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Preface

This symposium is organized by Major in Sustainable Resource Sciences, Graduate School of Bioresources Mie University with an aid of the Committee on Double Degree Master Program on "Integrated Food Production and Management Planning" between Graduate School, Mie University and Graduate Study, Sriwijaya University. The purpose of this symposium is to bring together researchers and graduate students working on sustainable agriculture and rural development in East and Southeast Asian countries. We hope this opportunity results in not only further improvements and progress in each study, but also "sustainable" collaborations between us.

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PRECISE MANAGEMENT OF SOIL NUTRIENT TO INCREASE ATMOSPHERIC CO_2 FIXATION BY OIL PALM (*Elaeis guineensis Jacq.*)

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Summary

The atmospheric CO_2 concentration has increased during the last century and it is estimated that if some actions are not taken against this increase, current CO_2 concentrations are expected to double before the end of this century. Plants and agricultural practices play important roles in atmospheric CO_2 emission and fixation. Current study examined carbon fixation in oil palm. We hypothesized that good soil nutrient management practices could increase the absorption of atmospheric CO_2, thereby mitigating the adverse effect of CO_2 on climate. Study was carried out in small-holder oil palm plantation in South Sumatra, Indonesia, covering an area of 2,000 hectares. Values of fixed CO_2 were determed by calculating the amount of CO_2 accumuled in oil palm fresh fruit bunch (FSB). In spite of the fact that the soils in the study area had moderate available P, the were chemically infertile dute to low pH, low to very low content of total-C and N and low very low avaliability of K. Therefore, oil palm suffered from N and K deficiency but not P deficiency. Corrected NPK application (rate, time and method) increased oil palm production, thereby increasing the amount of atmospheric CO_2 accumulation by oil palm. There results highlighted the importance of good nutrient management practices for the absorption of atmospheric CO_2 and its' storage in plant biomass.

Introduction

Oil palm (*Elaeis guineensis* Jacq.) has been one of the most dynamic Indonesia's agricultural sub-sectors. Dating from the late 1960s, the oil palm sub-sector expanded from around 106,000 hectares to 7,824,623 million hectares in 2010, as shown in Figure 1. This expansion was partly brought about by the Indonesian Government's encouragement of foreign investment where trade and economic liberalization as well as policy deregulation and debureaucratization created a conducive investment climate. Investment in the plantation sector was given priority since this is expected to increase the socio-economic standard of people in the rural areas.

In line with the development of the plantation areas, the volume of crude palm oil (CPO) production and export has also increased significantly. The most recent report by World Growth (2011) showed that palm oil has been Indonesia's most significant agricultural export, valuing over $14.5 billion in 2008 and 2009. In addition, there has also been a significant change in terms of business players in the past decade. From the dominance of big player at the beginning, smallholders emerged later on (see Figure 1). Until recently, private companies hold about 48% of the plantations areas, while about 43.76% are managed by smallholders and the rest (8,24%) is the state-owned enterprises (Rianto, 2010).

However, controversies have accompanied the oil palm boom particularly because oil palm expansion is an issue that raises significant environmental concerns. Elevated concentrations of carbon dioxide (CO_2) and other greenhouse gases in the earth's atmosphere that have resulted from anthropogenically-derived emissions is one of the most pressing environmental issues today (IPCC, 2007).

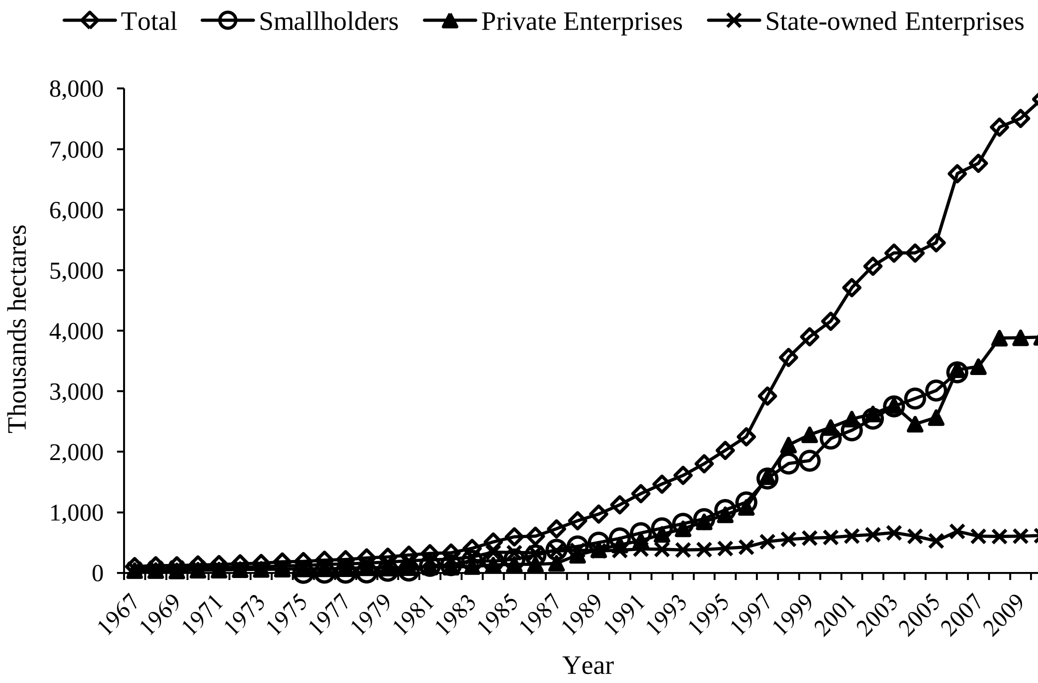

Figure 1. Development of palm oil plantation in Indonesia

Source: Directorate General of Estate Crops (2010). http://ditjenbun.deptan.go.id/cigraph/ index.php/viewstat/komoditiutama/8-Kelapa%20Sawit (Accesed on March 02, 2011).

Initially, the major opposition to palm oil was over deforestation with more recent concerns surrounding the impact of oil palm expansion on CO_2 emissions. Palm cultivation on peat land and indirect land use changes are often cited as the major threat to climate change. However, there is considerable uncertainty and debate about the data and models used to support these claims (World Growth, 2010).

In the present economic condition, it is unlikely that emissions from industry, vehicles, residential growth, energy production and other activities including oil palm industry will be reduced to meet the targets. Limiting CO_2 emissions and increasing sequestration of carbon from the atmosphere into 'sinks' therefore may become important. Plants absorb CO_2 from the atmosphere during photosynthesis and it becomes part of the plant tissue; standing vegetation, or biomass, therefore contains carbon and is a biomass carbon store. Palm oil production consumes considerably less energy, uses less land and generates more oil per hectare than any other oil seeds, has a comparatively smaller carbon footprint and is an effective carbon sink (World Growth, 2009).

Unforunately, oil palm plantations in Indonesia have been less productive than palm oil plantations in other countries, for example Malaysia. In fact, World Growth (2009) found that there is considerable potential for oil palm plantation in Indonesia to expand output on existing acreages through an appropriate use of fertiliser. Current research was undertaken to study the effect of precise soil nutrient management on the amospheric CO_2 fixation by oil plam in South Sumatra, Indonesia.

Materials and Methods

Study Site. The study site was a smallholder plantation of oil palm in Ogan Komering Ilir District covering an area of 2,000 hectares. The area belongs to Type A climate zone with ratio of dry month to wet month <1.5 (Schmidt and Ferguson, 1951). Although there has been a seasonal shift, rainy season usually starts in September and ends in March with average annual precipitation of 2,600 to 4,200 mm; dry season is from April to August. Air temperature is relatively similar all year long with mean annual temperature of 26.8ºC. The soils were Yellowish-brown Podzolic, and association between Yellowish-red Podzolic and Yellowish-brown Podzolic (LPT, 1974), equivalent to Acrisols (FAO/UNESCO, 1974) or Ultisols (Soil Survey Staff, 1992). The location was chosen because it covered a large area and represent roles of Indonesian farmers in atmospheric CO_2 fixation.

Soil and Plant Sampling. Field survey was conducted using a working map of 1 : 10,000. Sampling points were determined using a grid system at a 50 m x 50 m-grid. Disturbed soil samples were collected from the rooting zone (0 to 30 cm). In each grid, four disturbed soil subsampes were collected and composited leaving one sample per grid. The soil samples were air-dried, ground to pass a 2-mm sieved, and characterized for pH, total C, total N, available P (P-Bray II), exchangable K, Ca, Mg and Al, and CEC. Oil palm leaves were also collected from the same location, oven-dried at 70°C for 48 hrs and analized for N, P and K content.

Soil and Plant Analysis. Soil pH was measured with a glass electrode using a soil to water ratio of 25 g to 25 mL (designated as pH-H_2O). Total Carbon (T-C) and Nitrogen (T-N) were determined by Walkley-Black Method and Kjedhal digestion Method, consecutively (Stevenson, 1996). The P-Bray II procedure was used to extract available P (Bray & Kurts, 1945), and the extract was colorimetrically analyzed for available P using a spectrophotometer at 660 nm. Exchangeable Potassium (K) were extracted with 1M NH_4-OAc (pH = 7.0), followed by reciprocal shaking and centrifugation in a soil to solution ratio of 5 to 25, then measured by titration method. Plant samples were oven-dried at 70°C for 48 hours and ground for NPK content analysis.

Supply NPK by Soil. This study focused on three essential nutrients, namely N, P and K which were frequently limiting oil palm growth and yield in South Sumatra. To correct the availability of those nutrients precisely, it was important to calculate the inherent availaility of soil to supply those nutrient. This calculation was made based on the following data and asumptions:

1. Soil bulks density was 1.1 g cm^{-3}, soil sampling was conducted at the depth of 0 to 30 cm. Therefore, total weight of soil was 3.3 x 10^6 kg ha^{-1}. This data were then used in calculating total available N, P and K,

2. Available N ($N_{Avail.}$) in current study was supplied by tro different sources, namely inorganic N (N_i) and organin N (N_o). N_i was about 2.5% of total soil N, while N_o was 97.5% of the total N in soil (Stevenson & Cole, 1999). Therefore, N_i was calculated as follows

$N_{Avail.}$ = 2.5% x (% total N x 3.3 . 10^6 kg ha^{-1} (kg avail. N ha^{-1}) ....Eq. 1

N_o was supplied through the decomposition of organic N at the rate of 2.5% per year (Stevenson & Cole, 1999). Therefore, N_o was calculaated as follows

N_o = 2.5% x (97.5% total N x 3.3 . 10^6 kg ha^{-1} (kg avail. N ha^{-1}) ....Eq. 2

The summation of results obtained from Eq. 1 and Eq. 2 gave total available N in soil

Total $N_{Avail.}$ = N_i + N_o (kg $N_{Avail.}$ ha^{-1}) ....Eq. 3

3. Available P ($P_{Avail.}$) was supplied by two diffferent sources, namely inorganic P (P_i) and organic P (P_o). P_i was calculated as follows

P_i = P-Bray I x 3.3 x 10^6 kg ha^{-1} (kg P_i ha^{-1}) ....Eq. 4

P_o was derived from the decomposition of soil organic matter (SOM). Assuming that SOM contanibed 2% of P (Stevenson & Cole, 1999) and the decomposition rate of SOM is 1% per year, P_o was was calculate as follows

P_o = 2% (SOM Content x 3.3 . 10^6 kg ha^{-1}) x 1% (kg P_o ha^{-1}) ....Eq. 5

The summation of results obtained from Eq. 4 and Eq. 5 gave total available P in soil

Total $P_{Avail.}$ = P_i + P_o (kg P_2O_5 ha^{-1}) ....Eq. 6

4. Available K was calculated as follows

$K_{Avail.}$ = $K_{Exch.}$ x 3.3 . 10^6 kg ha^{-1} (kg K_2O ha^{-1}) ....Eq. 7

5. Other growth requirements (temperature, soil moisture, solar irradition) were favourable.

Nutrient Balance. Nutrient balance was the difference between the amount of nutrients (NPK) supplied by the soils and the amount of nutrients absorbed by oil palms to obtain certain levels of yield.

CO_2 Fixation Calculation. The amount of CO_2 fixed was calculated using an assumption that total carbon content in fresh fruit bunches (FFB) of oil palm is 44.05% (Syahrinuddin, 2005). The total carbon content in FFB was calculated using the following formula :

$$C_{FFB} = A \times B \text{ (tonnes C ha}^{-1}\text{)} \text{ .... Eq. 8}$$

where:

C_{FFB} : Carbon content in fresh fruit bunches of oil palm

A : Proportion of Carbon in FFB, 44.05% (Syahrinuddin, 2005)

B : Total FFB production (tonnes ha^{-1})

The calculated C content is then converted into CO_2 using the following formula :

$$CO_{2FIXED} = C_{FFB} \times \text{MW of } CO_2/\text{AM of C (tonnes } CO_2 \text{ ha}^{-1}\text{)} \text{ .... Eq. 9}$$

where:

CO_{2FIXED} : Total CO_2 fixation by oil palm

C_{FFB} : Carbon content in fresh fruit bunches of oil palm

MW of CO_2 : Molecular weight of CO_2 (44)

MW of C : Molecular weight of C (12)

Results and Discussion

Initial Soil Characteristics. All blocks were located in one compound area. Therefore, there might not be definitive differences in climate in geological time for long-term soil weathering. Topographically, all blocks were located at the slope of below 15%. Selected soil characteristics in the study area are given in Table 1. Soil acidity ranged from acid to slightly acid (pH of 4.79-5.03). Release and hydrolysis of Al under strong leaching condition produced acidity in these soils. At low pH, Al is present in the exchange complex and diffuses into soil solution where it may lower the pH.

Table 1. Selected chemical characteristics of soil in the study areas

Soil Characteristics *	Block								
	3	13	15	18	23	31	34	37	38
pH-H_2O (1:1)	5.03a	4.89a	4.82a	4.92a	4.80a	4.99a	5.01a	4.79a	4.89a
Total C (g kg^{-1})	11.9l	9.50vl	7.10vl	5.90vl	8.80vl	8.50vl	7.00vl	9.80vl	9.00vl
Total N (g kg^{-1})	1.20l	0.80vl	0.70vl	0.60vl	0.80vl	0.90vl	0.80vl	1.00vl	0,90vl
C : N Ratio	9.92	11.88	10.14	9.83	11.00	9.44	8.75	9.80	10.00
Avail. P (µg P_2O_5 g^{-1})	8.24vl	5.84vl	13.05l	14.08l	19.07m	12.71l	12.37l	7.90vl	7.56vl
Exch. K (cmol(+) kg^{-1})	0.19l	0.19l	0.13vl	0.19l	0.16vl	0.19l	0.13vl	0.26m	0.13vl

Note : * Based on criteria by LPT (1983); a = acid; vl = very low; l = low; m = moderate

Total C and N, reflecting the comparative amount of organic matter, was very low to low; while the total N was very low to moderate. Although, observation in the field showed that oil palm and growth floor debries were accumulated, these materials mostly consisted of undecomposted plant materials. Therefore, their contribution to the soil organic matter pools were not significant.

Available P (P-Bray II) was low to moderate in the study sites. Various soil properties, such as pH, Fe_{OX} and Al_{OX} contents and C content, have been reported to be closely related to the P availability and retention capacity of soils (Bertrand *et al*., 2003; Borling *et al*., 2001; Burt *et al*., 2002; Daly *et al*., 2001; Ige *et al*., 2005; Leclerc *et al*., 2001). Previous findings by Sabaruddin *et al.* (2001) showed that the low availability of P in soils of South Sumatra, Indonesia was significantly correlated (r^2 = 0.53**, P = 0.002) with high Al solubility and with low content of total C (r^2=0.67**, P < 0.001). Low pH found the current study prompted the solubility of Al, which eventually together increased the formation of insoluble complexes of Al-P. While very low to low content of total C in the current study reflected that the potential releases of inorganic P from soil organic matter was also insignificant. The amount of available K ranged from very low to low. Based on the results presented in Table 1, it was concluded that the soils in the study site had poor natural capacity to supply sufficient nutrients to the oil palm.

Calculated Available NPK and NPK Status of Oil Palm, Uptake and Budget. In general there are three main essential nutrients, i.e. N, P and K, frequently limiting growth and yield of oil palm in Indonesia. Therefore, the availability of these nutrients in soils are usually corrected by applying chemical fertilizers. To be efficient, it is necessary to know the amount of NPK that can be supplied by the soils prior to the fertilizer application. Calculated available NPK using Equation 1 to 7, and NPK content of oil palm, uptake and budget in the study area are given in Table 2.

Table 2. Calculated available NPK, NPK status of oil palm, NPK uptake, and NPK budget

Block	Calculated Available Nutrient			Nutrient Status of Oil Palm			Total Uptake			NPK Budget		
	N	P	K	N	P	K	N	P	K	N	P	K
	------------- kg ha^{-1} ------------			---------------- % ---------------			------------- kg ha^{-1} ------------			--------------- kg ha^{-1} -------------		
3	195.53	40.74	29.66	2.11d	0.27s	0.63d	230.41	29.48	68.79	-34.88	11.26	-39.13
13	130.35	30.09	29.66	1.84d	0.34s	0.38d	266.98	49.33	55.14	-136.63	-19.24	-25.48
15	114.06	51.13	20.30	2.48d	0.32s	0.75d	295.86	38.17	89.48	-181.80	12.96	-69.18
18	97.76	53.21	29.66	2.18d	0.19s	0.50d	252.88	22.04	59.00	-155.12	31.17	-29.34
23	81.47	86.69	29.66	1.71d	0.28s	0.50d	134.92	22.09	39.45	-53.45	64.60	-9.79
31	146.64	51.64	29.66	1.93d	0.33s	0.50d	303.39	51.88	78.60	-156.75	-0.24	-48.94
34	130.35	48.79	20.30	1.99d	0.24s	0.50d	262.88	31.70	66.05	-132.53	17.09	-45.75
37	162.94	37.23	40.59	2.08d	0.19s	0.75d	316.78	28.94	114.23	-153.84	8.29	-73.64
38	146.64	35.17	20.30	0.25d	0.19s	0.38d	294.18	27.27	54.53	-147.54	7.90	-34.23

Note: * Based on criteri by Benton (1991); s = sufficient; d = deficient

Data in Table 2 show that. Therefore, all plants in the study sites suffered from N and K deficiency. It was also supported by the fact that all blocks showed negative nutrient budget for N and K (Table 2). In contrast, in spite of very low to low availability of P (Table 1), oil palms in the study sites did not suffer from P defficiency (Table 2). Mycorrhizal fungi have been found to be essential components of soil-plant systems, especially in acid soils (Hooker and Black, 1995; Van der Heijden *et al*., 1998; Sabaruddin, 2004). Benefits derived by plants from mycorrhizal symbiosis include (i) increased plant uptake of P (Bolan, 1991), (ii) enhanced water absorption (George *et al*., 1992), and (iii) improved plant health by providing protection against some pathogens (Dehne, 1982).

Although farmers have regularly applied NPK fertilizers at 270 kg urea ha^{-1}, 129 kg SP36 ha^{-1} and 230 kg KCl ha^{-1}, the amount could not overcome nutrient deficiency. It confirmed that the amount of applied fertilizers was still lower than the amount of NPK uptaken by the oil palms. In addition, these rates were the equal for all blocks in spite of the differences in soil ability to supply nutrient. If such practices were continously employed, it was mostly likely that the sustainability of oil palm plantation could be at risk. Therefore, it was important to adjust the rate by taking into account the inherent ability of soils to supply nutrients for oil aplms.

Recommended Precise Nutrient Management on Oil Palm. Precise nutrient management in the current paper included block specific fertilizer rate, time of fertilizer application and method of fertilizer application. Recommended fertilizer rates are given in Table 3. These rates were determined by considering nutrients absorbed in soil complexes and organic matter decomposition. The recommended rates of N fertilizer varied from as low as 346 kg Urea ha^{-1} yr^{-1} to as high as 665 kg Urea ha^{-1} yr^{-1} (Table 3). These rates were much higher than the old rate due to two main reasons, namely (1) oil palms required high amount of N for their normal growth and production, (2) N reserve (organic N pool) in the soils were very low to low (Table 1).

Although oil palms did not show P deficiency symptoms and most blocks showed a positive P budget (Table 2), P fertilization was still required to balance the increases in N fertilizer rate. The recommended rates of P application varied among the blocks ranging from 75 kg TSP ha^{-1} yr^{-1} to 144 kg TSP ha^{-1} yr^{-1} (Table 3).

Similar to soil N, available K also showed negative balance (Table 2), confirming that K supply both from the soil and from the old fertilization practice was not enough. Therefore, it was recommended to increase the rate of K application to 180 kg KCl ha^{-1} yr^{-1} to 350 kg KCl ha^{-1} yr^{-1} (Table 3).

Table 3. Recommended feritilizer rate

Block	Fertilizer Rate					
	Urea		TSP		KCl	
	Old	New	Old	New	Old	New
	------------------ kg ha^{-1} ------------------					
3	270	346	102	118	230	290
13	270	566	102	114	230	260
15	270	665	102	115	230	345
18	270	607	102	75	230	280
23	270	386	102	102	230	250
31	270	610	102	103	230	310
34	270	558	102	106	230	300
37	270	604	102	125	230	350
38	270	590	102	126	230	287

In addition to the corrected rate of fertiizer application above, it was also important to know the appropriate time and place of fertilizer application. Fertilization on oil palms were usually conducted twice a year, at the beginning of rainy season (september to October) and by the end of rainy season (March to April). To minimize fertilizer losses, the fertilizer could be banded or spread around the oil palm tree.

Effect of Precise Nutrient Management on Oil Palm Yield and CO_2 Fixation. Precise nutrient management in the current study was based on optimising soil fertility to ensure normal growth and production oil palm because precise nutrient management was a fundamental pillar of the oil palm plantation. The effect of precise nutrient practice on the calculated atmospheric CO_2 fixation by oil palms was observed one year after implementation and the results are given in Table 4. The recommended nutrient management increased oil palm production, which also resulted in increases in amospheric CO_2 fixation. These results confirmed positive impacts of good practices of soil nutrient management on oil palm production, which increased fixation of atmospheric CO_2 and further helped to reduce CO_2 buildup.

Table 4. Increases in oil palm yield and CO_2 fixation due to precise nutrient management

Block	Change in					
	Oil Palm Yield (kg FFB ha^{-1})		Carbon (kg ha^{-1})		CO_2 Fixed (kg ha^{-1})	
	Before	After	Before	After	Before	After
3	10,920	13,026	4,810	5,738	17,638	21,039
13	14,510	17,308	6,392	7,624	23,436	27,956
15	11,930	14,231	5,255	6,269	19,269	22,985
18	11,600	13,837	5,109	6,095	18,736	22,349
23	7,890	9,412	3,476	4,146	12,744	15,210
31	15,720	18,752	6,925	8,260	25,390	30,287
34	13,210	15,758	5,819	6,941	21,336	25,451
37	15,230	18,167	6,709	8,003	24,599	29,343
38	14,350	17,117	6,321	7,540	23,178	27,648

Note : FFB = fresh fruit bunch

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