Monitoring of pH Level for Maximising Oil Palm FFB Yields

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Abstract.

Depending on the location of estates and types of soils, monitoring of pH changes is an integral part of soil-water management for realizing a sustainable Fresh Fruit Bunches (FFB) yields. In Sumber Tani Agung Resources Tbk, fluctuations in pH level in field blocks as well as nearby drains were monitored since 2019. Monitoring of pH was done on two types of soils namely peat (three estates in North Sumatra) and acid sulfate soils (two estates in South Sumatra). Piezometer was established in each block in all five estates and pH readings was taken biweekly, including at nearby watergates for comparison. Due to presence of pyritic layers, pH values in estates with acid sulfate soils were lower than those of planted on peat. Keeping water level at 40-70 cm on peat and at 45-60 cm for acid sulfate soils would have an impact on the improvement of soil physical chemistry and biology properties, besides creating aerobic conditions for roots of the cultivated oil palms. Organic fertiliser such as bunch ash was applied in 2020-2021 period which also resulted in an increment in pH values. Generally, there were improvements in oil palm growth as well as palm yield performance.

Keywords: acid sulfate soils, fresh fruit bunches, organic fertiliser, peat

1. Introduction

Generally, measurement of pH is used to describe the quality of water especially in terms of chemical reaction between acidity and alkalinity. The term pH is based on logarithmic transformation of the hydrogen ion concentration, $[H^+]$. The conditions of acidic to very acidic pH would greatly affect the growth of oil palm plants, especially the root growth. Generally, plant roots are unable to absorb water that carries nutrient molecules simultaneously in acidic areas. According to [1], states that an acidic to very acidic pH makes the roots thick, thick roots make the roots not long and the root hairs will shorten, this will cause the absorption of nutrients and water will be less so that it makes plants become deficient, causing the growth and development factors of oil palm to be threatened [2] in [1] added that peat and sulphate soils are acid with high active Al and Fe content. High Al and Fe content can be toxic to oil palm plants [3]. Optimal soil acidity (pH) to support the growth of oil palm is at 5.0-6.0 [4].

1.1 Averaging of pH Values

Historically many authors calculate average pH values directly. However, averaging of pH values should be initiated by translating pH values into ion Hydrogen concentration $[H^+]$. Generally, pH measurements are made for various purposes in almost every field of biology and chemistry. There is a confusion regarding the proper method of describing pH especially in fields as wide-ranging as anesthesiology [5].

Usually, scientists often wish to summarize and describe pH data with a simple measure of central tendency, such as the average. However, pH data are in Negative $\log_{10}$ which is a transformation of concentration $[H^+]$. Averaging of pH values directly would be an error[6]. For an instance, average pH value for pH=6 and pH=1 is pH =3.5. However, when the same pH values translated into concentration $[H^+]$, then averaging of pH 1= $10^{-1} mol\ [H^+]\ /l$ & pH 6= $10^{-6} mol[H^+]\ /l$ would yield a reading of $5 \times 10^{-2}\ mol[H^+]/l$ or pH = 1.3. As such, pH 1.3 is far different from pH 3.5. It has been extensively argued that pH values cannot be directly averaged but rather must be back-transformed to [H+] and then averaged. The average [H+] may then be re-transformed to average pH if desired [6]. As such, there are two approaches when pH values are being averaged for an interpretation of experiments.

Nevertheless, in this study all pH values were transformed into concentration $[H^+]$ and then after averaging, retransformed into pH values. It seems that there would be a mathematically a huge difference in pH values if pH range is big. However, if pH range is small, the pH readings in both approaches are nearly similar, resulting in mathematically less meaningful.

1.2 Influences and Changes of pH values

Soil acidification can occur under oil palm plantation [7] [8]. The soil pH changes very slowly and there are no visible symptoms of soil acidification other than declines in crop production which may be dramatic in serious cases [8][9]. In a study on the characteristics of commonly used eight soil types for oil palm in Southeast Asia, [9] revealed that these soils have a pH less than 5.0 on the topsoil (0 – 30 cm). [9] also showed that these soils have low to very low contents of nitrogen (N), available phosphorus (P) and exchangeable potassium (K) in six out of eight soil types. Therefore, availability of soil nutrients especially N, P & K become less as soils become more acidic.

However, K uptake by oil palm did not seem to be influenced by low pH levels as reported by [10]. In a study by [10], revealed that fertilizer application with acidifying fertilizers such as ammonium sulphate had increased the soil acidity. [10] also reported a decrease in soil pH values from 4.2 to 3.8 after seven years of NK fertilizer applications. [11] highlighted in their paper that ammonium-based nitrogen fertilizers in excess rates, leaching of nitrate nitrogen and continual removal of plant & animal waste products could accelerate the change of pH. Many researchers highlighted that oil palm can tolerate well to low pH values in the range of 4 and 5 for commercial oil palm production especially in Southeast Asia [3] [7] [8] [12]. [13] reported that (i) experiments carried out in four sites in Indonesia have shown that high yields are possible on soils with low pH and (ii) best management practices can increase pH. [3] also reported that a high FFB yields above 35 tonnes per ha per year is possible on acid sulfate soils with proper nutrient inputs as well as good water management.

1.3 Influences of pH Values on Oil Palm FFB Yields

There are many references published by various researchers on the FFB production in oil palm grown in acidic environments particularly on acid sulfate and peat soils [7] [12] [15] [17] [18] [19] [21]. A summary on FFB yields obtained on acid sulfate and peat soils are listed in **Table 1**. Maximum yields recorded for acid sulfate soils were generally higher as compared to those obtained generally on peat (**Table 1**). This is due to more compounded factors involved for oil palm cultivation on peat such as low bulk density, palm leaning and termite attacks [12]. Agronomic and management practices such as minimising leaching of nutrients, especially K fertilizers, maintaining water level at 50 to 75 cm from peat surface, detecting and treating termite are among the key aspects to achieve high yield in peat planting [3] [12] [17]. As such, besides pH values, there are many factors that determine high FFB production in oil palm.

Table 1: A summary on FFB yields on Acid Sulfate and Peat soils recorded and published by various researchers in oil palm industry

Soil Type/Series	Maximum FFB Yield (mt/ha/year)	Year of harvesting at	Sources and Remarks
Acid Sulfate soils Jawa	33.57	10th	-High yield by controlling water table at 45 -60 cm below soil surface [3]. Acidic due to presence of pyritic layers [14]. [15] found that liming was ineffective to control acidity in acid sulfate soils.
Linau	32.11	11th	
Jawa/Sedu/Tongkang	31.29	10th	
Sedu/Briah	38.53	7th	
Peat (Peninsular) Shallow (< 1m)	23.7	10th	-Water management and micronutrient inputs are key factors for maximising yields [16].
Moderate (1-2m)	20.2	9th	
Deep (> 2m)	17.3	4th	
Deep	17.1	3rd	- [17][18]
Peat (Sarawak) Peat	32.21	6th	- [19]
Anderson (>2m)	19.63	10th	-[20]
Moderate Peat (1-2m)	29.03	7th	- [21]
Shallow-Deep (>0.5m)	21.35	10th	-Commercial scale data; no liming was carried out [12] .

On acid sulfate soils, Al toxicity and excess sulfates are the major constraints to FFB production in oil palm [3] [22]. By maintaining water-table at 45 to 60 cm, accelerated pyrite-oxidation was avoided to obtain maximum oil palm yields [3] [15] [18]. [13] highlighted that in one of the treatments, bunch ash application had an ameliorative effect on pH as compared to treatment of ammonium sulfate fertilizer application. However, [13] had advocated to replace bunch ash with Empty Fruit Bunches (EFB). Long term application of EFB in oil palm fields had increased soil pH as well as oil palm FFB yields [23] [24]. Application of EFB over time generally had improved soil moisture, soil structure, nutrients availability especially N, P, K & Mg as well as pH values [24] [25]. This overall improvement had contributed in better FFB production in oil palm.

Although numerous information on the improvement of FFB production due to increase on soil pH available, there is still a lack of references on the improvement of pH values at commercial scale study. Analytical results on pH changes in soil and water are confined to green house, pot experiments or small-scale on-site trial plots. Therefore, an attempt was made to monitor water pH levels in commercial scale in five selected estates in Sumber Tani Agung Resources Tbk, Indonesia. This paper summaries the results of pH recorded mainly at piezometer as well as in watergates. A simple correlation analysis was also conducted to estimate the relationship between the recording of pH values and the FFB yield production in the respective field/block.

2. Materials and Methods

2.1 Details on Study Areas

Details on the location of estates as well as number of piezometers on estate basis are given in **Table 2**. This study was carried out in five estates in Sumber Tani Agung Resources Tbk (STAR). Studies on changes of pH values in the oil palm grown areas especially on peat soils (number 1,2 &3 in **Table 2**) and acid sulfate soils (number 4 & 5 in **Table 2**) were monitored for three-year period 2020-2022.

Table 2: Details on Estates where the study on pH values were carried out during 2020-2022

No	Location of estates under study	Coordinates	District	Ha	Number of Piezometer	Land to Piezometer	Soil type
1	Batu Mundom Estate, PT Dipta Agro Lestari, North Sumatra, Indonesia	Latitude 1°17'06"N Longitude 98°52'44"E,	Batu Mundom	686.82	29	24	Peat (Tropohemists/ Troposaprists/ Tropofibrists)
2	Sikapas Estate, PT Madina Agro Lestari, North Sumatra, Indonesia	Latitude 2°20'40.4"N Longitude 100°16'25.4"E,	Sikapas	5212.85	208	25	Peat (Tropohemists/ Troposaprists/ Tropofibrists)
3	Selat Beting Estate, PT Paten Alam Lestari, North Sumatra, Indonesia	Latitude 2°20'40.4"N Longitude 100°16'25.4"E	Selat Beting	1719.91	67	26	Peat (Troposaprists/ Tropofibrists)
4	Kuala Puntian Estate, PT Sumatera Candi Kencana, Palembang, South Sumatra, Indonesia	Latitude 2°33'59"S Longitude 104°39'51"E	Kuala Puntian	2972.45	83	36	Acid Sulfate (Hydraquents/ Fluvaquents/ Tropaquepts)
5	Upang Jaya Estate, PT Transpacific Agro Industry, Palembang, South Sumatra, Indonesia	Latitude 2°48'26"S Longitude 104°53'10"E	Upang Jaya	3859.57	146	26	Acid Sulfate (Sulfaquents/ Tropaquepts/ Hydraquents)

In this study, pH values were also recorded at two different locations, (i) piezometer and (ii) watergates. The watergates are located nearby to piezometer, approximately at 100-140 meters away from piezometer in each block. Efforts are taken to ensure the readings of pH values from piezometer as well as from watergates averaged in accordance with the concept of averaging of $[H^+]$ in the mixtures/solutions. Water level was kept at 40-70 cm on peat and at 45-60 cm for acid sulfate soils throughout the monitoring period as water level has an impact on the improvement of soil physical chemistry and biology properties, besides creating aerobic conditions for roots of the cultivated oil palms.

Generally, ratios of land to piezometer were within the range of 24 to 26 ha per piezometer in all estates except for Kuala Puntian Estate (number 4 in **Table 2**) where higher ratio of 36 was recorded. Basically, Kuala Puntian Estate was converted from ex-coconut plantation into the current oil palm plantation. Therefore, the slightly high ratio of land to piezometer in Kuala Puntian Estate was attributed to bigger block sizes of ex-coconut plantations era. The same block sizes of ex-coconut were adopted as field blocks for cultivation of oil palms in Kuala Puntian Estate.

The main soil types in peat areas as in number 1, 2 & 3 in **Table 2** are basically Tropohemists/Troposaprists/Tropofibrists, Meanwhile the dominant soil types in Kuala Puntian and Upang Jaya estates are mainly acid sulfate soils with the family of Sulfaquents,Tropaquepts and Hydraquents. One of the dominant soil series is Jawa series. This type of soil is a fine, mixed, isohyperthermic and brown family of Sulfic Tropaquept with poorly drained, have brown colored B horizons and a sulfuric horizon between 50 to 100 cm depth [22].

2.2 Observation of pH Values in Piezometer

For this study, pH value from each piezometer was recorded on bi-weekly basis (once in two weeks). A battery-powered Hanna Instruments portable unit was used for reading pH. All pH measurement was taken from the water samples collected at the piezometer in the field (**Figure** 2).

(a) (b) (c)

Figure 2: Materials used for pH measurement (a) Battery-powered Hanna Instruments unit for reading pH/EC/TDS, (b) samples of at the piezometer in the field and (c) recording of pH values with Hanna Instruments

Commercial recording FFB production on block basis was used to compare pH values registered for each block thoroughout three-year period (2020-2022). Data were collected from all five estates as in **Table 2** and analysed for correlation study to detect any relationship between pH values and FFB yield production.

Table 3: Monthly summary on blocks with five highest and five lowest readings of pH values in 2022 for Batu Mundom Estate. Frequency of occurrence is listed at four columns at far right

Estate : Batu Mundom
Piezometer : Top 5 High and Low pH at Piezometer
Monthly Summary -2022

JAN	FEB	MAR	APR	MAY	JUN	JUL	AGU	SEP	OCT	NOV	DEC				
Block	Block	Block	Block	Block	Block	Block	Block	Block	Block	Block	Block	Block	Frequency from 12 months	Block	Frequency from 12 months
High pH															
01M11C09	01M11C06	01M14G05	01M11E06	01M11C09	01M14G07	01M11C06	01M11E06	01M11E06	01M11C06	01M11D06	01M14G05	01M11C09	2	01M13F07	8
01M11C06	01M13F07	01M11D06	01M13F07	01M14G05	01M13F07	01M14G07	01M14G05	01M11D06	01M13F07	01M13F07	01M13F07	01M11C06	7	01M14G05	7
01M14G07	01M11E06	01M13F07	01M14G05	01M13F07	01M11C06	01M14G05	01M14G07	01M11C09	01M11D06	01M11E06	01M11E08	01M14G07	8	01M11D06	5
01M14G06	01M14G05	01M14G06	01M11D06	01M14G06	01M11C09	01M11E06	01M14G06	01M11C06	01M11C09	01M11C09	01M11C06	01M14G06	5	01M11E08	2
01M11E06	01M14G07	01M14G07	01M14G07	01M14G07	01M11E08	01M11C09	01M11C09	01M14G06	01M11E06	01M11E07	01M11E06	01M11E06	2	01M11E07	1
Low pH															
01M11D06	01M14G06	01M11E06	01M14G07	01M11E06	01M11E07	01M13F07	01M11C06	01M13F07	01M11E07	01M11E08	01M14G06	01M11D06	7	01M14G06	7
01M14G05	01M11C09	01M11C09	01M14G06	01M11D06	01M11D06	01M14G06	01M11D06	01M14G05	01M11E08	01M11C06	01M11D06	01M14G05	5	01M11C09	4
01M11E07	01M11D06	01M11E08	01M11E07	01M11E07	01M11E06	01M11E07	01M11E07	01M11E07	01M14G07	01M14G07	01M11E07	01M11E07	11	01M11C06	5
01M11E08	01M11E07	01M11E07	01M11C06	01M11C06	01M14G06	01M11D06	01M11E08	01M11E08	01M14G05	01M14G05	01M14G07	01M11E08	9	01M11E06	3
01M13F07	01M11E08	01M11C06	01M11C09	01M11E08	01M14G05	01M11E08	01M13F07	01M14G07	01M14G06	01M14G06	01M11C09	01M13F07	3		

pH studies involving various types of soils were mostly made with green house, pot experiments or small-scale on-site trial plots. However in this study, commercial oil palm blocks are involved and total land hectarages from five estates are of above 14,451.6 ha as shown in **Table 2**. As such a method was adopted by taking readings of high pH values, based on the observations for three years i.e., from 2020 to 2022. pH value for each block is recorded and monitored bi-weekly by estate personnel in each study site.

After observing blocks with highest pH values, a frequency of occurance of same block throughout the 12 months is calculated and colour-coded for easy identification of blocks. Five field-blocks that have high frequency of highest pH values throughout 12 months (for instance for Batu Mundom Estate in 2022) were identified. Then these high-ranking blocks were selected for correlating with respective block FFB yield recording. The same procedure was repeated for blocks with lowest pH values for the period 2021-2022. An example of selection of blocks with high and low pH values is shown in **Table 3**.

There are two calculation methods used in the experiments that involves readings of pH. At first pH values of mixtures are transformed into concentration of $[H^+]$ in the mixtures/solutions. According to [6] the concept of calculating the pH leads to the common conclusion that pH data cannot be averaged directly but rather must be transformed to $[H^+]$ before the mean is calculated and then retransformed to obtain the average pH. The same method was used in this study whenever average pH values are calculated from population pool. This means all average pH values are based on calculating the amount of H^+ in each solution rather than calculation based on direct averaging of pH values. In fact, [5] reported that $[H^+]$ averaging (rather than pH averaging) was the best measure of central tendency by making solutions of various pH values with either HCl or NaOH, mixing the solutions,and comparing the calculated pH with the actual pH measurement.

3 Results and Discussion

Results of pH values recorded with Hanna Instruments for the period of 2020-2022 are given in **Table 4.** In this study, pH values were recorded at two different locations, (i) piezometer and (ii) watergates which are located nearby to piezometer, approximately 100-140 meters away from piezometer. For the 2020-2022 period, lower pH values ranging from 3.5 to 3.7 were observed at piezometer and water gates on blocks established on acid sulfate soils (**Table 4**). Meanwhile on peat soil, pH values ranging from 4.3 to 5.6 were registered at piezometer and water gates. Lower pH values on acid sulfate soils are attributed to the presence of the pyrite layer. This pyrite layer can generate excessive acidity, resulting in a pH drops to below 3.5 [3] [14] [15]. Palms will suffer from hyperacidity symptoms. This would result in a poor yield, if oil palm continuously grown on acidity conditions [3] [15]. At Batu Mundom, Sikapas and Selat Beting estates, water pH values at piezometer were generally lower than those recorded for watergates. However, there was no distinct changes or trend seen for blocks/estates established on acid sulfate soils, probably attributed to (i) presence of pyritic layers within water-controlled horizons and (ii) smooth & continuous removal of H-ion rich-water by practicing a good water management [15] [18].

Table 4: Summary on changes in water pH values at piezometer & watergates on peat and acid sulfate areas in 2020,2021 & 2022

Estate	**Soil type**	**Piezometer**			**Average**	**Watergate**			**Average**
		2020	**2021**	**2022**		**2020**	**2021**	**2022**	
Batu Mundom	Peat	5.5	5.4	5.5	**5.5**	5.7	5.6	5.6	**5.6**
Sikapas	Peat	4.7	4.7	5.0	**4.8**	5.0	4.9	5.0	**5.0**
Selat Beting	Peat	4.2	4.3	4.3	**4.3**	4.3	4.3	4.2	**4.3**
Kuala Puntian	Acid sulfate soils	3.2	3.5	3.5	**3.4**	3.1	3.6	3.7	**3.5**
Upang Jaya	Acid sulfate soils	3.5	4.1	3.5	**3.7**	3.2	4.4	3.4	**3.7**

3.1 Results of pH Values in Piezometer

Results of a simple correlation analysis to estimate the relationship between the recorded water pH levels and the FFB production for peat and acid sulfate soils are shown in **Table 5** and **6** respectively.

Table 5: Linear relationship of pH values at piezometer versus oil palm FFB yields on peat areas (2020-2022)

Estate	**Year**	**n**	**y**	**R²**
Batu Mundom	2020	10	y = 36.825x - 181.52	0.6392
	2021	10	y = 24.304x - 108.14	0.7487
	2022	24	y = 23.898x - 109.66	0.4141
	(2020-2022)	44	y = 24.264x - 110.82	0.4519
Sikapas	2020	34	y = 31.477x - 129.8	0.6072
	2021	34	y = 11.806x - 35.662	0.5119
	2022	34	y = 8.4861x - 20.982	0.2074
	(2020-2022)	102	y = 10.732x - 30.815	0.2947
Selat Beting	2020	9	y = -8.8022x + 58.263	0.1795
	2021	9	y = 1.7904x + 19.419	0.2507
	2022	9	y = 3.0799x + 8.6334	0.2546
	(2020-2022)	27	y = 0.1556x + 22.71	0.0002

Outlier values were eliminated after a careful study over the linear correlation relationship. A total of 44, 102, 27, 45 and 90 recordings of pH values were used for obtaining coefficient of determination (R^2) for Batu Mundom, Sikapas, Selat Beting, Kuala Puntian and Upang Jaya estates respectively. Based on the results, it is observed that high correlation between pH values and FFB yield recordings was at Batu Mundom Estate in 2021 with R^2 value at 0.7487. Satisfactory R^2 values (> 0.5) were obtained in nine set of data out of fifteen, representing 60% from total set of recordings.

The value of coefficient of determination (R^2) was obtained after a simple linear correlation study involving all recorded pH values against the respective FFB production records. R^2 values ranging from 0.0002 to 0.7487 and 0.0235 to 0.7286 were recorded for estates established on peat and acid sulfate soils respectively. Generally , the value of coefficient of determination (R^2) in 2022 for blocks established on peat soils was lower than those registered in the years of 2020 and 2021. Lowest R^2 value was recorded in Selat Beting Estate for pH values versus cumulative FFB yields over three years i.e. from 2020 to 2022. This shows that there is other than pH values which has significant influence on the FFB yields of cumulative years. This also suggesting that there are other contributing factors for FFB yields such as palm age, harvesting interval, water management and balanced nutrient inputs. Contribution of such agronomic practices have significant influences on the FFB productions as stated by various researchers [7] [8] [10] [16] [18] [27].

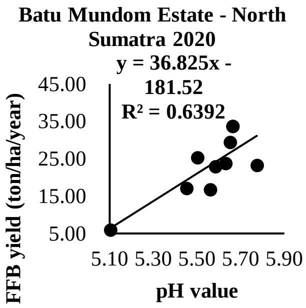
Table 6: Linear relationship of pH values at piezometer versus oil palm FFB yields on acid sulfate soils, (2020-2022)

Estate	Year	n	y	R^2
Kuala Puntian	2020	15	y = 2.1165x + 9.0357	0.0235
	2021	15	y = 6.0749x + 3.4116	0.6111
	2022	15	y = 15.809x - 38.596	0.6187
	(2020-2022)	45	y = 9.6679x - 13.534	0.3390
Upang Jaya	2020	30	y = 10.331x - 12.485	0.5480
	2021	30	y = 8.9421x - 10.832	0.7060
	2022	30	y = 8.6557x - 6.5016	0.7286
	(2020-2022)	90	y = 7.4848x - 3.1508	0.5502

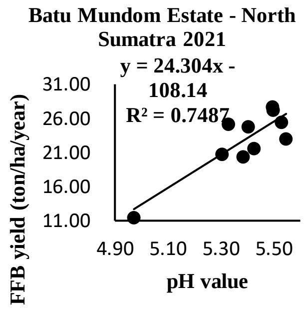
In Kuala Puntian and Upang Jaya estates, the value of coefficient of determination (R^2) in 2020 was relatively lower as compared to those readings from 2021-2022. One of the agronomic practices that have high influence on the changes in soil pH values is application of bunch ash. Application of bunch ash in 2021 in Kuala Puntian and Upang Jaya might have contributed towards an increase in pH values. This corelate well with the findings of [13] where application of bunch ash had increased soil pH compared to application of ammonium sulfate fertilizer. In this study, bunch ash was applied at the rate of 1.75 kg/palm up to 2.5 kg/palm in all estates. As such, application of bunch ash in the fields *might* had contributed towards the pH increment in the water/piezometer. This needs further verification.

3.2 Graphs of Linear Relationship

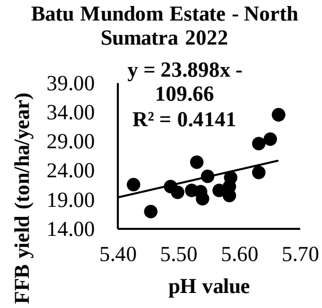
Linear relationship of oil palm FFB yield production versus water pH values of piezometer for 2020,2021 & 2022 are illustrated in **Figure 3**. In 2020, a negative linear relationship was observed for Selat Beting Estate (**Figure 3- (i)**). Eventually, this negative linear relationship also had an influence on the cumulative results of pH values versus FFB productions in the period 2020-2022 (**Figure 3- (l)**). Further monitoring will be carried out to witness the changes in the coming years.


Batu Mundom Estate - North Sumatra 2020
y = 36.825x - 181.52
R² = 0.6392
45.00
35.00
25.00
15.00
5.00
5.10 5.30 5.50 5.70 5.90
FFB yield (ton/ha/year)
pH value

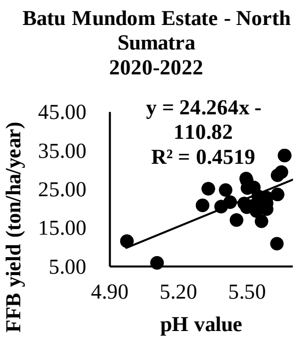
(a)


Batu Mundom Estate - North Sumatra 2021
y = 24.304x - 108.14
R² = 0.7487
31.00
26.00
21.00
16.00
11.00
4.90 5.10 5.30 5.50
FFB yield (ton/ha/year)
pH value

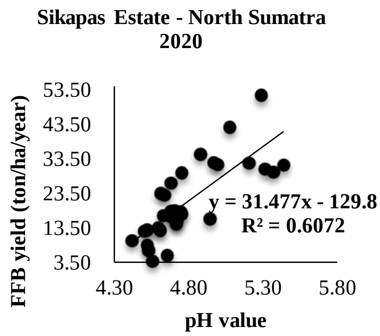
(b)


Batu Mundom Estate - North Sumatra 2022
y = 23.898x - 109.66
R² = 0.4141
39.00
34.00
29.00
24.00
19.00
14.00
5.40 5.50 5.60 5.70
FFB yield (ton/ha/year)
pH value

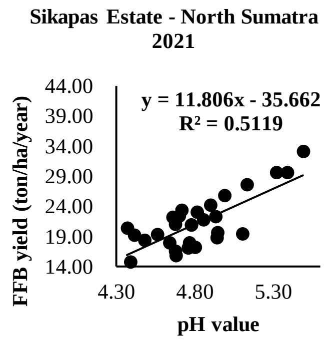
(c)


Batu Mundom Estate - North Sumatra 2020-2022
y = 24.264x - 110.82
R² = 0.4519
45.00
35.00
25.00
15.00
5.00
4.90 5.20 5.50
FFB yield (ton/ha/year)
pH value

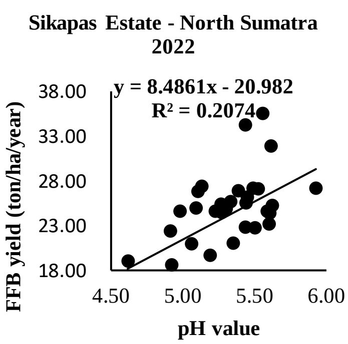
(d)


Sikapas Estate - North Sumatra 2020
y = 31.477x - 129.8
R² = 0.6072
53.50
43.50
33.50
23.50
13.50
3.50
4.30 4.80 5.30 5.80
FFB yield (ton/ha/year)
pH value

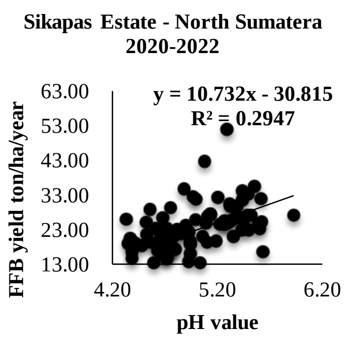
(e)


Sikapas Estate - North Sumatra 2021
y = 11.806x - 35.662
R² = 0.5119
44.00
39.00
34.00
29.00
24.00
19.00
14.00
4.30 4.80 5.30
FFB yield (ton/ha/year)
pH value

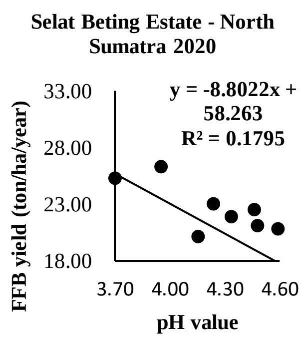
(f)


Sikapas Estate - North Sumatra 2022
y = 8.4861x - 20.982
R² = 0.2074
38.00
33.00
28.00
23.00
18.00
4.50 5.00 5.50 6.00
FFB yield (ton/ha/year)
pH value

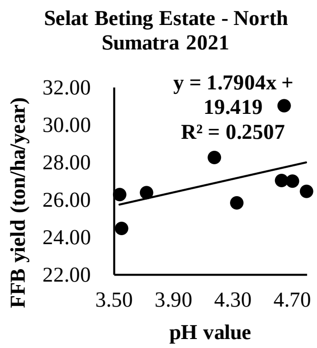
(g)


Sikapas Estate - North Sumatera 2020-2022
y = 10.732x - 30.815
R² = 0.2947
63.00
53.00
43.00
33.00
23.00
13.00
4.20 5.20 6.20
FFB yield ton/ha/year
pH value

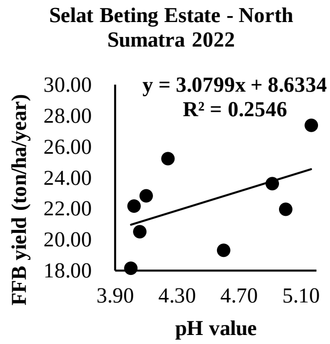
(h)


Selat Beting Estate - North Sumatra 2020
y = -8.8022x + 58.263
R² = 0.1795
33.00
28.00
23.00
18.00
3.70 4.00 4.30 4.60
FFB yield (ton/ha/year)
pH value

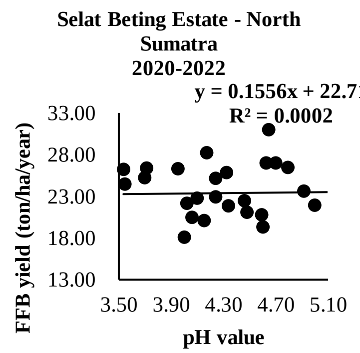
(i)


Selat Beting Estate - North Sumatra 2021
y = 1.7904x + 19.419
R² = 0.2507
32.00
30.00
28.00
26.00
24.00
22.00
3.50
3.90
4.30
4.70
FFB yield (ton/ha/year)
pH value

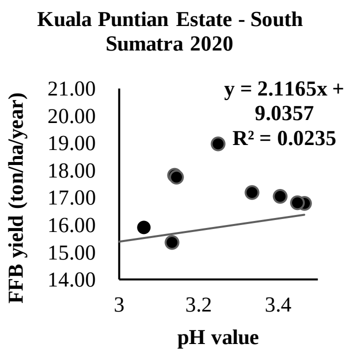
(j)


Selat Beting Estate - North Sumatra 2022
y = 3.0799x + 8.6334
R² = 0.2546
30.00
28.00
26.00
24.00
22.00
20.00
18.00
3.90
4.30
4.70
5.10
FFB yield (ton/ha/year)
pH value

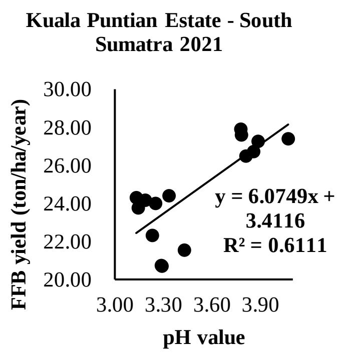
(k)


Selat Beting Estate - North Sumatra 2020-2022
y = 0.1556x + 22.71
R² = 0.0002
33.00
28.00
23.00
18.00
13.00
3.50
3.90
4.30
4.70
5.10
FFB yield (ton/ha/year)
pH value

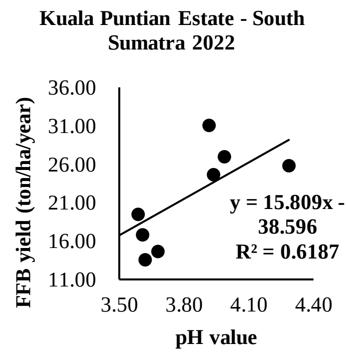
(l)


Kuala Puntian Estate - South Sumatra 2020
y = 2.1165x + 9.0357
R² = 0.0235
21.00
20.00
19.00
18.00
17.00
16.00
15.00
14.00
3
3.2
3.4
FFB yield (ton/ha/year)
pH value

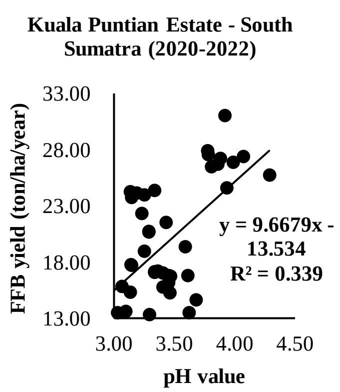
(m)


Kuala Puntian Estate - South Sumatra 2021
y = 6.0749x + 3.4116
R² = 0.6111
30.00
28.00
26.00
24.00
22.00
20.00
3.00
3.30
3.60
3.90
FFB yield (ton/ha/year)
pH value

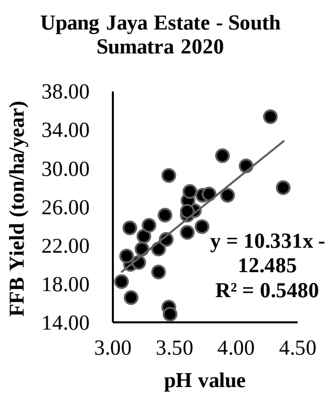
(n)


Kuala Puntian Estate - South Sumatra 2022
y = 15.809x - 38.596
R² = 0.6187
36.00
31.00
26.00
21.00
16.00
11.00
3.50
3.80
4.10
4.40
FFB yield (ton/ha/year)
pH value

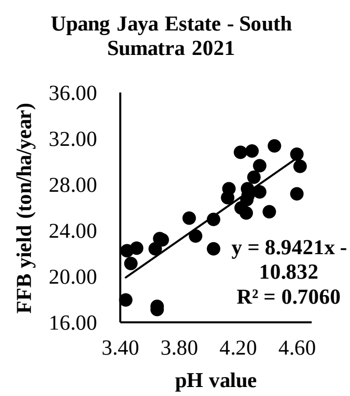
(o)


Kuala Puntian Estate - South Sumatra (2020-2022)
y = 9.6679x - 13.534
R² = 0.339
33.00
28.00
23.00
18.00
13.00
3.00
3.50
4.00
4.50
FFB yield (ton/ha/year)
pH value

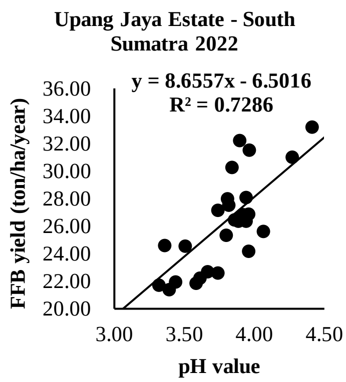
(p)


Upang Jaya Estate - South Sumatra 2020
y = 10.331x - 12.485
R² = 0.5480
38.00
34.00
30.00
26.00
22.00
18.00
14.00
3.00
3.50
4.00
4.50
FFB Yield (ton/ha/year)
pH value

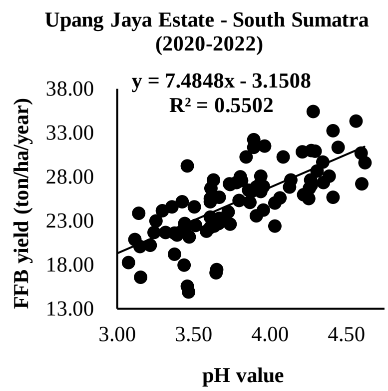
(q)


Upang Jaya Estate - South Sumatra 2021
y = 8.9421x - 10.832
R² = 0.7060
36.00
32.00
28.00
24.00
20.00
16.00
3.40
3.80
4.20
4.60
FFB yield (ton/ha/year)
pH value

(r)



(s)



(t)

Figure 3: Linear relationship of oil palm FFB yield production versus water pH values of piezometer for 2020,2021 & 2022 at (a) - (d) Batu Mundom Estate, (e) - (h) Sikapas Estate, (i) – (l) Selat Beting Estate, (m) – (p) Kuala Puntian Estate and (q) – (t) Upang Jaya Estate. Linear relationship for 2020-2022 period also illustrated at (d) Batu Mundom Estate, (h) Sikapas Estate, (l) Selat Beting Estate, (p) Kuala Puntian Estate and (t) Upang Jaya Estate.

4. Conclusions

Usage of portable units of pH meter made possible for planters to record and monitor the on-site changes of pH. Averaging of pH values directly should be avoided, the same pH values should be transformed into ion concentration $[H^+]$ for averaging purpose. The average [H+] then should be re-transformed to average pH. It seems that there would be a mathematically a huge difference in pH values if pH range is big.

Lower pH values ranging from 3.5 to 3.7 were observed at piezometer and water gates on blocks established on acid sulfate soils as compared to pH values recorded in peat areas where slightly higher pH values were registered (4.3 to 5.6). Presence of pyrite contributed to lower range of pH values on acid sulfate soils. A high correlation between pH values and FFB yield recordings was noticed at Batu Mundom Estate in 2021 with R^2 value at 0.7487. Satisfactory R^2 values (> 0.5) were obtained in nine set of data out of fifteen, representing 60% from total set of recordings.

Lowest R^2 value was also recorded for pH values versus cumulative FFB yields over three years i.e., from 2020 to 2022. This shows that there are agronomic factors other than pH values which had significant influence on the FFB yields of cumulative years such as palm age, harvesting interval, water management and balanced nutrient inputs. Nevertheless, monitoring of pH values should be continued for estates established on acid sulfate and peat soils.

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6. References

[1] Didy Sopandie. 2013. Physiology of Plant Adaptation to Abiotic Stress in Tropical Agroecosystems (Fisiologi Adaptasi Tanaman terhadap Cekaman Abiotik pada Agroekosistem Tropika). Pernerbit.PT Penerbit IPB Press

[2] De Datta S K. 1981. *Principles and Practices of Rice Production*. New York: John Wiley, pp. 618.

[3] Pupathy U.T. & Paramananthan S, 2014. Agro-management for Oil Palms Planted on Acid Sulfate Soils, In: Selected Papers on Soil Science: Volume 1: Problem Soils, Agricultural Crop Trust.

[4] Pahan, Iyung. 2010. Agribusiness Management from Upstream to Downstream: Jakarta Penebar Swadaya (Manajemen Agribisnis dari Hulu Hingga Hilir: Jakarta Penebar Swadaya)

[5] Giesecke, A H. 1979. Averaging values for gastric pH incorrect. Anesthesiology 50: 70-71.

[6] Nathan Leon P, Averaging pH and H^+ values, correspondence article in Anesthesiology,V51, No 5,November 1979, page 481-483.

[7] Corley, R.H.V., Tinker, P.B., 2003. The Oil Palm. Fourth Edition, World Agricultural Series. Blackwell Science United, UK, pp 562.

[8] Goh KJ. 2005 Fertiliser recommendation systems for oil palm: Estimating the fertiliser rates. Proceedings of MOSTA Best Practices Workshop Agronomy and Crop Management; 2005

[9] Mutert, E., 1999. Better Crops International 13(1), 36 -38.

[10] Kee, K.K., Chew, P.S., 1993. Oil Palm Responses to Nitrogen and Drip Irrigation in a Wet Monsoonal Climate in Peninsular Malaysia. In: Basiron, Y. et al. (Ed.), 1991 PORIM International Palm Oil Conference: Progress, Prospects and Challenges towards the 21st Century. PORIM, Kuala Lumpur, 321 – 339.

[11] Nur Aini, Ezrin M H, and Aimrun W. 2014. Relationship between soil apparent electrical conductivity and ph value of Jawa series in oil palm plantation. 2nd International Conference on Agricultural and Food Engineering, CAFEi 2014.

[12] Pupathy UT, Andrew Cheng M F, Kumaran R and Abdul Razak Ijang.2017. Planters' Experience on Managing Challenges and Limiting Factors for High Oil Palm Yield on Peat. International Soil Science Conference, MSSS-UPM, Bintulu, Sarawak, Malaysia.

[13] Nelson, P.N., Rhebergen, T., Berthelsen, S., Michael, J.W., Banabas, M., Oberthiir, T., Donough, C. R., Rahmadsyah., Indrasuara, K., Lubis, A., 2011. Soil Acidification under Oil Palm: Rates and Effects on Yield. Better Crops with Plant Food 95 (4), 22-25.

[14] Shamshuddin, J. and Paramananthan S,. 1988. Acidity and Charge Characteristics of Marine Alluvial Soils from Carey Islands, Selangor. In *Pertanika 11(1),* 15-23.

[15] Hew, C.K. and Khoo, K.M., 1970, Some methods of improving oil palms on acid sulfate soils in West Malaysia. Proc. 1st ASEAN Soil conference No 38.

[16] Mohd Tayeb D, 2002. Oil Palm Planting on Peat-Progress and Future Direction, MPOB, In:R&D for competitive edge in the Malaysian oil palm industry.

[17] Gurmit Singh, 1999, Agronomic Management of Peat Soil for Sustainable oil Palm Production, United Plantations' Experience, ISP Seminar on Peat, Kingtown,Sibu, Sarawak.

[18] *Xaviar*.A, 2005, Improvement of oil palm performance on some problem soils: peat and acid sulphate soils. Soil Science Conference of Malaysia, Soils 2005, Sungai Petani, Kedah, pg 153-157.

[19] Sharifah Sharul R.S.A., Sathashinikisan K, Tan Choon C., Noor H.H and Tan J.S, Oil Palm Planting Material for Peat: Performance and Challenges Factors Impacting the Competitiveness of the Palm Oil Industry, Planter,Vol.93, No 1092, March 2017.

[20] Jaman. O. and Kueh H.S. 1996. Oil Palm Research and Development on Peat Soil in Sarawak, Agricultural Department, Sarawak, Sibu, Sarawak.

[21] Musa B, Ahmad Fairuz Z, Mohaimi M and Harikrishna K, 2016, Planting Materials: Performance in Sarawak- Sime Darby's Experience, Planter, Vol.92, No. 1089, December 2016.

[22] Paramanthan S, 2000. Soils of Malaysia. Academy of Science Malaysia, Param Agriculture Soil Surveys.

[23] Michael O A, Kofi A, Emmanuel A, Paul A A, Peter B O, Eric O D, Kwame A F, Kwabena A S, Samuel A L, Richmond A, George M and Mathias.2022. The use of oil palm empty fruit bunches as a soil amendment to improve growth and yield of crops. A meta-analysis, Agronomy for sustainable development, volume 42, article number: 13

[24] Bakar A R, Darus S Z, Kulaseharan S, Jamaluddin N (2011) Effects of ten year application of empty fruit bunches in an oil palm plantation on soil chemical properties. Nutr Cycl Agroecosystems 89:341–349.

[25] Gurmit S, Kow D L, Lee K H, Lim K C and S.G Loong, 2009, Empty Fruit Bunch as Mulch, in book 'Sustainable production of palm oil - A Malaysian Perspective'