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Influence of Agronomic Practices on the Yield of Oil Palm (*Elaeis Guineensis Jacq*.) Grown on Various Soil Management Groups

Kayondo, Bonny[1*], Jalloh, Mohamadu Boyie [1], Binti Hasbullah, Nur Aainaa[1], IImas, Abdurofi [1], Selliah, Paramananthan [2]

[1]Faculty of Sustainable Agriculture, Universiti Malaysia Sabah, Mile 10, Jalan Sungai Batang, 90000, Sandakan, Sabah
[2]Param Agricultural Soil Surveys (M) Sdn. Bhd.

**Correspondence: bonnykayondo@gmail.com*

ABSTRACT

Compared to yields of 25-30 t ha^{-1} per year obtained elsewhere, the annual fresh fruit bunch (FFB) yields of 11 t ha^{-1} from oil palm plantations in Uganda are considered very low. Therefore, this study investigated the yield performance of oil palm progenies grown on various soil management groups (SMGs) in a large commercial plantation. A factorial randomized complete block design with two oil palm progenies planted in blocks of three replicates on six SMGs was used. Initially, the semi-detailed soil survey report of the plantation provided details about the SMGs. Rainfall records of 2012 to 2021 period were also documented. Site-specific agronomic techniques were implemented because of variations in the physicochemical sufficiency of the SMGs. Fresh fruit bunch data were collected every 10 days between 2016 and 2021 and subjected to analysis of variance using SPSS software version 20.0. Results showed that a change in the soil pH and cation exchange capacity (CEC) enhanced FFB yields across SMGs though in preceding years with uneven rainfall distribution, declines were experienced. However, the highest average yields were obtained from SMGs B (20.21 t ha^{-1}), and A (19.46 t ha^{-1}) and the lowest from Ait (18.03 t ha^{-1}) and Bi (17.79 t ha^{-1}). Also, the two progenies responded differently with the Deli x Ghana average yield being 19.98 t ha^{-1} and 17.60 t ha^{-1} for Guthrie D x P. Lastly, the highest average yield of 21.46 t ha^{-1} was obtained in 2021 in contrast to that of 2016, which was only 16.12 t ha^{-1}. Therefore, site-specific agronomic techniques contributed to an increase in FFB output from the plantation in 2021. This study provides a guide tool to managers to evaluate the influence of site-specific agronomic techniques for yield enhancement in the plantation towards attaining higher profit margins.

Key words: **Progenies, soil management groups, soil fertility, fresh fruit bunch yield, rainfall**

INTRODUCTION

The tropics have a diversity of soil types that support oil palm (*Elaeis guineensis Jacq*.) cultivation (Corley & Tinker, 2016; Woittiez *et al*., 2017). However, drought and low inherent soil fertility affect oil palm yields in several African plantations (Rhebergen *et al*., 2016). The continuous weathering of soils, intense leaching, and erosion brought on by high temperatures and excessive rains result in the formation of diverse marginal soils in the tropics (Paramananthan 2003; Shamshuddin *et al*. 2015; Shamshuddin and Wan 2011). The first oil palm plantation in Uganda is located in an area that receives the highest rainfall in Uganda, ideal for oil palm growth and fresh fruit bunch (FFB) production (KDLG, 2005). Initial reports from the pilot trials in this area showed FFB yields of 11 t ha^{-1} per year from 6–8 year-old oil palm plantations treated with no fertilizer (MAAIF/VODP, 2003). These yields are remarkably low in comparison to 25-30 t ha^{-1} year FFB from well-managed commercial plantations located in optimum biophysical environments (Donough *et al*. 2009; Pupathy and Sundian 2020). Studies (Manishimwe 2018; Muwanga 2019)show that the problem of low FFB productivity in Uganda has led to a low vegetable oil supply. In 2018 while the annual demand for vegetable oil was120,000 metric tonnes, the nation was only able to generate about 40,000 metric tonnes. There are claims that the oil palm trees of the commercial plantation in Uganda were planted on marginal soils (Wakabi, 2021). Consequently, failure to appreciate the variability that exists among soils poses a financial risk in agricultural investment in Africa. (Rushemuka *et al.*, 2014). This is because different soils in the plantation possess unique physicochemical characteristics that influence the performance of oil palm progenies and, as a result, create variation in the FFB yields (Harahap *et al.*, 2019). In the case of Malaysian plantations, adoption of site-specific agronomic practices tailored to the limitations found in different soil management groups (SMGs) increased oil palm FFB productivity (Oberthür *et al.*, 2017). Therefore, the objective of this study was to investigate how site-specific agronomic techniques influence FFB yield productivity in Ugandan plantations after its zoning into SMGs. The investigation was carried out from the pre-soil evaluation period in the year 2016 and compared with data from year 2021.

MATERIALS AND METHODS

Location and Description of the Study Area

This study was conducted in a privately-owned mature commercial plantation situated on Bugala Island, Kalangala District in Lake Victoria, Uganda between latitudes 0°10’S and 0°35’S and longitudes 32°04’E and 32°20’E. *Figure 1* shows the location of the study area. This Uganda plantation consists of scattered parcels of land totalling about 6,324.23 ha with 5,956.16 ha planted with oil palm. The elevation of the plantation is between 1,000 to over 1,500 meters above sea level. The area has a mean annual maximum and minimum temperature of 25^0C and 17. ^{0}C respectively, with an annual rainfall ranging from1,125to 2,250 mm (NEMA, 1998). It experiences two distinct rainy seasons: first rain (March to June) and second rain (August to December).

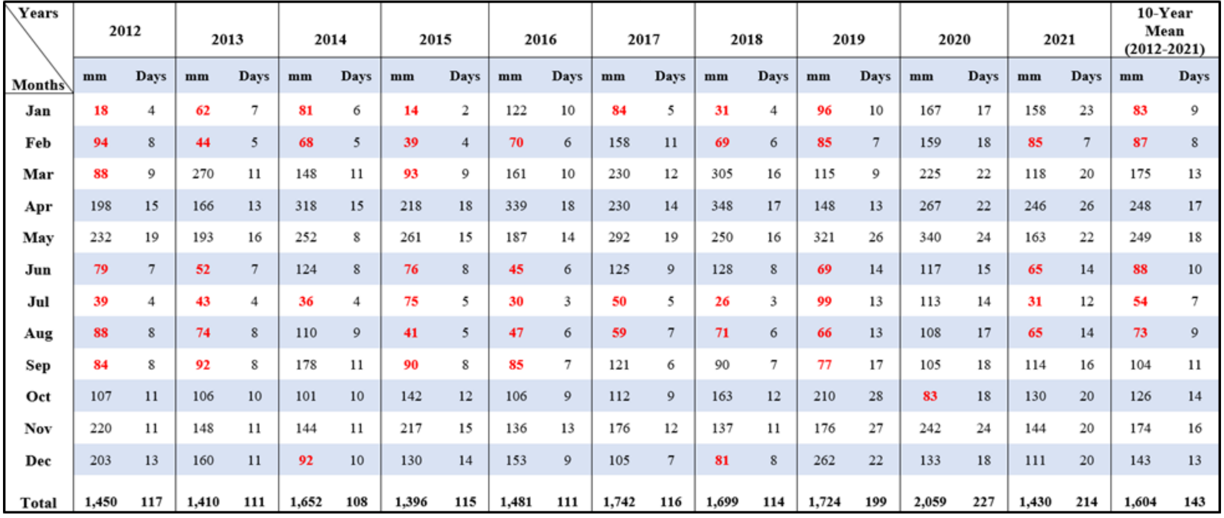
Figure 1. Location of Bugala Island, Kalangala District, Lake Victoria Uganda.
Source: ACAPS

Rainfall Data

Because oil palm requires a year-round supply of moisture to develop its yield potential, rainfall is taken into account in this study (Von Uexkull & Fairhurst, 1991). For the period of 2012 to 2021, the total monthly precipitation (mm) and rain days (see Table 1) data of the Uganda plantation was documented. Months with rainfall below 100 mm are marked red to indicate periods of moisture deficit for oil palm (Paramananthan, 2003).

TABLE 1

Data on collected rainfall (mm) and rain days for the oil palm plantation in Uganda (2012-2021)



Years / Months	2012		2013		2014		2015		2016		2017		2018		2019		2020		2021		10-Year Mean (2012-2021)	
	mm	Days	mm	Days	mm	Days	mm	Days	mm	Days	mm	Days	mm	Days	mm	Days	mm	Days	mm	Days	mm	Days
Jan	18	4	62	7	81	6	14	2	122	10	84	5	31	4	96	10	167	17	158	23	83	9
Feb	94	8	44	5	68	5	39	4	70	6	158	11	69	6	85	7	159	18	85	7	87	8
Mar	88	9	270	11	148	11	93	9	161	10	230	12	305	16	115	9	225	22	118	20	175	13
Apr	198	15	166	13	318	15	218	18	339	18	230	14	348	17	148	13	267	22	246	26	248	17
May	232	19	193	16	252	8	261	15	187	14	292	19	250	16	321	26	340	24	163	22	249	18
Jun	79	7	52	7	124	8	76	8	45	6	125	9	128	8	69	14	117	15	65	14	88	10
Jul	39	4	43	4	36	4	75	5	30	3	50	5	26	3	99	13	113	14	31	12	54	7
Aug	88	8	74	8	110	9	41	5	47	6	59	7	71	6	66	13	108	17	65	14	73	9
Sep	84	8	92	8	178	11	90	8	85	7	121	6	90	7	77	17	105	18	114	16	104	11
Oct	107	11	106	10	101	10	142	12	106	9	112	9	163	12	210	28	83	18	130	20	126	14
Nov	220	11	148	11	144	11	217	15	136	13	176	12	137	11	176	27	242	24	144	20	174	16
Dec	203	13	160	11	92	10	130	14	153	9	105	7	81	8	262	22	133	18	111	20	143	13
Total	**1,450**	**117**	**1,410**	**111**	**1,652**	**108**	**1,396**	**115**	**1,481**	**111**	**1,742**	**116**	**1,699**	**114**	**1,724**	**199**	**2,059**	**227**	**1,430**	**214**	**1,604**	**143**

Experimental Design

Prior to the study, a soil survey was conducted in the plantation in collaboration with Param Agricultural Soil Surveys in 2017, which generated a report about soil management groups (SMGs). The SMGs were characterized as per criteria by Paramananthan (2010). The 2016 soil nutrient evaluation data used was extracted from this soil survey report (Table 2) with the same points being sampled in 2021 (Table 3). Plantation management provided data about the oil palm progenies and their coverage on the plantation as shown in Table 4. From the aforementioned information, SMGs and progenies represented largely on the plantation were selected for this study. *Figure 2* shows the identified SMGs on the Uganda plantation. This study was arranged in a factorial randomized complete block design. The factors in this study were two tenera oil palm progenies (Deli x Ghana and Guthrie D x P) and six SMGs (A, Ai, Ait, B, Bi and Gi (Table 5). The progenies were 11 years old and planted in an equilateral triangular pattern at a density of 148 palms per hectare. Each of the factor combinations were replicated three times. This resulted in 36 experimental blocks. The blocks were sized between 13 to 30 hectares. The year 2016 was considered a pre-study period. Site-specific agronomic techniques were implemented from 2017 to 2021. The fertilizer regime for the Uganda oil palm plantation for the years 2016–2021 are shown in Table 6. Based on annual leaf analysis results, agronomists developed fertilizer regimes. Data on FFB were gathered annually at intervals of 10 days. Using SPSS software (version 20.0), analysis of variance was performed on this yield data.

TABLE 2

Soil nutrient concentrations of representative series in 2017

Parameter	Soil Series					
	Bungor/red (Pedon 1)		Jitra/red (Pedon 2)		Laka (Pedon3)	
Depth (cm)	0-12	12-39	0-12	12-42	0-10	10-30
pH	High	Low	Low	Low	Low	Low
Organic C (%)	Very High	Very High	Very High	High	Very High	High
Total N (%)	Very High	High	Very High	Low	High	High
Total P (µg g^{-1})	Very High	Very High	Very Low	Very Low	Low	Very Low
Available P (µg g^{-1})	Very High	Very High	Very Low	Very Low	Very High	Very High
Exchangeable K (cmol kg^{-1}) soil	Very High	Very High	Very High	Very High	High	Very High
Exchangeable Mg (cmol kg^{-1}) soil	Very High	Very High	Very High	Very High	Very High	Very High
CEC (cmol kg^{-1}) soil	Moderate	Low	High	Very High	Very Low	Very Low

TABLE 3

Soil nutrient concentrations of representative series in 2021

Parameter	Soil Series					
	Bungor/red (Pedon 1)		Jitra/red (Pedon 2)		Laka (Pedon 3)	
Depth (cm)	0-12	12-39	0-12	12-42	0-10	10-30
pH	High	High	High	High	High	High
Organic C (%)	High	High	High	Moderate	High	Moderate
Total N (%)	High	High	High	High	High	High
Total P (µg g^{-1})	Very High	Very High	Very Low	Very High	Very High	Very High
Available P (µg g^{-1})	Very High	Very High	Very High	Very High	Very High	Very High
Exchangeable K (cmol kg^{-1}) soil	Very High	Very High	Very High	Very High	Very High	Very High
Exchangeable Mg (cmol kg^{-1}) soil	Very High	Very High	Very High	Very High	Very High	Very High
CEC (cmol kg^{-1}) soil	Moderate	High	Moderate	Moderate	Moderate	Moderate

TABLE 4

Oil palm progenies and their coverage at Uganda plantation

Progeny	**Coverage**	
	Hectare (ha)	Percentage (%)
1.Deli x Compacta	8.28	0.14
2.Deli x Ghana	501.25	8.42
3. Deli x Nigeria	26.13	0.44
4. Tanzania x Ekona	290.43	4.88
5. Bamenda x Ekona	52.64	0.88
6. Guthrie DxP	4,343.66	72.92
7. IOPRI	245.54	4.12
8. Deli x La Me	488.23	8.2
TOTAL	**5956.16**	**100**

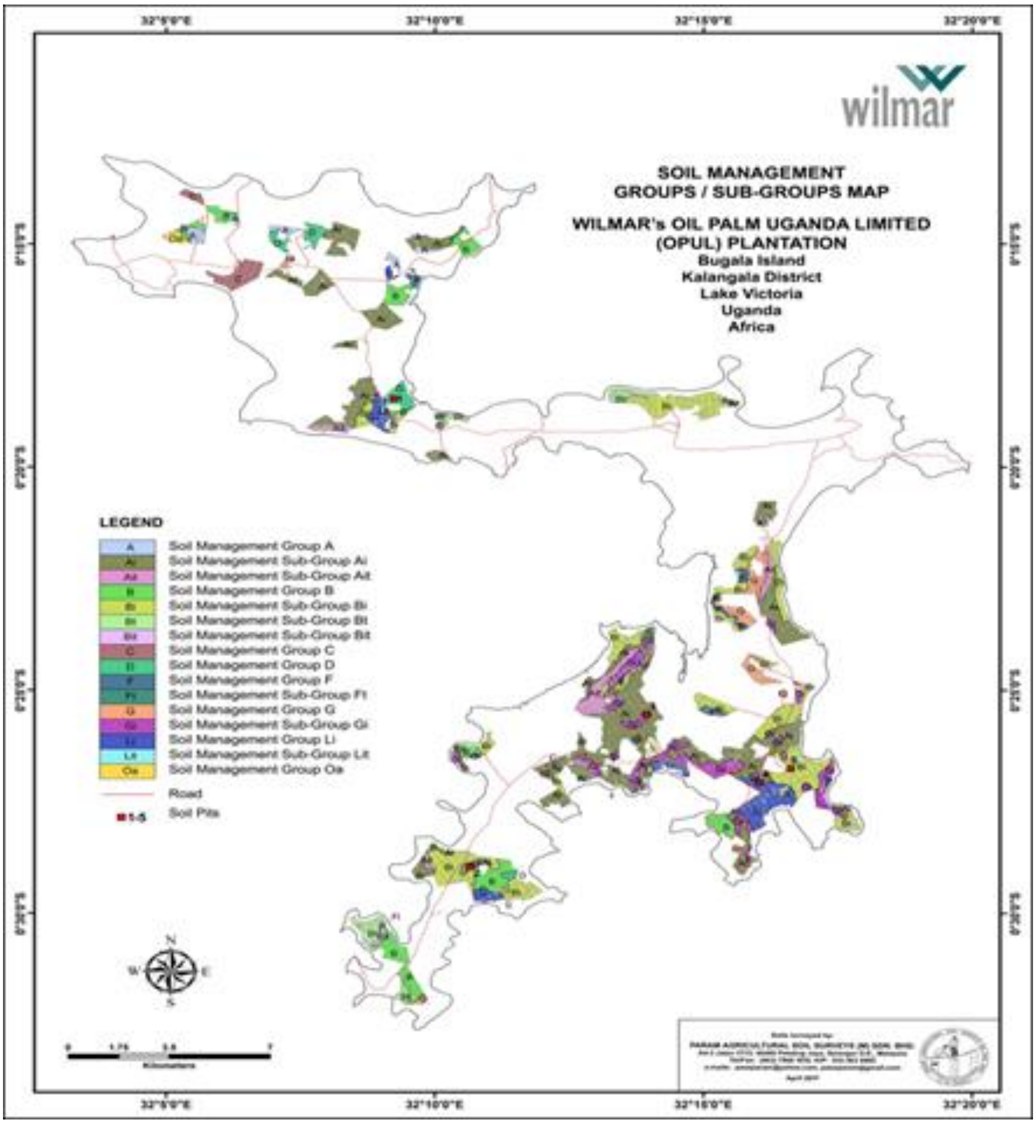


Figure 2: Map of the soil management groups found on the Uganda Plantation

TABLE 5

Soil management groups (SMGs) and implemented soil practices

Soil Groups	**Soil types (Classification according to Soil Taxonomy)**	**Main Characteristic/ Limitation**	**Implemented Agronomic Practices**	**Peak Yield Potential**	**Extent**	
				mt/ha/yr	**Ha**	**%**
A	Typic Paleudult Typic Kandiudult	• Deep (>100 cm) to moderately deep (50-100 cm) fine sandy clay to clay (>35% clay) textured soils • Low fertility	• Understory vegetation. • AS, MOP, NK Mixture, NPK compound and Gypsum • U-shape frond stacking and *Mucuna spp* maintained	28-32	94.4	1.6
Ai	Rhodic Paleudult	• Deep (>100 cm) fine sandy clay to clay (>35% clay) textured soils • Low fertility • High iron content • High P-fixation	• AS, MOP, NK Mixture, NPK compound, RP, Kieserite & Gypsum • Terracing • U-shape frond stacking • EFB mulch (40 t ha^{-1}) • Understory vegetation and *Tapak kuda*	28-32	1,946.8	32.6
Ait	Rhodic Paleudult	• Deep (>100 cm) fine sandy clay to clay (>35% clay) textured soils • Low fertility • High iron content • High P-fixation • Soils on hilly to steep slopes • High soil erosion	• AS, MOP, NK Mixture, NPK compound, RP, Kieserite & Gypsum • Terracing • U-shape frond stacking • EFB mulch (40 t ha^{-1}) • Understory vegetation and *Tapak kuda*	26-30	240.3	4.0
B	Typic Kandiudult Typic Hapludult	• Deep (>100 cm) to moderately deep (50-100 cm) well drained soils. Texture sandy clay loam (18-35% clay) • Moisture stress and yield fluctuations • Low fertility	• MOP, NK Mixture, NPK compound, RP, Kieserite & Dolomite • Terracing • Decanter cake (200 kg/palm) • U-shape frond stacking. • EFB mulch (40 t ha^{-1}) • Understory vegetation and *Tapak kuda*	26-30	566.1	9.5
Bi	Rhodic Kandiudult	• Deep (>100 cm) to moderately deep (50-100 cm) well drained soils. Texture sandy clay loam (18-35% clay) • Moisture stress and yield fluctuations • Low fertility • High iron content • High P-fixation	• MOP, NK Mixture, NPK compound, RP, Kieserite & Dolomite • U- shape frond stacking • EFB mulch (40 t ha^{-1}) • Understory vegetation and *Tapak kuda*	26-30	1,315.6	22.1
Gi	Rhodic Kandiudult	• Shallow (<50 cm) well drained soils. Gravelly sandy clay textures. Shallow soil depth. Dense lateritic/gravel layer (<50 cm) • Low fertility. • Poor rooting. • Moisture stress • Wind damage • High iron content • High P-fixation	• AS, MOP, NK Mixture, NPK compound, RP, Kieserite & Dolomite • U-shape frond stacking • EFB mulch (40 t ha^{-1}) • Understory vegetation and *Mucuna spp* • Decanter cake (200kg/palm)	22-28	532.2	6.0

TABLE 6
Fertilizer regime of the Uganda oil palm plantation for the 2016-2021 period

Fertilizer and liming materials	Annual application dosages (kg/palm)					
	2016	2017	2018	2019	2020	2021
Ammonium sulphate	2.0					
MOP (60%K2O)	2.0					
NK Mix 10.5/30 (50%SOA,50%MOP)	2.0		2.0		2.0	2.0
NPK (8.5-6-28-4.5+0.72 B)	2.0	3.0				
NPK (8 - 4 -23-4 + 0.48 B)		2.0				
NK Mix 15.75/15 (75%SOA,25%MOP)				2.0		
NPK (0-8-28-6.5+1.44)				2.0		
NPK (10-6-24-5+0.96B)			2.5		2.0	2.0
Egyptian RP (30%P_2O_5,46% CaO)					2.0	2.0
NK Mix 8.4/36 (40% SOA / 60% MOP)			1.5		1.5	2.0
Kieserite (27%MgO,22%S)	1.0			1.0	1.0	1.0
Average application per tree	**7.0**	**7.0**	**9.0**	**11.0**	**11.0**	**9.0**
Gypsum (32% CaO,18%S)		2.0	2.0	2.0	2.0	
Dolomite (30% CaO,18%MgO)		3.0		3.0	3.0	

Note: MOP-Muriate of Potash, RP-Rock phosphate, NPK-Nitrogen, Phosphorus, Potassium

RESULTS AND DISCUSSION

Rainfall Distribution from 2012 to 2021

The collected rainfall data over a period of 10 years is presented in Table 1. The average rainfall and rain days are 1,604 mm and 143 respectively. However, there is a wide variation between the lowest rainfall of 1,396 mm and the highest of 2,059 mm. The Uganda oil palm plantations face a long dry season from June to September. Another secondary dry spell is experienced in some months through December to February that sometimes extends to March but more frequently to January or February. From 2016 to 2021, rainfall was well distributed except for years 2016 and 2019 where four consecutive dry months were recorded, starting June to September. It is noted that there is no month with zero rainfall. However, current highest and lowest rainfall values differ from those earlier reported, in the range of 1,125 and 2,250 mm on Bugala Island (KDLG, 2005; NEMA, 1998). These differences could probably be due to climate change effect causing variations in metrological factors in tropical Africa (Tamara, 2021), hence the longer drought periods in the plantation. Continuous supply of rainfall is required by oil palm to counterbalance water lost through evapotranspiration (Paramananthan, 2003). Furthermore, rainfall is important to support various physiological and developmental functions such as flowering, bunch production, translocation of nutrients and photo-assimilates. Therefore, oil palm requires a high annual well- distributed rainfall of at least 2,000-2,500 mm with no dry month recording less than 100 mm (Corley & Tinker, 2003; Paramananthan, 2003). In the presence of a dry month, yields decline even where the total annual rainfall exceeds the required 2000 mm (Hartley, 1988). Consequently, the rainfall of the Uganda oil palm plantation is typical of the moderate type that ranges between 1,450-1,700 mm as discussed by Paramananthan (2011) and Paramananthan *et al.* (2000).

FFB yields of Deli x Ghana and Guthrie D x P Progenies in the Uganda Plantation

Statistical analysis results indicate a significant interaction *P*= 0.038, between SMGs and progenies for FFB yields in years 2016 and 2021 (*Figure 3*). It is seen that the overall mean productivity of FFB yields of both progenies (M=18.79, SD=3.31) increased annually across all SMGs after implementation of site-specific agronomic practices. This is justified by the significant *(P<0.05)* difference in FFB productivity between years 2016 and 2021. The mean yield in 2016 was M=16.12, SD=2.06 and in 2021 it was M=21.46, SD=1.81. In other words, FFB yields of the plantation increased by 33% or 5.34 t ha^{-1} in 2021.

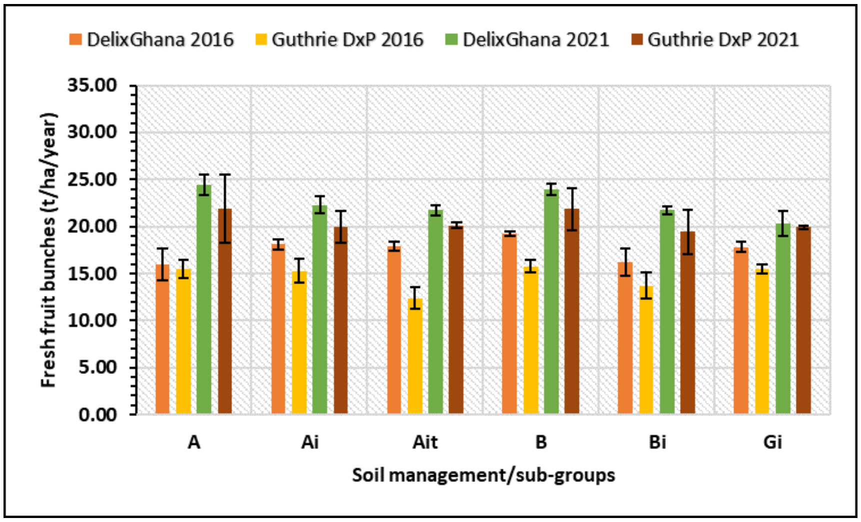


Figure 3: Interaction effect of soil management groups and progenies for mean FFB yield between years 2016 and 2021; error bars represent standard deviation and n=3.

Figures 4 and *5* show the yield trends for the DelixGhana and Guthrie DxP progenies respectively from 2016 to 2021. The mean FFB yield of M=17.56, SD=1.42 for DelixGhana in 2016 increased by 28% or 4.85 t ha^{-1} (M=22.41, SD=1.61) in 2021. The mean yield for Guthrie DxP in 2016 was M=14.69, SD=1.54, an increase of 40% or 5.83 t ha^{-1} (M=20.52, SD=1.52) in 2021. However, DelixGhana's FFB mean yields declined by 14% (2.45 t ha^{-1} to 15.11 t ha^{-1}) in 2017 and again by 13% (2.59 t ha^{-1} to 17.70 t ha^{-1}) in 2020. It is also observed that the mean yield of Guthrie DxP declined by 23% (3.37 t ha^{-1} to 11.32 t ha^{-1}) in 2017 and again by 10% (1.86 t ha^{-1} to 17.07 t ha^{-1}) in 2020 before increasing again in 2021. Statistically, there is a significant *(P<0.05)* difference between the mean FFB yield of DelixGhana (M=19.98, SD=2.88) and Guthrie DxP (M=17.60, SD=3.32) progenies. The highest yield in 2021 of M=23.17, SD=1.69 and M=22.89, SD=1.89 was observed on SMGs A and B respectively and the lowest of M=20.10, SD=0.85 on Gi. However, DelixGhana's mean FFB yields on A and B were M=24.43, SD=0.94 and M=23.94, SD=0.60, respectively. On SMGs A and B, the Guthrie DxP mean yields were M=21.92, SD=3.63 and M=21.83, SD=2.26, respectively. DelixGhana yields were lowest on Gi (M=20.31, SD=0.5), while Guthrie DxP yields were lowest on Bi (M=19.45, SD=2.34). Therefore, the productivity of DelixGhana was higher by 13% or 2.37 t ha^{-1} than that of the Guthrie D x P cultivar.

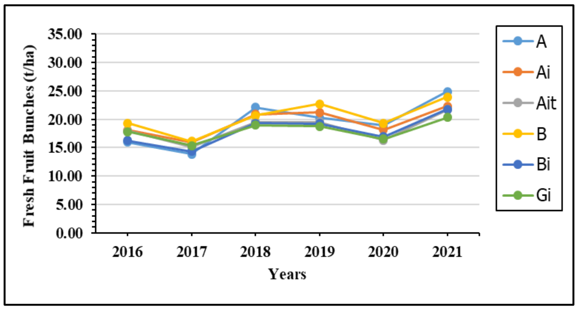


Figure 4: Yield trend of DelixGhana on the six SMGs from 2016-2021

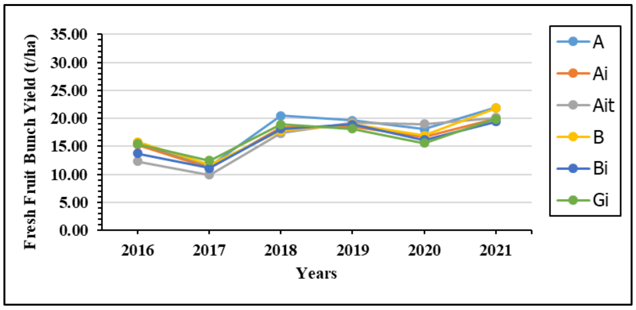


Figure 5: Yield trend of Guthrie DxP on the six SMGs from 2016-2021

Figure 6 shows the significant (*P<0.05*) difference in the mean (M) FFB yields of the six SMGs. SMG B yields were highest (M=20.21, SD=3.34) closely followed by SMG A (M=19.46, SD=4.13). However, mean yields of sub-groups of SMG A, Ai (M=18.90, SD=2.86) and Gi (M=18.37, SD=2.11) do not differ much. Mean yields of sub-groups Ait (M=18.03, SD=3.74) and Bi (M=17.79, SD=3.55) were the lowest and did not differ much.

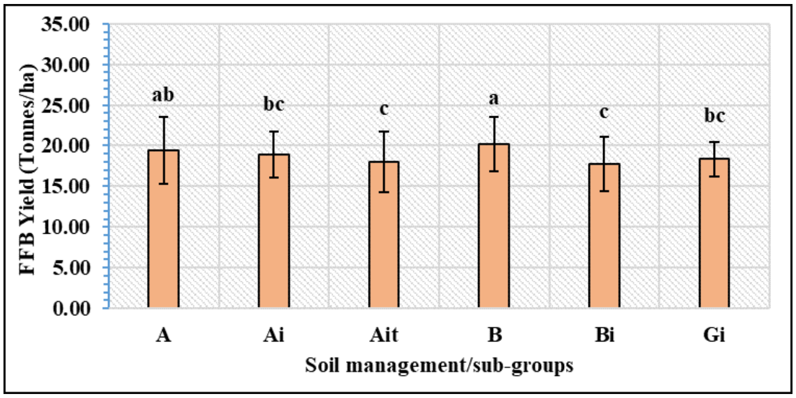


Figure 6: Mean FFB Yields of the various soil management groups (2016-2021)). Bars with different letters are significantly different (p<0.05) and error bars represent standard deviation

The observed increase in 2021 FFB yields justifies the effectiveness of adopting site-specific soil agronomic techniques on the SMGs. This is because soil management altered the physico-chemical properties of the soils. Hereafter, the two progenies positively adapted to the changes and responded by producing increasing FFB yields as illustrated in *Figures 4* and *5*. The soils of the Uganda plantation initially showed a low soil pH and poor cation exchange capacities (CEC), two problematically prevalent traits of tropical soils (see Table 2). These soil traits probably contributed to the initial low FFB yields across SMGs. Though oil palm tolerates a low soil pH, acidic conditions cause severe chemical imbalances resulting from toxic levels of Al^{3+} and H^+ at exchangeable sites This is compounded by nutrient deficiencies of N, P, K, Ca, Mg, Mo and B. Additionally, as the soil CEC is pH-dependent, its low levels point to leaching of K, Mg, and Ca. This implies that the Uganda plantation soils have a limited capacity to retain the added cations from mineral fertilizers.

The applied organic fertilisers increased the capacity of soils store added K, Ca and Mg from inorganic fertilizers, which improved the CFC of soils and subsequently increased FFB output. This clearly indicated that fertilizers aided the physiological functions of the cultivars thereby causing a significant increase in FFB yields (Sundram *et al.* 2019). Furthermore, split fertiliser application encouraged the roots of the progenies to efficiently absorb nutrients from the soil and reduce nutrient leaching (Reetz, 2016).Because of the acidic nature of the soils in the plantation, rock phosphate dissolved more quickly, releasing phosphorus and reducing the effects of iron fixation (Uwumarongie-Ilori *et al.*, 2012). Also, Kieserite released magnesium in a form that was easily absorbed by oil palm roots. Further, the long-lasting ameliorating effects of dolomite which releases exchangeable cations Ca^{2+} and Mg^{2+} also enhanced available phosphorus levels in the soil and a rise in soil pH as shown in Table 3.

The improved CEC (Table 3) from the pruned fronds increased the initial low pH of the soil (Formaglio *et al.* 2021) allowing for the availability of nutrients (Kotowska *et al.* 2016). Additionally, pruned fronds had the effect of increasing OC, total N, exchangeable K, Ca, and Mg while exchangeable Al^{3+} decreased in the soil with the addition of organic matter (Comte *et al.* 2013). In the moisture-stress year of 2020 compared to 2017, organic matter also improved the soil's structural stability and reduced the consequences of the drought. The decanter improved soil quality and moisture storage which promoted the growth of the oil palm roots (Sahad *et al.* 2014). Additional soil nutrients were also extracted from decanter wastes by oil palm roots (Rahman *et al.*, 2021). The *Mucuna bracteata* fixed nitrogen in the soil, decreased soil erosion, and enhanced water infiltration into the soil (Arifin *et al.* 2015; Wawan *et al.* 2019). Additionally, it strengthened the structural stability of the soil. The individual planting platform maximized the effectiveness of retaining the fertilizer as well as conserving soil moisture (Goh *et al.* 2016; Hidayat 2017). On the other hand, the understory vegetation improved soil and water conservation by halting surface runoff and soil erosion (Corley and Tinker 2016; Pardon *et al.*2016).

The constructed terraces minimized soil erosion, intercepted surface run-off and increased infiltration. However, it is conceivable that the physical constraints of SMGs Ait and Bi lessened the effectiveness of the practices that were put in place, resulting in low FFB yields. The prevalence of iron oxides in these SMGs could have resulted in the formation of pseudo-sands and pseudo-silts. These enhanced the porosity of the soil, resulting in the loss of water and nutrients through infiltration and leaching respectively. Hence yields were affected. This is because they create conditions of moisture stress even after the application of high-quality inorganic fertilizer (Hoffmann *et al.* 2014).

The temporal and spatial diversity in topography and physicochemical soil factors was another factor contributing to the observed FFB yield differences seen in *Figure 6*. This is consistent with the earlier observations from the research by Aniku (2001) that crop yields vary across the catena, indicating differences in the soil's physicochemical properties. Because of the severity of the limitations related to steep topography, shallowness, and high iron content, SMGs Ait and Bi did not respond well to soil management approaches. This accounts for the low FFB yields.

However, in contrast, the two progenies across SMGs differ in how they responded to the soil agronomic techniques. This is an indication of their differential preference for soil conditions. The higher FFB yields of progenies SMGs A and B indicate sufficiency of their physicochemical characteristics after modification contrary to those of Bi and Gi. On shallow Gi, the Deli x Ghana's low FFB yields were caused by the inability of the roots to fully absorb nutrients and moisture because of the stones and gravel, but Guthrie's DxP was limited by low moisture on Bi. The yield troughs shown in years 2017 and 2020 (*Figures 4* and *5*) were a result of the consecutive four dry-month periods that were experienced in the preceding years of 2016 and 2019 respectively. This indicates that the years with consecutive four dry months (Table 1) are responsible for the low and fluctuating yields. Surprisingly, despite having a good texture and being well drained, SMG A was also affected by the drought.

This observation supports studies by Padi and Ehlers (2008) that drought impact occurs on well-drained soils without moisture replenishment from rainfall. The observed reduction in FFB yields after a 12-month lag period was a result of abortion of female inflorescences and bunch rotting signalled by dominance of the male inflorescences. Similar findings in an oil plantation were reported by Adam *et al.*(2011) and Carr (2011). Higher FFB yields were achieved in the years 2018, 2019, and 2021 with judicious fertilizer application and moisture availability. This study results are consistent with those of Goh *et al*. (2016) that an even distribution of rainfall is required for soils with low water-holding capacity and/or where root development is restricted. The fact that both cultivars in this study were impacted by drought also supports the findings that FFB yield output is a non-heritable trait predominantly influenced by changes in the environment, as described by Arolu *et al.* (2016).

The yield decline ranging from 10% to 23% shown in *Figures 4* and *5* further justify the effect of the occasional drought faced by the Uganda plantation. This is consistent with the findings of a study that drought reduces FFB yields by up to 20% on poor soils and by 10% to 15% on excellent soils (Caliman and Southworth, 1998). The persistent yield of the two progenies despite the drought prevalence in this study justifies tolerance of *Tenera* cultivars under harsh environmental conditions as per reports by Almeida *et al*. (2020) and Corley and Tinker (2003). However, the observed difference in yields between the two progenies is an indication of their variation in the genotypes and origins (Arolu *et al*., 2016; Swaray *et al.,* 2020). The drought and cold tolerant DelixGhana progeny is bred from ASD Costa Rica (Escobar *et al.* 2006). In contrast, the Guthrie D x P progeny which originates from Malaysia (SDSAS 2011) has high yields under optimal conditions of rainfall distribution and a good fertilizer supply (Yong *et al*., 1997; Yong and Chan 1992).

This partly explains why it responded well to well-managed soil groups A and B in this study. This finding is similar to that of Nodichao *et al*. (2011), that a genetically superior material produces high and stable FFB yields under drought conditions. This study therefore confirms that DelixGhana is better adapted to the Uganda plantation condition. This is also consistent with other findings that DelixGhana yields are favourable even under suboptimal environments of low fertility and rainfall(Aye *et al.* 2005). Based on *Figure 3*, the mean FFB yields of SMGs A, Ai, Ait, B, Bi, and Gi, increased by 47%, 26%, 38%, 31%, 38%, and 21%, respectively, in the year 2021. Our findings show that events that result in changes to oil palm yields or stress-related effects occur within a period of one to three years (Haniff *et al.*, 2016).

Comparing the Uganda plantation mean potential yield of 28.17 t ha^{-1} and the actual mean of 18.79 t ha^{-1} shows a yield gap of 33% or 9.37tha^{-1}. Based on *Figure 7* below, the yield gaps on soil management groups A, Ai, Ait, B, Bi and Gi are 35%, 37%, 36%, 28%, 36% and 27% respectively. These are within the range of 25% to 35% reported by Palat *et al.* (2008) in a Thailand oil palm plantation that experienced a dry period of 3 to 4 dry months. Also the actual FFB yields of between 17.1 t ha^{-1} and 21 t ha^{-1} (*Figure 6*) are similar to those reported in Peninsular Malaysia state of Kelantan State faced with extreme weather of 2 to 3 dry months (Chan 2005). Therefore, the yield gaps of the Uganda plantation SMGs confirm that drought also significantly contributes to the potential for low site yield.

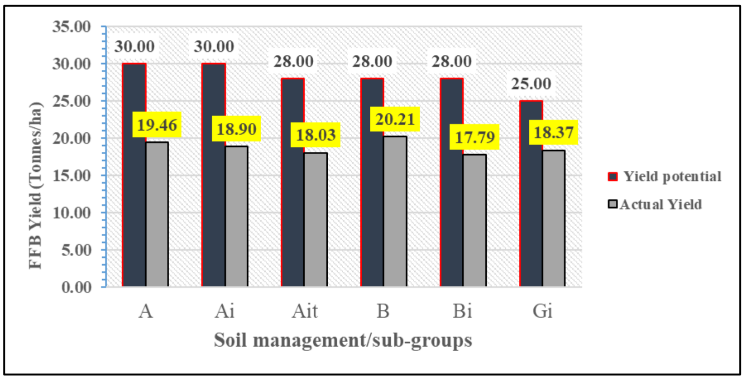


Figure 7: Mean comparison between potential and actual FFB yields for the six-soil management groups.

CONCLUSION

The moderate rainfall, defined by a four-month dry spell (between June and September), resulted in an FFB yield decline of between 10% and 23%. However, altering the fertilizer regime and utilizing both organic and inorganic fertilizers, as governed by annual leaf analysis, increased the FFB yields under soil moisture availability. The use of decanter solid at a rate of 200 kg palm^{-1}, EFB mulch at a rate of 40 t ha^{-1}, terracing, planting leguminous cover crops, maintaining understory vegetation, and construction of *Tapak kuda* resulted in the best FFB yields of 20.21 t ha^{-1} and 19.46 t ha^{-1} on SMGs B and A, respectively. For the Uganda plantation to fulfil its yield potential, these techniques should be maintained or further optimized.

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