & Idris, A.S. (2020) An overview of the oil palm industry: Challenges and some emerging opportunities for nanotechnology development. *Agronomy* 10 (3): 356. DOI: 10.3390/agronomy10030356

Migolet, P., Goïta, K., Ngomanda, A., & Biyogo, A.P.M. (2020) Estimation of aboveground oil palm biomass in a mature plantation in the Congo Basin. *Forests* 11: 544. DOI: 10.3390/f11050544

Murdiyarso, D., van Noordwijk, M., Wasrin, U.R., Tomich, T.P., & Gillison, A.N. (2002) Environmental benefits and sustainable land-use options in the Jambi Transect, Sumatra. *Journal of Vegetation Science* 13: 429–438.

Nozawa, K. (2011) *Oil Palm Production and Cooperatives in the Philippines.* UPSE Discussion Paper No. 2011–13. University of the Philippines, School of Economics (UPSE). Quezon City. 42p.

Palm, C.A., van Noordwijk, M., Woomer, P., Alegre, J.C., Arévalo, L., Castilla, C.E., Cordeiro, D.G., Hairiah, K., Kotto-Same, J., Moukam, A., Parton, W.J., Ricse, A., Rodrigues, V., & Sitompul, S.M. (2005) Carbon losses and sequestration after land use changes on the humid tropics. *In:* Palm, C.A., Vosti, S.A., Sanchez, P.A., & Ericksen, P.J. (eds.), *Slash-and-Burn Agriculture–The Search for Alternatives.* Columbia University Press, New York. pp. 41–63.

Pulhin, F.B., Lasco, R.D., & Urquiola, J.P. (2014) Carbon sequestration potential of oil palm in Bohol, Philippines. *Ecosystems and Development Journal* 4(2): 14–19.

Sati, V.P. & Vangchhia, L. (2017) Prospects of oil palm plantation in Mizoram, India. *Indian Journal of Hill Farming* 30(1): 139–143.

Syahrinudin, S. (2005). The Potential of oil palm and forest plantations for carbon sequestration on degraded land in Indonesia. *Ecology and Development Series* No. 28: 1–115.

Tomich, T.P., de Foresta, H., Dennis, R., Ketterings, Q., Murdiyarso, D., Palm, C., Stolle, F., Suyanto, S., & van Noordwijk, M. (2002) Carbon offsets for conservation and development in Indonesia. *American Journal of Alternative Agriculture* 17: 125–137.

Villamor G.B., Pampolina, N., Forcadilla, R., Bugtong, N., Alano, J., Rice, D., Omas, T., Castillo, R., & Pulan, D. (2010) Rapid Carbon Stock Appraisal: Kalahan, Nueva Vizcaya, Philippines. Working Paper 106. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Program. 87p.