

The Impact of Oil Palm Plantation Management on Soil Fertility Dynamics

¹Ikhsanul Adli, ²Aprisal, ³Jabang Nurdin

^{1,2,3}Universitas Andalas

Korespondensi : ikhsanul.adli@gmail.com

Abstrak

Industri kelapa sawit merupakan penopang ekonomi terbesar bagi perekonomian Indonesia dari sektor pertanian. Di balik kisah sukses kegiatan ini, terdapat konsekuensi lingkungan mengenai penurunan kualitas lahan sebagai akibat dari pengelolaan lahan yang tidak tepat. Untuk mempelajari pengaruh pengelolaan perkebunan kelapa sawit terhadap kesuburan tanah, sebuah penelitian dilakukan di tiga lokasi, Kabupaten Dharmasraya (Kanhapludult), Solok Selatan (Dystrudepts) dan Pesisir Selatan (Haplohemists) di Sumatera Barat. Data penelitian dikumpulkan masing-masing dari tahun 2017 hingga 2022, dan dianalisis. Hasil penelitian menunjukkan bahwa tanah dari Dharmasraya (DM) dan Solok Selatan (SS) mengalami penurunan nilai pH dalam periode penelitian, sedangkan hasil yang berlawanan ditemukan di lokasi PS. Kandungan Karbon Total (C) dan Nitrogen (N) di lokasi DM dan SS ditemukan serupa, sedangkan di lokasi PS parameter ini jauh lebih tinggi karena tanah berasal dari bahan organik. Hasil yang sebanding juga ditemukan untuk KTK, di mana lokasi penelitian DM dan SS lebih rendah dibandingkan dengan lokasi PS. Kandungan unsur hara makro (nitrogen, fosfor dan kalium) pada tanah menggambarkan lokasi PS jauh lebih baik dibandingkan dengan DM dan SS. Karena lokasi PS merupakan tanah organik, kandungan unsur hara yang lebih tinggi dapat membahayakan lingkungan karena mudah bocor ke badan air yang dapat memicu eutrofikasi.

Kata kunci: Manajemen, Kelapa Sawit, Jenis Tanah, Pupuk, Biochar

Abstract

The palm oil industry is the largest economic supporter for the Indonesian economy from the agricultural sector. Behind the success story of this activity, there are environmental consequences regarding the decline in land quality as a result of improper land management. To study the effect of oil palm plantation management on soil fertility, a study was conducted in three locations, Dharmasraya Regency (Kanhapludult), South Solok (Dystrudepts) and South Coast (Haplohemists) in West Sumatra. Research data were collected from 2017 to 2022 respectively, and analyzed. The results showed that soils from Dharmasraya (DM) and South Solok (SS) experienced a decrease in pH value during the study period, while opposite results were found at the PS location. Total Carbon (C) and Nitrogen (N) content at the DM and SS locations were found to be similar, while at the PS location these parameters were much higher because the soil came from organic matter. Comparable results were also found for KTK, where the DM and SS research locations were lower compared to the PS location. The content of macro nutrients (nitrogen, phosphorus and potassium) in the soil describes the PS location much better compared to DM and SS. Because the PS location is organic soil, the higher nutrient content can be harmful to the environment because it can easily leak into water bodies which can trigger eutrophication.

Keywords: Management, Oil Palm, Soil Type, Fertiliser, Biochar

1. INTRODUCTION

Oil palm plantations began to be developed in the 1960s and have continued to expand to the present day. In 1967, the area of oil palm plantations was only 105,808 ha. By 1997 it had grown to 2.5 million ha. The rapid increase occurred in the period 1990-1997, with an average increase of 200,000 ha per year, dominated by private oil palm plantations. In the period 1999-2003, oil palm plantations again expanded significantly, from 2.96 million ha to 3.8 million ha. In 2010, the area of oil palm plantations was 8 million

ha, and by 2019 it will have reached 14.6 million ha (BPS, 2020). Currently, around 90% of oil palm plantations in Indonesia are located on the islands of Kalimantan and Sumatra, which produce 95% of Indonesia's crude palm oil (CPO) production. The role of the palm oil industry is very large in Indonesia's macroeconomy. The palm oil industry has long been the country's main foreign exchange earner, the locomotive of the national economy, energy sovereignty, the driver of the people's economic sector, and employment.

Table 1. Palm oil production in several districts of Sumatra, 2017-2021 (BPS, 2020)

No	Province	(Ton)					Growth (%)
		2017	2018	2019	2020*)	2021**)	
1.	Aceh	911.697	1.03.402	1.133.34	1.134.60	1.167.337	9,25
2.	Riau	8.113.85	8.496.02	7	6	10.270.14	11,97
3.	Sumatera	2	9	9.513.20	9.984.31	9	0,41
	Barat	1.302.95	1.248.26	8	5	1.350.125	
4.	Jambi	2	9	1.253.39	1.312.25		7,18
5.	Sumatera			4	3	3.109.205	6,74
	Selatan	1.849.96	2.691.27			4.388.731	
		9	0	2.884.40	3.022.26		
		3.199.48	3.793.62	6	5		
		1	2	4.049.15	4.267.02		
				6	3		

Source: Directorate General of Plantations

Notes: *) Provisional figures; **) Estimated figures

Form of production: Palm oil

The growth of oil palm production (Table 1) in several provinces on the island of Sumatra is highly variable. In the 2017-2021 period, several regions, such as Aceh, Riau, South Sumatra and Jambi provinces, saw an increase in production of 6-11%. Meanwhile, in West Sumatra Province, there was an increase in production of 0.41% during the same period. Expansion of this plantation had been put some pressure to the land. Both lands consist of minerals and organic soil origin has been converted to palm oil plantation which generally manage in different ways to robust the plant productivity. The long-term soil management on cultivated land could related to the changes of soil characteristic. The main purposes of this study is to evaluate the changing pattern of soil chemical characteristic both on mineral and organic soils.

2. METHOD

This study was conducted in Dharmasraya (S=01014'22.4": E=101032'31.0"), Solok Selatan (S=01032'03.04": E=101025'05.07") and Pesisir Selatan (S=0207'53.74": E=100051'15.43") districts. The soil types in the study sites are Ultisol, Inceptisol and Histosol, respectively. Soil samples were taken once a year, from 2017-2021. The disturbed soil sample were taken by hand auger soil sampler and undisturbed samples used stainless steel soil core sampler. All of soil samples were analyzed for pH (1:5 and 1:2.5 soil and solution ratio for organic and mineral soil, respectively), total carbon content (spectrophotometric method); CEC (ammonium acetate pH 7 method); base saturation (base cations/KTK*100%); available phosphorous (Bray I method); total nitrogen (Kjeldahl method), C/N ratio and bases cations (K, Na, Ca and Mg with ammonium acetate, pH 7), (PPT Bogor, 1995). All of analytical data were classified according to

the table of criteria for soil chemical properties in the Technical Guidelines for Soil Fertility Assessment (PPT, 1995). Criteria for evaluation of soil chemical properties and soil fertility.

3. RESULTS AND DISCUSSION

Palm oil plantation management

The information about land management practice at the study site, collected through informal discussion with some palm oil plantation staff. based on the statements of several employees, obtained that during the period 2017-2021, the form / process of maintaining PP (Producing Plants) of oil palm in this plantation, the types of fertiliser used are NPK pearl, NPK hikay, kieserite, borate and NPK hi-kay bio (only in PT. SMP). Dosage and spacing of fertiliser use in PP (Producing Plants), namely NPK 3 kg to 4 kg spacing of 4 months per staple. Kieserite 1000 gr, borate 100 gr and on peat 1-2 kg / semester (fertilizer dose is recommended by a third party, namely an agronomic consultant, and is applied on the plantation land by day labourers, in this case day laborer are only tied to specific jobs until the job is completed). In PT SJAL-SS, dolomite ($\text{CaMg}(\text{CO}_3)_2$) will only be applied in 2021 in quantities of 30,000-40,000 kg. The maintenance process in PPs (Producing Plants) involves the addition of other media to the land in the form of fertilisers, solids and raw oil palm empty fruit bunches (TKKS without processing) are applied to the plantation land and left alone without composting first or without processing by the daily workers.

The maintenance process in PP (Producing Plants) is water management on the land, namely arranging ditches so that they do not become blocked when it rains, draining swamp areas and, in the case of peat, building a water gate in the primary drain, with the groundwater level at 40-60 cm from the ground surface, but during the rainy season at 20-40 cm from the groundwater level to the ground surface. Harvesting on this plantation is done by human labour using a tractor and the crop is transported by dump truck to the nearest factory, the same group company, Incasi Raya Group.

The effect of land management on soil chemical characteristic

1.1.1 Soil pH

Soil pH is one of soil's most important chemical properties because it influences nutrient availability thereby affecting plant growth. Maintaining soil pH in the proper range is critical for success as plant growth is poor when the soil pH is outside of the desired range. An incredible number of chemical, biochemical, and biological reactions occur in soils. Through these reactions, nutrients, whether already present in the soil or added by fertilizers, are converted into forms that can be taken up by plant roots. The pH of the soil affects these reactions and in doing so, determines the availability of the nutrients essential for plant growth. It does this by affecting a nutrient's solubility in the water that occurs in the soil. The more soluble a nutrient is, the more that is dissolved in the soil water. Plant takes up water from the soil with the dissolved nutrients in it through their roots. This is how plants get the majority of the nutrients needed for growth and development.

The study shows the pH values of soil from DM and SS site decreased gradually within the study period. The DM and SS sites found decline from 5.64 to 5.02 and 5.97 to 5.49, respectively; while the PS site shows oppose where it has increase from 4.41 to 4.81 within the study period. The discrepancy of these results might be due to the different soil material and land management practice as well. The mineral soil with oxidative environment at DM and SS sites, content high amount of aluminum which tend to reduce soil pH with the presence of hydrogen ion. In oppose, the drained of organic soil (PS site) accelerate their decomposition which lead to release organic acid into water body nearby and elevate the pH value. In addition, application of lime as calcite (CaCO_3) or dolomite ($\text{CaMg}(\text{CO}_3)_2$) may play the key role of this condition.

According to Brady and Weil (2017) intensive application of nitrogen fertilizer (urea) may lead on soil acidification, as reaction of urea and water in soil will release huge amount of hydrogen ion which may responsible on pH decreasing in soil. On the other hand, acceleration of peat decomposition and frequent addition of lime elevate the soil pH at PS site (Table 2 and Figure 1).

Table 2. The changes of soil pH on sampling site from 2017 to 2021

Sampling time	DM (Ultisols)	SS (Inceptisols)	PS (Organosols)
2017	5.64 a	5.97 a	4.41 a
2018	5.57 a	5.95 a	4.43 a
2019	5.20 ab	5.83 a	4.43 a
2020	5.10 ab	5.81 a	4.49 a
2021	5.02 b	5.49 b	4.81 b

Note: The number in the same column follow by the same small character are not significantly different statistically at 0.05 level.

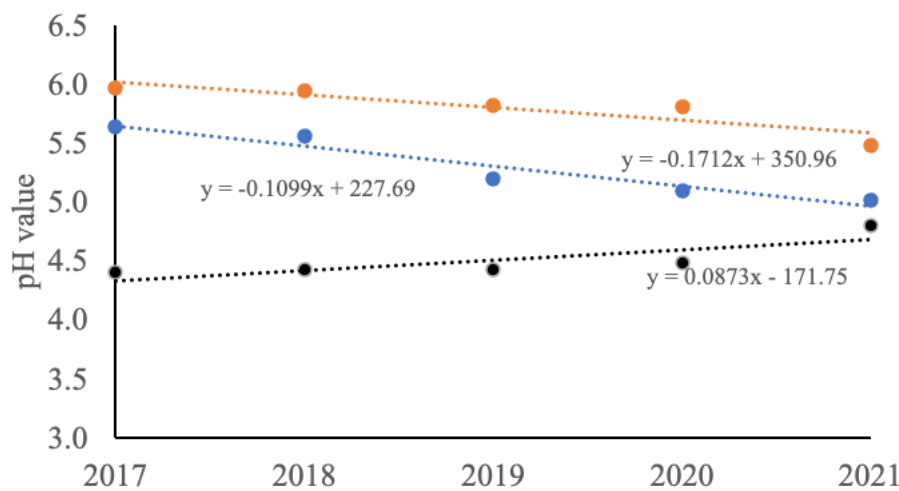


Figure 1. The changing pattern of soil pH from 2017 to 2021 on each study site.

● DM ● SS ● PS

1.1.2 Total carbon and nitrogen

The total carbon and nitrogen in soil reflected amount and quality of soil organic matter. In most mineral soils, the percentage of soil organic matter is small, but its effects on soil function are profound. This ever-changing soil component exerts a dominant influence on many soils physical, chemical, and biological properties and ecosystem functions of soils. Soil organic matter provides much of the soil’s cation exchange capacity (CEC) and water-holding capacity. Certain components of soil organic matter are largely responsible for the formation and stabilization of soil aggregates. Soil organic matter also contains large quantities of plant nutrients and acts as a slow-release nutrient storehouse, especially for nitrogen. On the contrary, organic matter is the main material of peat soil. Therefore, total carbon and nitrogen at PS site found much higher as compare with DM and SS sites (Figure 2).

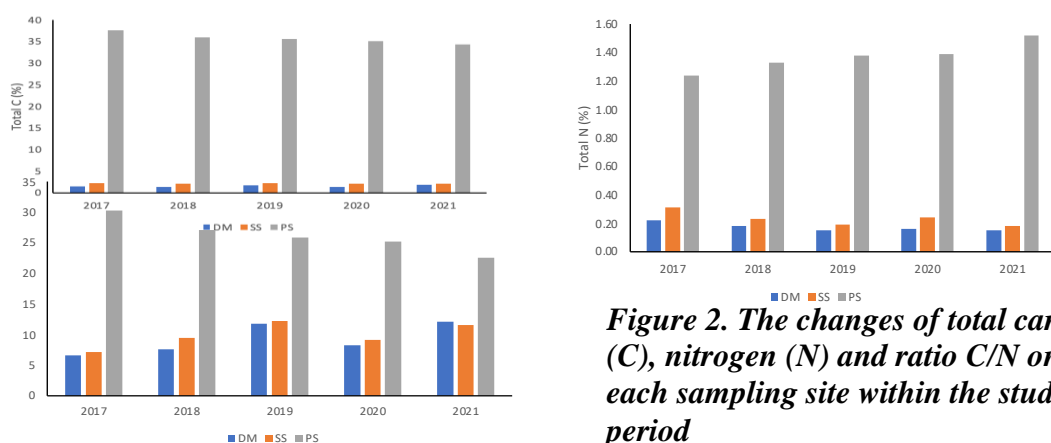


Figure 2. The changes of total carbon (C), nitrogen (N) and ratio C/N on each sampling site within the study period

Table 3. The change of total carbon (C), nitrogen (N) and ratio C/N of soil at DM, SS and PS site within the study period.

Sampling time	Total Carbon (%)			Total Nitrogen (%)			Ratio C/N		
	DM	SS	PS	DM	SS	PS	DM	SS	PS
2017	1.45 ^m	2.22 ^m	37.57 ^{vh}	0.22 ^m	0.31 ^m	1.24 ^{vh}	6.59	7.16	30.30
2018	1.37 ^m	2.17 ^m	36.01 ^{vh}	0.18 ^l	0.23 ^m	1.33 ^{vh}	7.61	9.43	27.08
2019	1.76 ^m	2.31 ^m	35.62 ^{vh}	0.15 ^l	0.19 ^l	1.38 ^{vh}	11.73	12.16	25.81
2020	1.32 ^m	2.18 ^m	35.05 ^{vh}	0.16 ^l	0.24 ^m	1.39 ^{vh}	8.25	9.08	25.22
2021	1.82 ^m	2.07 ^m	34.31 ^{vh}	0.15 ^l	0.18 ^l	1.52 ^{vh}	12.13	11.50	22.57

Note: l = low; m = medium; vh = very high

Data in Table 3 proved that the total carbon content both at DM and SS site were keep maintain within the study period, while the PS site found decrease gradually. Application of palm oil empty bunches as organic mulch at DM and SS sites could the reason for that condition, and on the other hand, rapid decomposition of organic matter at PS site was responsible for declining of total carbon at that site. The total nitrogen content was found fluctuated in all of study site. Frequent application of nitrogen as the additional source of N, and the N uptake by palm oil plant might be the cause of this condition. The gradual increase of total nitrogen at PS site resulted from double N sources such as nitrogen fertilizer application and the other source from decomposition of organic matter which the main material of peat soil.

Within the study period, the total carbon content at DM and SS seemed unchanged. Since the palm oil is perennial crop which doesn't need intensive soil tillage, it will protect soil organic matter from rapid decomposition rate. In addition, application of solid waste such as palm oil empty bunches also play important role to keep soil organic matter from deterioration. According to Brady and Weil (2017), there are several method we may use to keep soil organic matter contain in suitable level, such as continues supply of plant residues, reduce soil tillage intensity and planting perennial crop.

The effect of nitrogen fertilizer application shown more obvious at DM and SS sites, where the ratio of carbon to nitrogen falls below 8.0. According to Brady and Weil (2017), the average ratio C/N of organic matter in arable land is about 12:1, where at DM and SS the average value is just about 9.26 and 9.87, respectively. The average ratio C/N at PS site during the study period was 26.19 which much higher as compare with another sites. This value indicates that the peat soil in PS site mainly derive from hard wood with high in carbon content and relatively slow decomposition rate. Within the study period, ratio C/N of

DM and SS fluctuated and has no clear pattern as it influences by addition of organic mulch and application of nitrogen fertilizer. On the other hand, ratio C/N at PS site found decreased gradually from 2017 to 2021. This condition indicate that decomposition rate of organic matter had been running faster as the result of draining process which change the soil environment from reductive to oxidative condition. This process creates the loss of carbon to the atmosphere in form of CO₂, and lowering the ratio C/N at that study site.

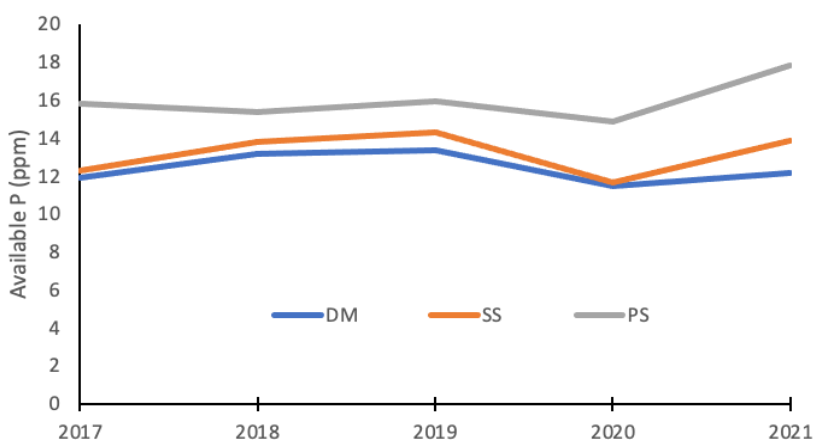
1.1.3 Available phosphorus

Of all the macronutrients found in soils, phosphorus has by far the smallest quantities in solution or in readily soluble forms in mineral soils. In addition, inorganic phosphorus in mineral soils is notoriously immobile. Two phenomena tend to control the concentration of phosphorus in the soil solution and the movement of phosphorus in soils: (1) the solubility of phosphorus-containing minerals, and (2) the adsorption or fixation of phosphate ions on the surface of soil particles. In practice, it is difficult to separate the influence of these two types of reactions or even determine the exact nature of inorganic phosphorus compounds present in a particular soil.

Phosphorous often become the limiting factor for plant growth and productivity because the total quantity of phosphorous in most native soils is low, with most of what is present in forms quite unavailable to plants. Low phosphorus availability in agricultural soils often leads to major social and environmental problems. Unproductive soils fail to produce adequate crops, forcing poor people to clear more land in order to produce enough food to survive. The cleared land supports little vegetative cover and so is subject to erosion that further degrades the soils and pollutes rivers and lakes with sediment laden runoff. Adequate phosphorus nutrition enhances the fundamental processes of photosynthesis, flowering, fruiting (including seed production), and maturation. Phosphorus is needed in especially large amounts for cell division and growth in meristematic tissues. Root growth, particularly development of lateral roots and fibrous rootlets, is encouraged by phosphorus.

Because of this, palm oil plantation used to add frequent phosphorous fertilizer to support plant growth and productivity. Application of this fertilizer at DM and SS study sites conducted every three months with the dose of 100 kg per hectare of triple superphosphate. To compensate some nutrient loss to the water body, PS site had been supplied with the higher dose phosphorous fertilizer as this study site frequently submerge, especially in the rainy season. Since P fertilizer use efficiency is low (10 – 15%), some amount of P will remind in soil, mostly in unavailable form. Some part of this residual P may change into available form through chemical and or biological processes.

Figure 3. The available phosphorous (P) content on each study site within the period of 2017 – 2021.



This study found that the available P content in DM and SS site were kept similar within the study period. That might be due to the balance between input of P through fertilizer application and the output via harvest. On the other side, the PS site was always having higher available P content and tend to increase gradually from 2017 to 2021. All of study sites experience the similar condition at 2020, where the available P content was decreased similarly. Some limitation applied during COVID-19 was affected the supply of fertilizer and created the impact of fertilizer shortage. Although the available P content of this sites was decrease at 2018 and 2019, but in general it tends to recover at the recent condition.

3.2.4 Cation Exchange Capacity

The cation exchange capacity (CEC) of soil refers to the total capacity of soil to hold, absorb and exchange cations. CEC represents the number of negative charges in soil existing on the surfaces of clay and organic matter. The ability of sediment to bind with cations often measured by CEC which could relate to migration of metals in soil (McLean and Bledsoe, 1992). Difference abilities for cation in exchanging cation process may be varied due to several factors such as pH, particle size and organic matter content in soil. Cation exchange capacity (CEC) is one of the most important concepts in soil fertility, and it is an important way to measure how many cations can be retained on soil particle surfaces (Brady and Weil, 2011).

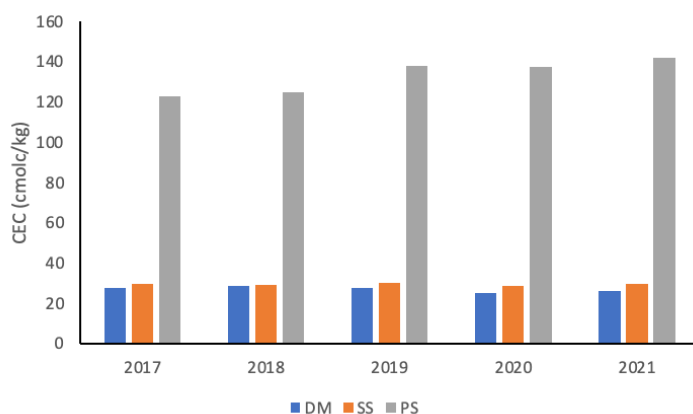


Figure 4. The fluctuation of CEC value on all of sampling sites clearly proved the effect of organic matter content on that parameter.

Cation exchange capacity (CEC) affect the structural stability, availability of nutrients, fertilizer, pH and related soil amelioration reaction (Whetton et al., 2017). In mineral soils, the value of CEC is dependent on type and amount of organic matter and type and amount of clay in soils. Also, dictates the total amount of negatively charged interchangeable sites on soil colloids and increase with the proportionally with soil pH, clay and organic matter. The estimated relative contribution of SOM to CEC varies depending on SOM amount, soil texture and mineralogy, pH, and other factors, but typical values are between 25% and 90% (Murphy, 2015; Oorts et al., 2003). On the other side, the CEC value in peat soil determine by the amount of organic matter and its decomposition rate. The highly decomposed peat soil tends to have more electric charge as compare with the fresh and medium decomposition ones. That may be due to the mature peat soil has more stable organic matter fraction than the younger one (Figure 4).

1.1.4 Exchangeable bases cations

Exchangeable base cations refer to the positively charged base ions which are loosely attached to the edge of clay particles or organic matter in the soil. The cations include Calcium (Ca), Magnesium (Mg), Potassium (K) and Sodium (Na). The amount of these cations in soils influenced by soil weathering process,

climate especially the amount of rainfall and land management practices (Wairiu and Lal, 2003). The highly weathered soil in tropical region tend to has lower base cations as compare with in tempered region, and on the other side, regular application of fertilizer and lime in form of calcite and dolomite will enhance the number of base cations in soil.

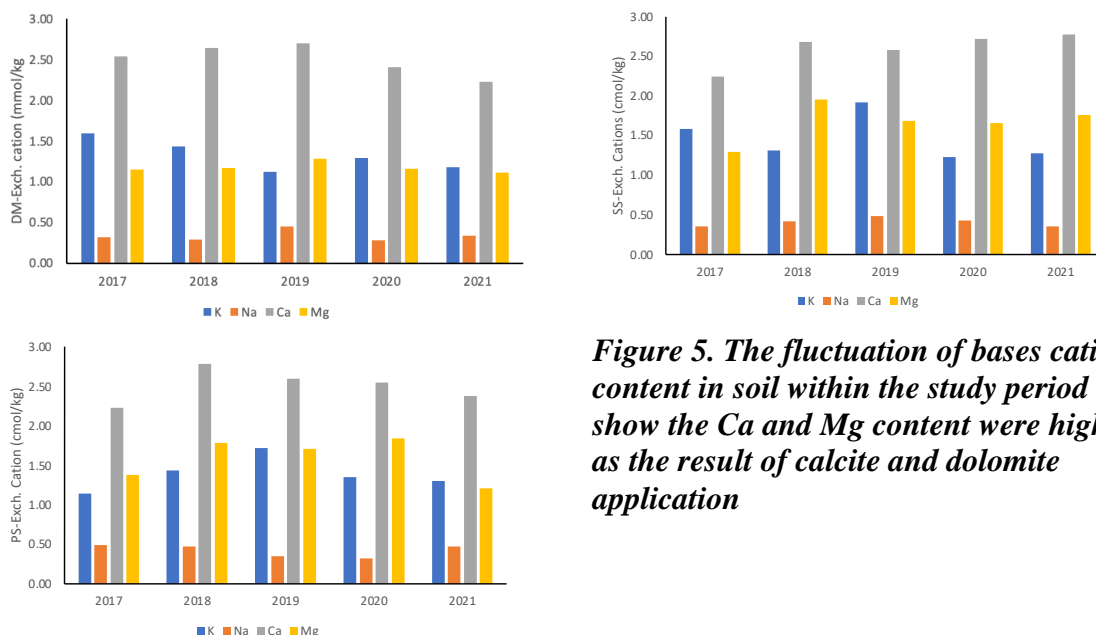


Figure 5. The fluctuation of bases cation content in soil within the study period show the Ca and Mg content were higher as the result of calcite and dolomite application

In order to keep soil quality and its fertility status, all of palm oil plantation in the study area have been applied chemical fertilizers and lime (calcite and or dolomite) as well. These kinds of management were found succeed to maintain soil productivity. Within the study period, the exchangeable bases cations content in soil found fluctuated in the range which suit the palm oil requirement. To protect soil acidification from long time nitrogen fertilizer application all of studied location ameliorate with lime material in form of calcite and dolomite. The frequent used of these materials resulted in high of exchangeable calcium (Ca) and magnesium (Mg) content in soil. Although the dose of lime applied at PS was much higher compared with DM and SS site, the residue of this materials detected in all of study site were found similar. This may be due to the dissimilarity of environmental condition within the study site. The DM and SS are consisting of mineral soils which located at higher elevation, that kept soil in dray condition. On the other side, PS consist of peat which located in lowland and often submerged by standing water. This condition might dilute some of lime materials and flown with drainage water. The exchangeable potassium (K) content in all study sites found slightly fluctuated as the effect of potassium chloride (KCl) fertilizer application and the rate of this nutrient uptake by plant.

1.1.5 Intercorrelation of soils parameters

All of soil parameters has correlation with each other. The level of this correlation influenced by natural and or anthropogenic factor such as soil type, environment and management practices applied. Although some parameters naturally have strong relationship, the human induce may create some modification on this affiliation (Darmawan et al., 2007). For example, under natural circumstance total carbon (C) has significant positive correlation with total nitrogen (N) (Brady and Weil, 2017). Nevertheless, under strong anthropogenic condition the relationship of those two soil parameters changed substantially (Table 4). Dissimilarities of land management and soil type also found created some discrepancy in correlation of soil parameters examined in this study.

Matrix correlation at DM sampling site show the soil pH value play important role on other soil properties, such as available P and exchangeable base cations, except for exchangeable K. this trend of relationship were reasonable as most of nutrient availability influenced by the increasing of pH value. Available P content in soil has strong correlation with exchangeable base cations (Ca, Mg and Na) and CEC value as well. The improvement of soil reaction could be the reason for relationship pattern of those soil parameters. The unusual relationship occurred for total N and total C which show weak negative relation. Addition of N as nitrogen fertilizer could be the reason for such kind strange phenomena as total C has antagonist effect on total N. Application of lime materials as calcite and dolomite also influenced the relation pattern of those parameters. The exchangeable Ca and Mg show strong positive correlation in this site. The exchangeable K value found has strong negative correlation with total C content and negatively correlated with total N in soil. This data indicated that some of exchangeable K may release from organic matter mineralization process in soil. Generally, the matrix correlation pattern of soil parameters in this study site was close with natural condition of soil. This might be due to proper land management practices which suit the plant need and environment as well.

The similar soil parameters correlation at DM also found at SS site, where the soil pH value has strong correlation with almost all parameters examined in this study, except for the total N content and CEC in soil. This kind of correlation indicate that improving of soil pH will affect several factors in soil. Since all of nutrient in soil available at nearly neutral pH value, increasing of soil pH has strong relationship with exchangeable base cations (Ca, Mg, K and Na) and also available P content in soil. Furthermore, the total C content has strong correlation with available P, and exchangeable potassium and sodium. It might be because some of P, K and Na in soil at SS site derived from decomposition (mineralization) of organic matter.

Total N content in soil has negative effect on available P and exchangeable Ca and Mg. This kind of relationship proved that long-term addition of N in form of chemical fertilizer (Urea), has cause acidification which decreased the soil pH and affect the availability of those nutrient. And since the phosphorous and potassium had been added into the soil frequently, both of them show strong positive relationship each other. The trend of soil parameter relationship at DM and SS sampling sites found similar as both of them heavily weathered mineral soils.

The uncommon relation among soil parameters found at PS site which is categorize as peat soil. At this site, soil pH value has negative strong relation with total C, exchangeable Mg and C/N ratio. The lost of carbon during the decomposition also release some organic acid which washed out from soil triggering the improvement of soil pH. Although this peculiar site had been amended with lime to protect the drop of soil pH, the correlation of pH and exchangeable base cations show unaffected by those activities. Most of exchangeable base cation seemed reversely corelated with the soil pH, especially magnesium. That may be due to the type of lime material added to the soil mostly calcite (CaCO_3) and that material did not retain in the soil profile as they were splashed out from soil profile.

	pH	C	N	C/N	Avai.P	CEC	Exch. K	Exch. Na	Exch. Ca	Exch. Mg
pH	1									
C	-0.06083	1								
N	-0.01500	-0.51676	1							
C/N	-0.03283	0.90389	-0.83285	1						
Avai.P	0.66971	0.34260	-0.21780	0.31569	1					
CEC	0.52954	0.02814	0.44542	-0.21812	0.77130	1				
Exch. K	-0.11210	-0.68106	0.96354	-0.92308	-0.27558	0.37030	1			
Exch. Na	0.57855	0.76232	-0.38116	0.68539	0.59435	0.28416	-0.59838	1		
Exch. Ca	0.93787	-0.22623	0.25451	-0.27876	0.69868	0.74239	0.18541	0.38360	1	
Exch. Mg	0.95225	0.19359	-0.25902	0.25568	0.66645	0.37526	-0.38698	0.76280	0.79851	1

	pH	C	N	C/N	Avai.P	CEC	Exch. K	Exch. Na	Exch. Ca	Exch. Mg
pH	1									
C	0.81477	1								
N	0.31653	0.26241	1							
C/N	-0.63389	0.01801	-0.9643	1						
Avai.P	0.82965	0.96451	-0.7044	0.76592	1					
CEC	-0.26573	0.09504	-0.2501	0.42261	0.24915	1				
Exch. K	0.57172	0.85020	-0.0268	0.28539	0.80994	0.24384	1			
Exch. Na	0.69279	0.95512	0.4569	0.45692	0.27278	0.34931	0.78500	1		
Exch. Ca	0.87062	-0.09544	-0.8089	0.63460	0.02886	0.87806	-0.12284	0.19976	1	
Exch. Mg	0.74427	0.23206	-0.7153	0.56356	0.23857	-0.09938	-0.29774	0.32733	0.26608	1

	pH	C	N	C/N	Avai.P	CEC	Exch. K	Exch. Na	Exch. Ca	Exch. Mg
pH	1									
C	-0.74963	1								
N	0.88099	-0.96174	1							
C/N	-0.80607	0.99133	-0.98799	1						
Avai.P	0.84643	-0.41827	0.64938	-0.52900	1					
CEC	0.67827	-0.89055	0.89447	-0.90420	0.454302	1				
Exch. K	-0.09373	0.11251	-0.22393	0.19655	-0.463659	-0.155306	1			
Exch. Na	0.03571	0.55844	-0.34332	0.46444	0.450375	-0.581744	-0.33150	1		
Exch. Ca	-0.27714	-0.28454	0.09056	-0.21545	-0.425923	0.008874	-0.28423	-0.42330	1	
Exch. Mg	-0.70587	0.24864	-0.39625	0.29279	-0.579125	-0.354575	-0.42387	-0.13560	0.811555	1

Table 4. Matrix correlation among soil parameters on each study site (DM = above; SS = middle and PS = lower). The bold number indicated those parameters significantly correlated each other (P<0.05).

4. CONCLUSION

The long-term palm oil plantation management had caused some advantages and disadvantages on soil and environmental as well. Frequent application of chemical fertilizers and lime successfully protect soil from the worse acidification and kept soil pH with similar value within the study period, both in mineral and peat soils. However, the declining of soil organic matter content could be create some serious problem

on soil physical, chemical and biological in the future in all of study sites. At mineral soils (DM and SS), deteriorating of soil organic matter will enhance soil compaction and decrease soil water permeability which lead to elevating run off and erosion. At the same time, this condition will decrease capability of plant to absorb the nutrients as plant root growth abnormally. This condition may also lead to water pollution from the leak of nutrient from oil palm plantation into the waterbody. On the other site, the excess drained of PS which consist of peat had accelerate organic matter decomposition rate which increase the carbon loss to the atmosphere. Application of chemical fertilizer and lime materials at this site, seemed has no significant effect on soil pH and also nutrient availability. Since peat soil has sponges like structure, some of chemical's fertilizer and lime applied to the soil washed away from the soil profile into the water canal nearby. At the certain condition, this process may create eutrophication which harmful for the water biota. In order to mitigate the demerit effect of oil palm plantation, artificial addition of organic matter is needed at DM and SS site, while at PS the alternate drainage system is require for sustainable soil management.

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