Key agronomic management factors for maximising oil palm 
(Elaeis guineensis Jacq.) yields on acid sulphate soils in 
Malaysia and Indonesia

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Abstract. In Malaysia, approximately 110,000 ha of acid sulphate soils are estimated to occur mostly along the west coast, while about 102.80 million ha are under acidic nature in Indonesia. Acid sulphate soils generally have significant amounts of free and absorbed sulphate, pale yellow mottles of jarosite along old root channels and on ped surfaces with pH (in water) below 4. These soils are high in Aluminium (Al) and phosphorus (P) fixation capacity, contributing towards their low fertility which limits the normal growth of oil palm (Elaeis guineensis Jacq.). However, Fresh Fruit Bunch (FFB) production in oil palm was improved significantly when water level in the field drains was maintained up to 60cm from soil surface mainly to cover jarosites and pyrite layers. Application of organic fertiliser mainly of Empty Fruit Bunches (EFB) and Palm Oil Mill Effluents (POME) to oil palm land proved to be beneficial as significant FFB yield up to 35 ton/ha/year was obtained in field trials. Maintaining water table in the drains to cover the pyritic horizon in order to inhibit further oxidation would be an important management tool for managing oil palms on acid sulphate soils.

1. Introduction

Generally, oil palm (Elaeis guineensis Jacq.) can grow well on a wide range of soil types. However, yield and vegetative growth of oil palm planted on acid sulphate soils are severely affected by the presence of excess sulphates. In Indonesia, according to [1], out of poor soils of about 148 million ha, 102.80 million ha (69.46%) are under acidic nature. In addition, as quoted by [2], in Indonesia about 34.52 % of total area is highly weathered soils, mainly classified as Ultisols (47,526,000 ha or 24.89%) and Oxisols (18,382,000 ha or 9.63%). On the other hand, in Malaysia, about 0.5 million ha of acid sulphate soils occur according to [3]. These acid sulphate soils are also low in bases, cation exchange capacity, water retention, organic matter, water holding capacity and microbial activity, contributing towards their low fertility which limits the normal growth of crops [4] [5]. Furthermore, these types of soils usually have high reaction with Al fixation resulting in low nutrient contents or low nutrient availability to crops especially P [6].

Hence, acid sulphate soils are unfavourable for agricultural activities and these soils are known to have significant amount of (i) free and absorbed sulphate, (ii) pale yellow mottles of jarosite along old root channels and on ped surfaces and (iii) low pH (in water) i.e. below 4 [4]. Of these, Al toxicity and excess sulphates are the major constraints to Fresh Fruit Bunch (FFB) production in oil palm [7]. In this review paper, the key agronomic factors, especially of soil and water management are discussed in detail to ensure the sustainability productivity of oil palm on acid sulphate soils.
2. Materials and methods

Fresh fruit bunch (FFB) yield data recorded at commercial scale on a few types of acid sulphate soils from oil palm plantations of Malaysia and Indonesia were gathered and updated for comparison. Commercial FFB yield of selected acid sulphate soils were taken from estates in Carey Island, Kuala Kurau and Sepang areas (Malaysia) [7] meanwhile for Indonesia, FFB yields from Kebun TPAI [8] was used for comparison.

Kebun TPAI is an oil palm estate owned by Sumber Tani Agung Resources (STAR) and is established mainly on acid sulphate soils near Palembang covering an area of 4062 ha. Various agronomy practices were implemented in this estate and improved from time to time with an objective of obtaining Fresh Fruit Bunches (FFB) in a sustainable approach. For example, a total of 55 water-gates were established in order to flush out acidic water that build-up due to oxidation of pyritic layers. Major activities done on this property were also adopted from successful key agro-management practices that had been embarked in Malaysian plantation industry. Yield data recorded at commercial scale on various acid sulphate soils were also gathered and updated for comparison.

3. Results and discussion

Generally, on acid sulphate soils, high acidic and toxic levels of aluminium as well as the low availability of phosphorus (due to fixation of aluminium) are known to restrict plant growth [8]. By nature, these soils are located along coastal areas thus, exposed extremely to the risks of high salinity. Furthermore, these soils also bear the high risk of strong acidification especially during droughts or after rapid drainage when the pyrite layer is oxidised to sulphuric acid.

On the other hand, they may be permanently flooded, limiting the normal functions of crop roots. The following characteristics of acid sulphate soils generally pose problems to maximising FFB productions as confirmed by [8], [9], [10] and [11].

1. Acid sulphate soils occurs mostly on flat and coastal areas. As such these soils are naturally in water-logging conditions and an artificial-drainage is required before oil palm cultivation.
2. Draining especially beyond the pyrite layer would results in an excessive acidic condition which is detrimental to palm growth. Palms will suffer from hyperacidity and poor yields when pH drops to below 3.5.
3. Aluminium solubility and toxicity are most pronounced at low soil pH. The severe acidity is due primarily to the increased solubility and toxicity of aluminium and possibly also ferric, manganese and hydrogen ions.
4. Decreased availability of phosphate.
5. Low base status and nutrient deficiencies.
6. High salinity problems.
7. Impeded root development.

3.1 Effects of water management on oil palm on acid sulphate soils

Based on oil palm performance, [12] classified acid sulphate soils into 3 categories (Table 1). Their classification was basically due to presence of acidic layer within 120 cm, being the severe category at the depth of 0 to 60 cm. However, the current soil classification in Malaysia tags this category at the depth of 0 to 50 cm for shallow acid sulphate soils, such as Linau and Sedu Series.

The average FFB yield for four consecutive periods of four years revealed that yields were not seriously affected when the acidity occurs at 90-120 cm. The substantial improvement in FFB production in severe and moderate acid areas was mainly attributed to ameliorative measure of raising water table. The findings of these experiments were helped the industry to establish a drainage system to manage water levels on acid sulphate soils.
Table 1. Details on category of acidity and FFB yield in consecutive periods of four years from 1968-1979\textsuperscript{a}

| Category of acidity | Depth of acidic layer (cm) | Ha | FFB Yield (tones/ha/year) |
|---------------------|----------------------------|----|--------------------------|
|                     |                            |    | 1964-67 | 1968-71 | 1972-75 | 1976-79 |
| Severe              | 0-60                       | 273 | 11.44  | 15.59  | 17.52  | 18.06  |
| Moderate            | 60-90                      | 366 | 16.38  | 19.27  | 19.08  | 18.98  |
| Mild                | 90-120                     | 12  | 22.81  | 23.43  | 22.14  | 17.32  |
| Non-acid sulphate   | -                          | 888 | 23.89  | 24.14  | 22.44  | 20.41  |

\textsuperscript{a}adapted from [12]

Oil palms subjected to acidic conditions on acid sulphate soils were showing hyperacidity symptoms. [13] mentioned that the presences of numerous desiccated fronds or leaves especially on older fronds are typical symptoms of oil palm planted on acid sulphate soils. With field experiment, [14] studied the FFB yield and growth responses in the acid and non-acid areas. Their study revealed that low FFB production in acid areas than those from non-acid areas. The water table was raised by blocking the drains (in late 1966) which resulted an improvement in FFB production on acid areas and its performance was as good as the non-acid areas. This proofs that the effect of acidity on the oil palm was greatly reduced by merely controlling water table in the field.

Aluminium solubility and toxicity are most pronounced at low soil pH. During the formation of acid sulphate soils the cations Mg, Ca and K are commonly leached and replaced by aluminium in the exchange complex, resulting in multiple nutrient deficiencies in oil palm [15]. [15] also found that aluminium (Al) toxicity symptoms have almost disappeared in the conditions of raised water table.

Figure 1. Managing water level for oil palms grown on acid sulphate soils by keeping water above the layers of pyrite (P) and jarosite (\(\theta\)) (adapted from [7])

[10] and [16] also further emphasized that on acid sulphate soils, periodic flushing of water (in/from the drains) is needed to remove the extreme acidic water as well as the accumulated toxic polyvalent
ions such as Al$^{3+}$. Hence, during the wet season, flushing of drain-water should be carried out by opening all the water retention blocks and water gates. Generally, one or two flushing(s) of drain-water is/are suffice especially during the wet season to alleviate the problems of acidity and as well as salinity [16]. Before the end of the wet season, all the blocks and water gates are closed in order to retain fresh water in the drains.

Upon the implementation of water management programme, FFB production were increased with improved agronomic practices where without drought stress effects, yields of 25 to 30 t FFB/ha per year are achievable on acid sulphate soils [12]. A network of drainage which was introduced in 1960’s, still being practiced nowadays for the betterment of oil palm production on acid sulphate soils [7] [8] [14] [19].

3.2 Nutrient inputs

Majority of oil palm roots are generally found within 60 cm of soil surface [16]. [12] found severe adverse effect on oil palm performance with the acid layer at 0-60 cm e.g. Sedu and Parit Botak Series. As such, utilisation of organic fertilisers is preferable as the organic matters would be an excellence substitutes for inorganic fertilizers. Nowadays, Fruit Bunches (EFB) and Palm Oil Mill Effluent (POME) which are considered as by-product in oil palm mills, are being applied to oil palms as an organic fertiliser. These EFB and POME would be able to improve soil structure and thus improve oil palm nutrient uptake [17] [18].

3.2.1 Empty Fruit Bunches (EFB) application. Oil palms on shallow acid sulphate soil may suffer from moisture stress due to poor rooting and the tendency for the surface horizon to dry irreversibly. In early days, [19] found significant yield increases following the applications of EFB at 23 kg per palm per year. However, nowadays application of EFB was made at every alternate point between two palms at the rate of 500-600 kg/application point or 250-300 kg/palm [20]. At this rate, each palm would receive nutrients that are equivalent of 2 kg urea, 0.6 kg of CIRP, 4.6 kg of MOP and 1.3 kg of Kieserite. EFB mulching improves the soil chemical properties such as in the pH, CEC, exchangeable bases, soil moisture and organic matter content of the soils [18].

3.2.2 Palm Oil Mill Effluent (POME) application. POME is one of main by-products in oil palm industry which is considered as excellent substitutes for inorganic fertilizers [17]. According to [17], the recommended application rates of POME would be about 360 and 550 litres per palm per year for coastal and inland areas respectively. Raw POME at one tonne is estimated to have nutrient values equivalent to 2 kg urea, 1.3 kg of CIRP, 4.0 kg of MOP and 3.0 kg of Kieserite [18]. In oil palm industry, application of POME played an important role on elevating the effects of acidity on the palm growth and performance on acid sulphate soils [8] [7].

3.2.3 Leguminous Cover Crops (LCC). According to [16] [8], LCC are grown during the early establishment of oil palm. These legumes are fixing nitrogen in the roots besides returning the phosphates in the form of litters to soils. LCC also help in converting the phosphorus into organophosphate complex which will be more useful for the oil palm nutrient uptake.

3.3 Fresh Fruit Bunches (FFB) yield on acid sulphate soils

[19] [14] carried out a series of trials involving liming and manuring experiments, then in Harrisons & Crosfield Oil Palm Research Station, Banting, Malaysia. They found that oil palm grown on acid sulphate soils responded significantly in growth and bunch yields to applications of fertilisers. [19] also found that liming was not an effective way to control acidic conditions in acid sulphate soils as (i) the effect of liming was short-lived and (ii) required a repetitive/periodical application rounds of liming which was expensive and labour intensive. [21] showed that by controlling water management on oil palm, at about 60 cm from the surface oil palm performance was enhanced. The objective of this
controlled/artificial drainage is to retain the water-table at 45 to 60 cm for as long as possible and not exceeded 75 cm depth [21][20].

Figure 2 shows the effect of different water management on FFB yields in oil palm [19] [14]. Commercially FFB yield production on acid sulphate soils is viable by merely controlling water at 45-60 cm throughout the year [8] [20] [19]. In the case of extreme dry weather conditions, there is a high risk of accelerated oxidation of the pyrite layer [21] [19]. Thus, a drainage network/system was proposed and implemented by [7] [14] [19] as a means of controlling water level at 45-60 cm from soil surface for maximising oil palm FFB yields on these soils (Table 2).

Table 2. Dimension of drains (in m) designed for effective water management for oil palms grown on acid sulphate soils

| Type of drain | Width   | Depth |
|---------------|---------|-------|
|               | Top     | Bottom|       |
| Field         | 1.0-2.0 | 0.5-0.6 | 0.9-1.0 |
| Collection    | 1.8-2.5 | 0.6-0.9 | 1.2-1.8 |
| Main          | 3.0-6.0 | 1.2-1.8 | 1.8-2.5 |

*a adapted from [7][14][19]

[20] also highlighted that agro-management practices such as EFB & POME application and inorganic fertilizer application had contributed towards higher FFB yields of above 35 ton/ha/year in Malaysia. Meanwhile in Indonesia, by implementing proper water and nutrition management, FFB yields above 30 mt/ha are achievable from palms that grown on acid sulphate soils in Sumatera. In TPAI Estate (Sumatra, Indonesia) FFB yield of above 25 tonne/ha/year at the seventh harvesting year is possible as shown in Figure 3. By maintaining water table to cover the pyritic horizon in order to prevent further oxidation, higher FFB yields are possible for oil palms grown on acid sulphate soils in both Malaysia and Indonesia.

Figure 2. Changes in FFB production in oil palm to with and without water management on acid sulphate soils (adapted from [14] [7])
Figure 3. FFB production in oil palm planted on acid sulphate soils in TPAI Estate, Sumatra, Indonesia (adapted from [8])

4. Conclusions

In acid sulphate soils, the presence of pyritic and jarosite layers strongly limits the potential for high yield in oil palm. With proper water and nutrient management, FFB yields are comparable to palms that grown on some best soil types. Nowadays, FFB yields above 35 mt/ha are achievable for oil palms grown on acid sulphate soils in Malaysia. Similar yield improvement also obtainable on acid sulphate soils in Indonesia. The FFB yield improvement was basically due to proper water-table maintenance.

Two important management tools for managing oil palms on acid sulphate soils are (i) raising the water table to cover the pyritic horizon in order to inhibit further oxidation and (ii) well-balanced nutrient inputs.

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