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Effect of slope, aspect, and position on soil properties at various depths in an oil palm plantation in Selangor, Malaysia

OMAR MOHAMED IBRAHIMI ABDALRAHEM[1,3,♥], MOHD HASMADI ISMAIL[1,♥♥], PAKHRIAZAD HASSAN ZAKI[1], DALJIT SINGH A/L KARAM SINGH[2]

[1]Department of Forestry Science and Biodiversity, Faculty of Forestry and Environment, Universiti Putra Malaysia. 43400 UPM Serdang, Selangor, Malaysia. Tel.: +60-3-8946-7171, ♥email: omosat26@gmail.com

[2]Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia. 43000 Seri Kembangan, Selangor, Malaysia. Tel.: +60-3-9769-4802, ♥♥email: mhasmadi@upm.edu.my

[3]Department of Forestry, Faculty of Environmental Sciences and Natural Resources, Omar Al-Mukhtar University. El-Beida, Libya

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Abstract. *Abdalrahem OMI, Ismail MH, Zaki PH, Singh DSAK. 2024. Effect of slope, aspect, and position on soil properties at various depths in an oil palm plantation in Selangor, Malaysia. Biodiversitas 25: 2507-2514.* Limited information exists regarding the study of land and topographic characteristics and their influence on palm oil yield, as well as the effects on the physio-chemical properties of the soil. This study examined the impact of slope, aspect, and position at different soil depths on the physical and chemical properties of an oil palm (*Elaeis guineensis* Jacq.) plantation in an oil palm plantation in Selangor, Malaysia. Two sites with distinct north and south aspects were chosen for each slope site. Three equal positions were identified within each slope: Summit, Sideslope, and Toeslope. Random sampling determined soil physical and chemical properties at two depths (0-20 cm, 20-40 cm). This study analyzed soil chemical properties, including pH, EC, total N, P, Ext K, Ca, Mg, and soil texture, and the soil properties across different slope positions, depths, and aspects results indicated a significant difference ($p<0.05$). The soil properties' main factors contributing to the observed variations were slope position and soil depth. Slope position had a significant effect ($p<0.05$) on soil pH, EC, Ca, Mg, K, and N. Soil depth significantly influenced ($p<0.05$) all soil properties examined. The slope aspect also significantly affected ($p<0.05$) pH, Ca, Mg, and K. The soil texture classification ranged from sandy clay to sandy clay loam. Sand constituted the highest proportion of soil particles in both aspect slopes, followed by clay. The clay content increased with depth, specifically in the 20-40 cm range.

Keywords: Aspect, oil palm, slope, soil depth, soil properties

Abbreviations: N: total nitrogen; EC: Electrical Conductivity; Av-P: Available Phosphorus; Exc-Ca: Exchangeable Calcium; Exc-K: Exchangeable potassium; Exc-Mg: Exchangeable Magnesium; pH: pH H_2O

INTRODUCTION

Due to limited arable land in countries such as Malaysia and Indonesia, new oil palm plantations have expanded into marginal land regions, such as hill slopes (Moradi et al. 2012; Mutsaers 2019). However, hill slopes are susceptible to soil erosion by surface water runoff, which impacts the physical and chemical qualities of the soil, leading to decreased soil fertility (Chalise et al. 2019; Wolka et al. 2021). Flooding, sedimentation, water supply, and declining water quality are potential consequences of degraded soil quality. Examining soils on a slope is the best way to understand the spatial interrelationships between soils and topography. The geomorphic and hydrological conditions influence the sequence of soils from the crest down to the valley bottom. Toeslopes are the bottom slopes, receiving sediment and water from higher altitudes and overflowing streams. Due to sediment accumulation, toeslopes have a finer texture than other slope parts, resulting in thicker topsoil and stronger, more prominent wetness indicators (Životić et al. 2017).

Topography is vital in biogeochemical processes occurring in the earth's near-surface layer. It governs hydrological regimes and controls gravity-driven soil movements, making it a crucial factor in soil formation. Quantitative and qualitative topography data are required to understand soil chemistry and physics (Li and McCarty 2019). The slope aspect regulates solar insolation, affecting local vegetation growth and ecosystem types, directly influencing soil water content and temperature regimes (Lozano-García et al. 2016). The aspect and slope of a hillslope also influence the transport of water and nutrients (Dearborn et al. 2017). As spatial changes in soil qualities have shown, the slope aspect has a greater impact on plant communities than elevation. The vegetation structure within a given site can change dramatically over short distances, as seen in the north and South-facing slope sides (Qin et al. 2019).

According to Akbari et al. (2014) and Normaniza et al. (2018), slope affects soil genesis, microbial function and diversity, biomass production, soil organic matter, hydrology, and microclimate regulation. These factors impact the physicochemical qualities of soil by influencing microclimate. The slope aspect can also affect surface runoff and erosion (Akbari et al. 2014; Normaniza et al. 2018). Changes in topography create diverse microclimates, resulting in variations in faunal abundance and diversity, soil water content, temperature, and organic matter. This, in turn, affects soil fertility and quality (Akbari et al. 2014). The composition and distribution patterns of vegetation and soil biological characteristics differ depending on the slope aspect of mountainous landscapes' hydrological and solar energy systems.

The angle of the slope indirectly affects surface runoff and erosion. Soil erosion varies on slopes of the same grade but with different perspectives due to differences in microclimate. The slope aspect has a principal effect on surface runoff and erosion through differences in solar radiation received by sloping landforms. The importance of the slope aspect is more apparent in drier areas than in humid regions (Singh 2018). According to Jucker et al. (2018) and Singh (2018), topography alters the microclimate, leading to rapid evapotranspiration in southern aspects. Meanwhile, north-facing slopes have a thicker solum with higher organic matter and denser flora due to the rate of soil formation. The slope aspect had no significant influence on soil parameters due to substantial rainfall and compensation for radiation disparities between aspects. In other words, the humid environment in the area reduces the impact of radiation differences on different aspects (Singh 2018).

Slope gradient and length have been extensively studied; however, limited research exists on the impact of slope aspects on soil geochemical processing in Malaysia. Wong et al. (2020) and Devi (2021) revealed a strong correlation between soil nitrogen, Soil Organic Carbon (SOC), and soil Cation Exchange Capacity (CEC) of coarse-textured soil under oil palm plantations in West Kalimantan. Therefore, soil's physical and chemical properties are vital in determining site-specific management, as highlighted by Yao et al. (2014). Consequently, this study aims to investigate the impact of slope aspects on certain soil physicochemical properties under oil palm plantations in Selangor, Malaysia.

MATERIALS AND METHODS

Study area

This study was carried out at an oil palm plantation established on a sloping terrain in FELDA Gedangsa plantation, Selangor, Malaysia (Figure 1), at the latitude and longitude of 03 43'N and 101 24'E, respectively. The plantation has a tropical rainforest climate. Based on rainfall data collected at the Tanjung Malim Meteorological Station, located approximately 15 km from the study area, the average annual rainfall in the study areas for two years, 2019 and 2020, was 3,410 mm.

Field study

An eleven (11) year old oil palm plantation on sloping land in the study area was used for the research. Two slope aspects, the south-facing and north-facing slope aspects, were selected. The first site faced South with an area of 100.1 ha, while the second faced north with a land mass of 168.21 ha. The palm trees are planted in an equilateral triangular pattern, with slope positions: the Summit, Sideslope, and Toeslope. The experimental design uses was a split-plot arranged in RCB design with three replications. On each slope aspect, three sectors were arranged at a 50 m × 100 m spacing along the horizontal contour Figure 2. In each sector, three plots were established in a row and spaced 50 m × 20 apart. The sampling was carried out 1m away from the palm trunk. The sampling was done twice: March 2019 and March 2020. The North and South slope aspects form the main plot, while the Summit, Sideslope, and Toeslope positions constitute the subplot.

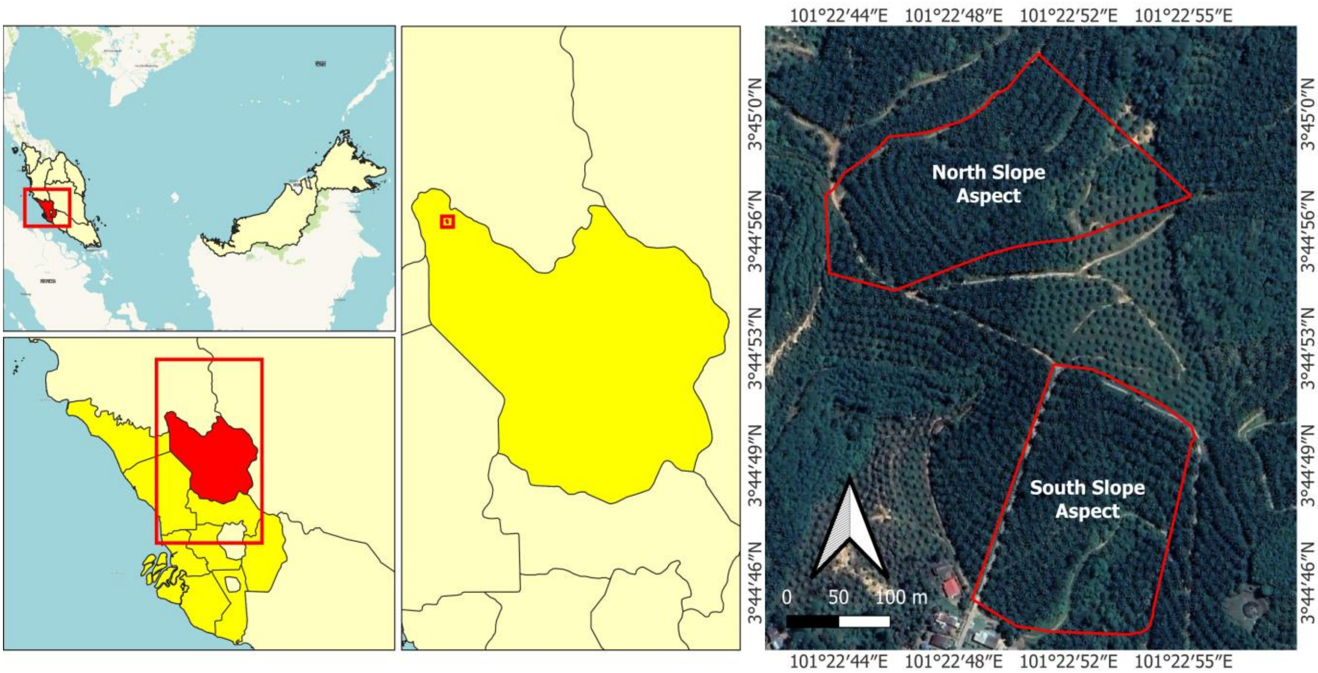

Figure 1. The FELDA Gedangsa; Hulu Bernam, in the district of Hulu Selangor, and the study site of North and South slope aspects

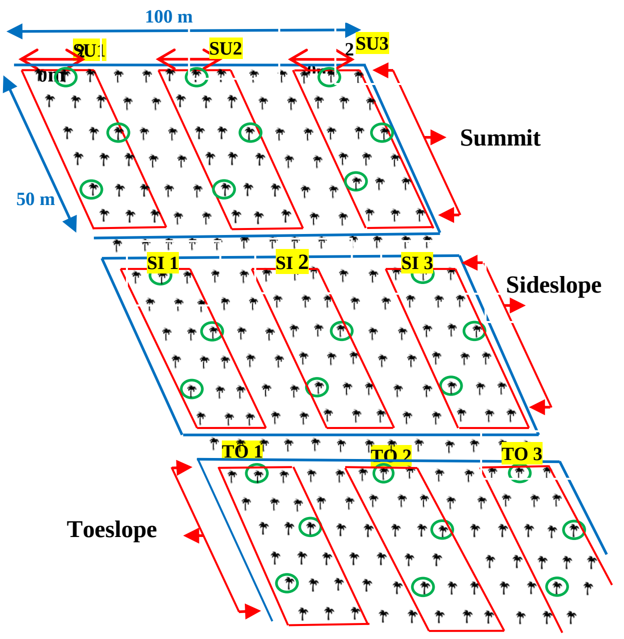

Figure 2. Slope layout for the experimental design and sampling protocol for leaf, soil, and yield within a typical block. Note: SU1, SU2, SU3: Three replications in summit position; SL 1, SL 2, SL3: Three replications in sideslope position; TO1, TO2, TO3: Three replications in toeslope position; (palm symbol) : The selected palm trees for sample collection (Yield, soil, and leaf)

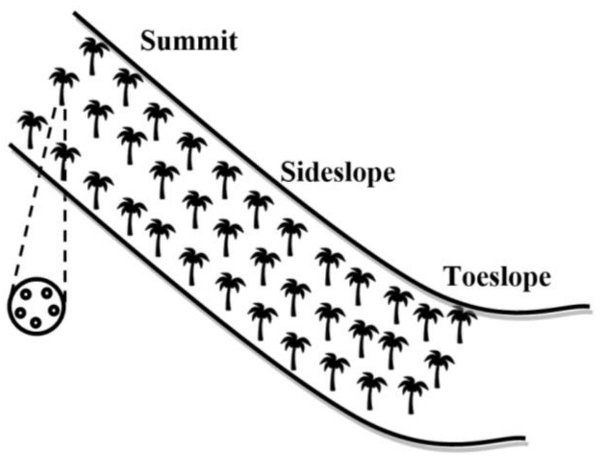

Figure 3. Layout soil sampling at oil palm plantation FELDA Gedangsa

Soil Sampling

Two sampling depths of 0-20 cm and 20-40 cm were employed. Each analysis was conducted on a composite sample formed by mixing five soil subsamples from five points (Figure 3). A soil auger was used in the sampling. The soil samples were crushed, air-dried at room temperature, debris removed, and then sieved through a 2 mm sieve.

Soil analysis

Total nitrogen was determined using the Kjeldahl technique. Available phosphorus was determined colorimetrically after extraction with Bray P-1 solution (Bray and Kurtz 1945). The soil pH was measured by a pH meter (Model Metrohm 827, Riverview, FL, USA) after mixing the soil with distilled water in a ratio of 1:2.5. The EC was measured using an EC meter (Mettler Toledo Seven Easy TM Conductivity Meter S30, Hamilton, New Zealand) (Alarefee et al. 2021). Soil exchangeable cations such as potassium (Exc. K), calcium (Exc. Ca), and magnesium (Exc. Mg) were extracted by ammonium acetate method and determined by flame photometry (K+) and atomic absorption spectroscopy (Ca2+ and Mg2+) (Tan et al. 2014; Behera et al. 2017). The pipette or hydrometer method determines particle size distribution (Adzemi et al. 2017).

Statistical analysis

A two-way variance analysis (ANOVA) determines the significant differences in oil palm yield and soil properties between different slope positions and aspects. Differences between means of parameters were considered significant at the 0.05 level using Tukey's studentized test. Pearson's correlation, using the SPSS version 26 software package, determined the variables' relationships.

RESULTS AND DISCUSSION

Effect of slope aspect on selected soil properties for the northern and southern slopes at 0-20cm depth

The slope position and aspect influenced different soil properties, as shown in Table 1. The means of the selected soil at 0-20 cm depth on both the northern and southern slopes for 2019/2020 were compared.

Soil pH

In this study, the pH of the soil in both slope aspects was found to be acidic, which ranged from 4.09±0.02 to 5.62±0.29. The highest soil pH was observed in the Toeslope at the South aspect, while the lowest was in the North aspect of the Toeslope. Oil palm can survive in acidic soil and grow in pH levels from 4.00 to 5.50. Significant differences ($P<0.05$) were observed between the North and South aspect slopes at all three positions in both aspect slopes. In the South aspect slope, the highest value was in the Toeslope and the lowest in the Summit. The increased pH levels in the soil are caused by the buildup of ions and salts resulting from root biomass, crop residue mineralization, and plantation management practices, and this is consistent with (Tan et al. 2014) and (Behera et al. 2020), who reported that soil pH was higher at the Toeslope position under oil palm plantations.

Similarly, Yasin and Yulnafatmawita (2018) mentioned that soil organic matter, among several factors, contributes to the higher pH value at the bottom slope. Rosenani et al. (2016) reported that increasing organic matter application at the bottom slope position had increased the soil pH.

The variation in soil pH was notably significant ($P<0.05$) in the Southern aspect, consistent with the findings of Ofori et al. (2013) and Olubanjo and Maidoh (2017). They stated that the rise in pH downhill may be attributed to increased exchangeable cations, especially magnesium and calcium, in the lower slope position due to higher clay content. A significant contrast ($P<0.05$) was observed between the slope of the Northern aspect and that of the Southern aspect, with higher pH in the Southern aspect than in the Northern aspect slope (Ofori et al. 2013; Olubanjo et al. 2017).

Electrical Conductivity (EC)

Electrical Conductivity (EC) observed a significant difference ($P>0.05$) among three slope positions at both aspect slopes in-depth; the highest value of the electrical conduction was 0.08±0.01 on the toe slope at the north slope. In contrast, the lowest value was 0.03±0.00 on the Sideslope for both slopes, while there was no significant difference between the north and south aspect slopes. The erosion process depletes soil productivity by changing the salts in the root zone concentration (Khan et al. 2013). The suspended clay accumulates water-soluble cations and anions, which move down the slope with surface runoff. Therefore, it accumulates at the Toeslope, which might have caused an increase in EC at the Toeslope positions.

Calcium (Ca), magnesium (Mg), and potassium (K)

The calcium (Ca), magnesium (Mg), and potassium (K) content of the soil in the study area were significantly ($P<0.05$) affected by different slope positions. The calcium (Ca) concentration ranged between 2.50±0.34 and 0.99±0.11 in the south aspect slope, while in the north aspect slope ranged from 1.22±0.06 to 1.07±0.10 cmol kg^{-1}. Furthermore, calcium was significantly ($P<0.05$) affected by different slope positions in the South aspect slope, with the highest Ca concentration in the Toeslope. In contrast, the lowest was on the Sideslope. In contrast, no significant differences ($P>0.05$) existed between the three positions in the North aspect slope. On the other hand, the aspect slope had a significant effect ($P<0.05$) on Ca content, with a higher value observed at the South aspect, while the lowest was recorded at the North aspect slope.

On the other hand, the magnesium (Mg) concentration ranged between 0.31±0.05 and 0.13±0.01 cmol kg^{-1} in the South aspect slope, while in the North aspect slope, it ranged from 0.19±0.04 to 0.14±0.02 cmol kg^{-1}. Magnesium was significantly ($P<0.05$) affected by different slope positions in the South aspect slope. The highest concentration of Mg was at the Toeslope, whereas the lowest was at the Summit. In comparison, no significant difference ($p>0.05$) between the three positions in the North aspect slope. The slope aspect had a significant effect ($P<0.05$) on the Mg content, and the higher values were recorded at the North aspect slope while the lower Mg were obtained at the South aspect slope.

The potassium (K) concentration ranged from 0.18±0.06 to 0.05±0.01 in the South aspect slope and 0.06±0.01 to 0.03.±.0.01 in the North aspect slope. The potassium (K) value was highest at the Toeslope, which differed significantly ($P<0.05$) from other slope positions in the South aspect slope. There was no significant difference ($P>0.05$) between the three positions of the North aspect slope. On the contrary, a significant difference ($P<0.05$) between the South and North aspect slopes, especially in the Toeslope. This is due to increased clay content at the Toeslope, downward movement with runoff water from the Summit, and accumulation at the Toeslope position. This agrees with Rasool et al. (2014) and Olubanjo and Maidoh (2017), who reported that calcium and magnesium were significantly ($P<0.05$) affected by different slope positions. The bottom slope position had the highest values for calcium and magnesium due to an increase in the clay content at the bottom slope (Rasool et al. 2014; Olubanjo and Maidoh 2017).

Total nitrogen (N)

The significantly higher Nitrogen (N) (0.08±0.01) was observed in the Toeslope of both slopes (North and South), and the lowest (0.04±0.01) was similarly obtained in the Summit of the slopes. There was a significant difference ($P<0.05$) in terms of the total nitrogen across the slope positions, but there was no significant difference ($P>0.05$) between the South and north aspect slopes; this is due to the effect that soil nutrients are transported from the Summit to the Toeslope of the slope at the planting site by hydro erosion processes, which promotes increased microbial activity, which may, in turn, enhance the decomposition process and the release of nutrients. This agrees with Mesfin et al. (2018). Also, Rahman et al. (2021) and Liu et al. (2023) reported that crop residue and N fertilizer increased SOC and total N stocks at 10 cm depth. However, the effects of N fertilizer and crop residue retention were only seen in the early years of conservation practices; it did not continue to increase SOC and total soil N over time.

Table 1. Mean comparison of soil properties at 0-20 cm depth on Northern and Southern slopes for 2019 and 2020

Soil properties	Northern slope			Southern slope		
	Summit	Sideslope	Toeslope	Summit	Sideslope	Toeslope
pH	4.33±0.27^{c}	4.43±q.0.11^{bc}	4.09±.0.02^{c}	5.13±0.45^{ab}	4.56±0.13^{bc}	5.62±0.29^{a}
EC ds/m	0.04±0.01^{b}	0.03±0.00^{b}	0.08±0.01^{a}	0.04.±.0.01^{b}	0.03±0.00^{b}	0.07±0.01^{a}
Ca (cmolc kg^{-1})	1.22±0.06^{bc}	1.07±0.10^{bc}	1.16±0.15^{bc}	1.61±.0.03^{b}	0.99±0.11^{c}	2.50±0.34^{a}
Mg (cmolc kg^{-1})	0.15±0.01^{b}	0.14±0.02^{b}	0.19±0.04^{b}	0.13±.0.01^{b}	0.13±0.01^{b}	0.31±0.05^{a}
K (cmolc kg^{-1})	0.05±0.01^{b}	0.03.±.0.01^{b}	0.06±0.01^{b}	0.07±0.06^{ab}	0.05±0.01b^{a}	0.18±0.06^{a}
N%	0.04±0.01^{b}	0.06±0.01^{ab}	0.08±0.01^{a}	0.04.±.0.01^{b}	0.06±0.01^{ab}	0.08±0.01^{a}
Avai P (mg kg^{-1})	2.90±1.11^{a}	2.70±.0.60a	3.22±1.17^{a}	1.71±0.23^{a}	3.18±1.46^{a}	3.29±0.41^{a}
Clay (%)	35.36±2.75^{b}	35.27±6.12^{b}	46.03±0.39^{a}	36.31.±.4.36^{ab}	36.32±0.89^{ab}	46.10±4.38^{a}
Silt (%)	1.93±0.85^{a}	1.09±.0.22^{a}	1.90±0.23^{a}	1.82±0.26^{a}	1.69±2.23^{a}	1.80±0.110^{a}
Sand (%)	62.70±3.57^{ab}	63.69±.6.23^{a}	52.06±0.27^{bc}	61.85±2.26^{ab}	59.40±2.72^{b}	50.09±3.31^{c}

Note: Ca: Exchangeable Calcium; Mg: Exchangeable Magnesium; K: Exchangeable Potassium; N: Total Nitrogen; Avai. P: Available Phosphorus

Available phosphorus (P)

The distribution of available phosphorus (P) indicates that phosphorus content in slope soil is medium to high, and the available phosphorus decreases as the slope segment increases. Table 1 showed no significant difference (P>0.05) between the three slope positions concerning the available phosphorus in the soil. Table 1 also showed no significant difference (P>0.05) between the North aspect slope and the South aspect slope, which might be due to nutrient downward movement with runoff water from the Summit position and accumulation there at the Toeslope position; this agrees with several researchers (Khan et al. 2013; Ofori et al. 2013; Rasool et al. 2014) who reported that the highest value of phosphorus occurred at the bottom slope.

Soil texture

At a depth of 0-20cm, the textural class of the soil of the study area ranged from sandy clay to sandy clay loam. The clay content of the Summit, Sideslope, and Toeslope positions under the South slope were 36%, 36%, and 46%, respectively, which differed significantly. Also, under the North slope, the Summit to Sideslope and Toeslope positions were 35%, 35%, and 46%, respectively. However, there was no significant difference (P>0.05) between the North and South slopes regarding the clay content.

The silt content of Summit, Sideslope, and Toeslope positions under the South slope was 1.8%, 1.7%, and 1.8%, respectively, and there was no significant difference (P>0.05) between the slope aspects. Similarly, there was no significant difference (P>0.05) between the aspects of the North slope, with 1.95%, 1.1%, and 1.9% for the Summit, Sideslope, and Toeslope aspects; there was no significant difference in the North and South slopes.

The sand was the highest soil particle in both aspects' slopes, with 61%, 59%, and 50% from the Summit, Sideslope, and toeslope positions under the South slope. However, under the north slope, the Summit, Sideslope, and Toeslope positions had 62%, 63%, and 52%, respectively. There was a significant difference (P<0.05) between the three slope positions (Summit, Sideslope, and Toeslope) in terms of the sand in both slope aspects. In the South slope aspect, the slope positions differ significantly (P<0.05), with the higher value at the Summit position and the lowest at the Toeslope position. The highest value was recorded in the side slope position on the north slope, and the lowest was found in the Toeslope position. However, on average, there was no significant difference (P>0.05) between the North and South slopes.

The clay and silt percentages were highest in the Toeslope position, while the Summit position had the lowest value. However, sand was the dominant particle size irrespective of the slope positions, despite the greater sand content at the Summit and the lower at the Toeslope. When soil erosion occurs, especially in terraces, fine particles are suspended in the accumulated water and transported down the slope, leaving the coarse material in the upper slope sites with less porous areas and greater soil density. Negasa et al. (2017) reported that slopes affect the distribution of soil particles (sand, silt, and clay) under different land management systems. Moreover, they reported that the sequential topography tends to increase clay particles. However, Tan et al. (2014) reported a lack of <8% slope erosion susceptibility at oil palm plantations in central Pahang.

Effect of slope aspect on selected soil properties for the northern slope and southern slope at a depth of 20-40 cm

The slope position and aspect influenced different soil properties, as shown in Table 2. The result compared the means of the selected soil at 20-40 cm depth on both the northern and southern slopes for 2019-2020.

Soil pH

The soil pH at 20-40 cm depth in both slopes aspects was found to be acidic, whereas the soil pH in both aspects slope ranged from 5.03±0.12 to 3.96±0.22, with the highest value in the Toeslope position of the South aspect, while the lowest was in the Summit position of the North aspect. In addition, there was no significant difference (P>0.05) observed between the three slope positions at the South aspect slope; however, significant differences were observed (P<0.05) between the slope aspects of North and South. This is consistent with various studies (Ofori et al. 2013; Olubanjo et al. 2017), which found a decreased pH of the North aspect slope and attributed it to higher soil water content, organic matter, and vegetative cover. In addition, depth affected soil pH, with pH decreasing with depth. The highest pH was 0-20 cm depth, and the lowest was 20-40 cm depth.

Electrical Conductivity (EC)

There was no significant difference (P>0.05) between the North aspect slope and the South aspect slope in terms of Electrical Conductivity (EC) among the three slope positions, irrespective of the slope aspects at a depth of 20-40 cm. The highest EC of 0.06±0.01 dS/m was observed in the Toeslope position, while the lowest of 0.03±0.00 dS/m was recorded in the Sideslope position. Similarly, there was no significant difference (P>0.05) between the two (North and South) slope aspects. However, N, P, K, and Ca uptake significantly increased with higher EC values. Also, the increase in EC with depth is due to the downward movement of soluble ions with percolating water during the erosion processes and its accumulation in the compact subsoil (Khan et al. 2013; Karimizarchi et al. 2014; Goh et al. 2016).

Calcium (Ca), magnesium (Mg) and potassium (K)

The soil's calcium (Ca) content in the South aspect ranged between 1.51±0.25 to 0.88±0.05 at the Toeslope and Sideslope positions. Meanwhile, the calcium in the north slope ranged between 1.05±0.02 to 0.98±0.08 in the Summit to Sideslope position. There was a significant difference (P<0.05) between the three positions in the South slope aspect, while there was no significant difference (P>0.05) between the three positions in the North slope aspect. On the other hand, there was a significant difference (P<0.05) between the South aspect slope and the North aspect slope at the Toeslope position. On the other hand, the magnesium (Mg) ranged between 0.23±0.01 to 0.11±.0.01 from Toeslope and Summit positions in the South aspect slope, while it ranged between 0.13±0.00 to 0.12±0.01 from Toeslope to Summit positions in the North slope aspect. The three slope positions differ significantly ($P<0.05$) from one another at the South slope aspect; however, the slope positions did not differ under the North slope aspect. On the other hand, there was a significant difference ($P<0.05$) between the South aspect slope and the North aspect slope at the Toeslope position. This agrees with Olubanjo and Maidoh (2017), who reported that calcium and magnesium were significantly ($P<0.05$) affected by variations in slope positions.

The potassium (K) content in the South slope aspect was 0.14±0.02 in the Toeslope position and 0.05±0.02 in the Sideslope position. In the North slope aspect, it was 0.07±0.02 in the Toeslope position and 0.03±0.02 in the Sideslope position. Potassium (K) concentration was the highest at the Toeslope, which differed significantly ($P<0.05$) from other slope positions in the South slope aspect. In contrast, there was no significant difference in the three positions in the north aspect slope. On the other hand, there was a significant difference ($P<0.05$) between the South and North aspect slopes, mainly in the Toeslope positions. Depth influenced calcium, magnesium, and potassium content, where the lowest value was recorded at the 20-40 cm depth. This agrees with (Olubanjo et al. 2017), who reported that different soil depths significantly affected calcium and magnesium ($P<0.05$).

Total nitrogen (N)

The concentration of total nitrogen (N) in 20-40 cm depth was highest at the Toeslope irrespective of the aspects with 0.05±0.01, and the lowest value of 0.02±0.01 was recorded in the summit position under both slopes' aspects. There was a significant difference ($P<0.05$) in the total nitrogen across the slope positions, but there was no significant difference between the South aspect slope and the North aspect slope. The depth of 20-40 cm had the lowest value of total nitrogen while 0-20 cm depth had the highest value, which agrees with Olubanjo and Maidoh (2017) who reported a decrease in total nitrogen content with an increase in depth in a study about the influence of slope and depth on soil chemical properties in an oil palm plantation.

Available phosphorus (P)

The distribution of available phosphorus (P) at 20-40 cm depth showed the highest value at the South slope was 1.63±0.07, obtained in the Summit position. Meanwhile, the lowest value of 1.35±0.18 was found in the Sideslope position. In the North slope aspect, the highest and lowest available P of 1.85±0.77 and 1.48±0.15 were obtained in the Sideslope and Summit positions, respectively. There was no significant difference between the three slope positions in the North and South aspect slopes. Depth influenced the soil's phosphorus. The 20-40 cm depth was observed as the lowest value. This agrees with Khan et al. (2013), Rasool et al. (2014), and Olubanjo et al. (2017).

Soil texture

Based on the particle size distribution (sand, silt, and clay), the soil's textural class in the study area ranged from sandy clay to sandy clay loam at the lower depth of 20-40 cm.

The average clay content at the South slope was 41%, 40%, and 52% in the Summit, side slope, and Toeslope positions, respectively. A significant difference ($P<0.05$) across the three slope positions on the South slopes existed. Also, in the North slope aspect, the averaged clay content of Summit, Sideslope, and Toeslope was 39%, 40%, and 51%, respectively, which differ significantly ($P<0.05$) from one another. Similarly, there was a significant difference ($P<0.05$) between the North and South slope aspects.

The silt content of the South slope was 1.6%, 1.4%, and 1.6% in the Summit, Side slope, and Toeslope position slope, respectively, which did not differ significantly ($P>0.05$). Also, in the South slope, silt content was 1.8%, 1.3%, and 1.7% in the Summit, Sideslope, and Toeslope positions, respectively, with no significant difference. In addition, there was no significant difference between the North and South aspect slopes.

Table 2. Mean comparison of soil properties at 20-40 cm depth on Northern and Southern slopes for 2019 and 2020

Soil properties	Northern Slope			Southern Slope		
	Summit	Sideslope	Toeslope	Summit	Sideslope	Toeslope
pH	3.96±0.22^{b}	4.21±.0.10^{b}	4.26±.0.18^{b}	4.96±0.43^{a}	4.56±0.08^{ab}	5.03±0.12^{a}
EC ds/m	0.05±0.01^{a}	0.03±0.00^{a}	0.04±0.01^{a}	0.04.±.0.02^{a}	0.04±0.00^{a}	0.06±0.01^{a}
Ca (cmolc kg^{-1})	1.05±0.02^{b}	0.98±0.08^{b}	1.03±0.03^{b}	1.09±.0.15^{b}	0.88±0.05^{b}	1.51±0.25^{a}
Mg (cmolc kg^{-1})	0.12±0.01^{b}	0.13±0.02^{b}	0.13±0.00^{b}	0.11±.0.01^{b}	0.12±0.01^{b}	0.23±0.01^{a}
K (cmolc kg^{-1})	0.05±0.02^{a}	0.03.±.0.02^{a}	0.07±0.02^{a}	0.07±0.02^{a}	0.05±0.02b^{a}	0.14±0.02^{a}
N%	0.02±0.01^{b}	0.04±0.01^{ab}	0.05±0.01^{a}	0.02.±.0.01^{b}	0.04±0.01^{ab}	0.05±0.01^{a}
Avai P (mg kg^{-1})	1.48±0.15^{a}	1.54±.0.10^{a}	1.85±0.77^{a}	1.63±0.07^{a}	1.35±0.18^{a}	1.42±0.50^{a}
Clay (%)	38.87±2.15^{c}	39.70±2.14^{bc}	50.88±1.63^{ab}	40. 98.±.7.47^{b}	39.61±1.63^{bc}	51.69±6.58^{a}
Silt (%)	1.82±0.12^{a}	1. 31±.0.14^{a}	1.67±0.07^{a}	1.60±0.26^{a}	1.41±0.32^{a}	1.64±0.22^{a}
Sand (%)	58.96±1.79^{a}	59.31±.1.72^{a}	47.44±1.60^{b}	61.07±1.48^{a}	58.97±1.46^{a}	49.66±1.42^{b}

Note: Ca: Exchangeable Calcium; Mg: Exchangeable Magnesium; K: Exchangeable Potassium; N: Total Nitrogen; Avai. P: Available Phosphorus

Table 3. Soil profile analyses for typical inland and coastal soils of Malaysia

Soil series	Depth (cm)	Texture (%)			C (%)	N (%)	PH	Exchangeable cations (meq/100 g)		
		Sand	Silt	Clay				K	Ca	Mg
Inland soils, sedimentary rock parent material										
Serdang	0-8	76	2	22	1.27	0.10	4.7	0.14	0.08	0.42
(sandstone derived)	8-120	59	2	38	0.37	0.04	4.6	0.09	0.05	0.13
Coastal soil, alluvial parent material										
Selangor (marine clay)	0-15	2	18	80	1.31	0.20	4.7	1.57	4.8	14.2
	15-135	8	18	74	1.08	0.12	5.4	1.21	7.0	12.9

Note: 1 meq/100 g = 1 cmol/kg for K and 0.5 cmol/kg for Ca and Mg. CEC is given as cmol electric charge/kg soil equal to meq/100 g. Simplified from (Corley and Tinker 2015)

The sand was the highest particle of soil texture in both aspect slopes, with 61%, 58%, and 50% in the Summit, side slope, and toeslope position of the South slope aspect, respectively. In the north slope aspect, the Summit, Sideslope, and Toeslope positions had 59%, 59%, and 47%, respectively. There was a significant difference ($p<0.05$) across the three slope positions (Summit, Sideslope, and Toeslope) in terms of the sand proportions of both the North and South slope aspects. The Summit position had the highest sand content on the South slope, while the Toeslope had the lowest. While in the North slope, the highest sand content was recorded in the Sideslope position, and the lowest was observed in the Toeslope position. On the other hand, there was no significant difference ($P>0.05$) between the north and south slope aspects.

The clay content increased with depth as the higher content was gained at the lower depth (20-40 cm), while the lowest clay content was recorded at the upper depth (0-20 cm). The silt and sand proportions were highest at 0-20 cm and decreased downwards with their lower content at 20-40 cm depth. This is consistent with Olubanjo et al. (2017), who stated that the highest content of sand was found on the Summit slope. The clay and silt fractions were highest in the Toeslope position, while the Summit position had the lowest content. The sand was the dominant fragment in the three slope positions, with the highest value occurring at the Summit and the lowest at the bottom. This is also in line with the work of Khan et al. (2013), Yasin and Yulnafatmawita (2018).

You can refer to Table 3 to analyze the soil characteristics of typical inland and coastal soils in Malaysia for geological information about the parent soil materials and nutrient availability (Corley and Tinker 2015).

In conclusion, the study on physio-chemical characteristics of the soil in different slope positions and aspects in FELDA Gedangsa plantation, Selangor, Malaysia indicated variations in soil properties among the different slope positions and slope aspects. The soil pH at 0-20 cm and 20-40 cm depths was acidic across all slope aspects. However, significant differences ($p<0.05$) were observed between the North and South aspect slopes and among their three distinct slope positions at the 0-20 cm depth. At the 20-40 cm depth, while the pH remained acidic, no significant difference was noted among the three slope positions. Regarding Electrical Conductivity (EC), no significant difference was found between the slope aspects and their positions at the 20-40 cm depth. However, the aspect slope significantly influenced ($p<0.05$) the concentrations of calcium (Ca) and magnesium (Mg) at both depths. The potassium (K) concentration was similarly affected by the slope aspect at both surface and subsurface depths. Regarding total nitrogen (N), the slope aspects did not influence the N content at any soil depth, with no significant difference observed between the two. However, a significant difference was noted among the slope positions of both the North and South slope aspects. The available phosphorus (P) in the slope soil ranged from medium to high, decreasing with an increase in the slope segment. No significant difference ($p>0.05$) was found between the North and South aspect slopes at both depths. The percentages of clay and silt were highest in the Toeslope position, while the Summit position recorded the lowest value. The sand was the dominant particle, irrespective of the slope positions and depth.

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