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The Effects of Sweet Corn and Groundnut Intercropping on the Growth of Durian Seedlings (Musang King Variety) and Soil Physico-chemical Properties in a Durian Orchard

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ABSTRACT

Between 2016 and 2021, the area under durian (*Durio zibethinus* Murr.) cultivation expanded by 29% in Malaysia, with farmers increasingly preferring high-value varieties such as Musang King. During the durian tree's five-year vegetative stage, intercropping with crops like sweet corn and groundnut offers farmers an additional income stream and supports durian growth. From January 2020 to April 2021, a two-season study at Pusat Pertanian Putra Puchong, Universiti Putra Malaysia, employed a between-subjects design, comparing durian plots with and without intercropping. Crop growth variables and soil physical and chemical properties were measured, and differences were analyzed using independent t-tests. Results showed that intercropping had minimal effects on durian seedling height, canopy diameter, and stem girth. However, the intercropping practices significantly increased chlorophyll a (by 17.80%), chlorophyll b

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(11.57%), total chlorophyll (15.46%), and carotenoid content (28.57%) in durian leaves. Soil quality also improved in the intercropped plots, with pH rising from 4.35 to 5.38 and calcium concentration increasing from 0.07 to 0.30%, representing 1.89% and 109.46% increases compared to the control plot after the second season. Soil compaction was reduced, as penetration resistance dropped from 1.59 MPa in the control to 0.70–0.78 MPa in the intercropped plots. These findings indicate that intercropping sweet corn and groundnut in young durian orchards can be considered a sustainable practice, enhancing soil health and diversifying farmers' income without compromising durian growth. Farmers are encouraged to adopt intercropping during the non-fruiting stage to maximize both economic and agronomic benefits.

Keywords: Agroforestry, durian, groundnut, intercropping, smallholders, sweet corn

INTRODUCTION

Durian, scientifically known as *Durio zibethinus* Murr., is the most popular species in the Durio genus, has been cultivated for centuries and known as the king of tropical fruits (Salma et al., 2018). In Malaysia, the planted area for this crop increased by approximately 29% from 66,000 hectares in 2016 to 85,000 hectares in 2021, as reported by the Ministry of Agriculture (2019) and Department of Agriculture (DoA, 2021). In 2021, the production value of durian reached 4.5 million tons, equivalent to 8.5 billion in value, the highest among other types of fruit (DoA, 2021). One of the factors contributing to the increase in the planted area for durian was the involvement of small farmers who were changing their existing crops to durian. Additionally, there were farmers who were converting their existing durian plants to commercial and high-value varieties such as Musang King (D197) and Black Thorn (D200). This trend was in line with government encouragement (DoA, 2016).

During the vegetative stage of durian cultivation, smallholders need to find additional income for their livelihoods. Practicing intercropping is one way to help farmers earn an income before profiting from the durian crop. This is because durian only bears fruit five years after planting (Rushidah et al., 2006). In durian orchards, two types of intercropping systems can be implemented. Firstly, durian can be intercropped with permanent crops such as cocoa (Mohd Jelani et al., 1992), coconut (Pamplona & Garcia, 1997), and mangosteen, rambutan, longkong, and petai (Issarakraisila et al., 2014). Secondly, durian can be intercropped during its vegetative or uneconomical stage with options like banana (DoA, 2000; Pamplona & Garcia, 1997), or cereals such as corn and legumes like groundnut (Ratanarat et al., 1997; Susiloadi et al., 1994).

Banana is a popular crop often intercropped with durian, a practice commonly adopted by many durian growers to provide temporary shading before durian trees begin to bear fruit (Pamplona & Garcia, 1997; DoA, 2000). Durian seedlings intercropped with banana exhibit greater height, larger stem diameter, and higher survival rates compared to those grown in open areas. Nonetheless, the incidence of phytophthora disease increases under this system (Pamplona & Garcia, 1997). Additionally, researchers have noted that durian trees grown in proximity to coconut trees tend to be slender, tall, and frequently afflicted by phytophthora. Phytophthora canker have been reported when durian is intercropped with cocoa (Solpot, 2022).

To overcome this problem, intercropping durian with short term cash crops such as sweet corn and groundnut between the wide rows of durian plants can be a solution. Additionally, smallholders often possess limited land size that may not be economically viable for monoculture durian planting. This necessitates reducing the number of planted durian trees to allow for larger spacing between them, facilitating intercropping with other plants. This preference for monoculture durian planting is driven by the desire to maximize the number of durian trees per area, thereby increasing revenue potential compared to intercropping with jungle fruit trees or other cultivation systems such as durian with forestry or durian with para rubber (Radchanui & Keawvongsri, 2017).

The produce from sweet corn and groundnuts can be sold to enable smallholders to earn a profit. However, the effects of intercropping activities on durian seedlings and soil conditions in the orchard need to be studied. This is because durians are susceptible to root disease infection. Additionally, the cost of establishing durian orchards is very high, and improper management will increase production costs. A study conducted by Susiloadi et al. (1994) concluded in general terms that the growth of durian seedlings is not adversely affected by intercropping with sweet corn and several types of legumes, including groundnuts, in young durian orchards. Therefore, this study was conducted to investigate the effects of intercropping sweet corn and groundnuts in a young durian orchard on the (i) growth of durian seedlings and (ii) soil physical and chemical characteristics.

MATERIALS AND METHODS

Experimental Site Description and Duration of Study

The experiment was conducted in a one-year-old durian orchard at Pusat Pertanian Putra – Putra Agricultural Center (PPP), Universiti Putra Malaysia (UPM), Puchong, Selangor (N 2º 98’ 61.9”, E 101º 64’ 65.6”), from January 2020 to April 2021. During this period, a study on intercropping sweet corn and groundnut was carried out over two cropping seasons. The soil at the experimental site belongs to the Bungor Series, which is classified as a Typic Paleudult (Radziah et al., 2006). The monthly mean temperatures ranged from 24.40 to 34.70 °C, monthly rainfall varied between 3.70 and 17.40 mm, and the monthly mean relative humidity ranged from 49.20% to 74.60% (Table 1) (Malaysian Meteorological Department, 2022).

Table 1
Selected climatic factors during the experimental period from January to April 2020, and from January to April 2021

Year/month	Temperature (ºC)		Rainfall (mm)	Mean relative humidity (%)
	Minimum	Maximum		
2020				
January	25.70	33.7	8.3	70.0
February	25.70	33.8	7.0	66.5
March	26.00	34.6	12.5	71.2
April	25.70	34.7	17.4	74.6
2021				
January	25.00	31.7	4.9	70.4
February	23.40	31.6	3.7	49.2
March	25.20	33.9	13.1	71.9
April	24.40	32.6	11.1	73.0

Source: Malaysian Meteorological Department (2022)

Experimental Design and Treatments

The experimental design employed in this study was a between-subjects design comparing two treatments, consisting of durian area where, (1) without intercropping (control) and (2) with intercropping of sweet corn and groundnut. Each treatment was replicated using six durian seedlings. The size of the experimental area for both treatments (with and without intercropping) was 7,200 m² (120 m × 60 m) (Figure 1). The intercropped sweet corn and groundnut plots were established within the durian planting rows, approximately 2.00 m

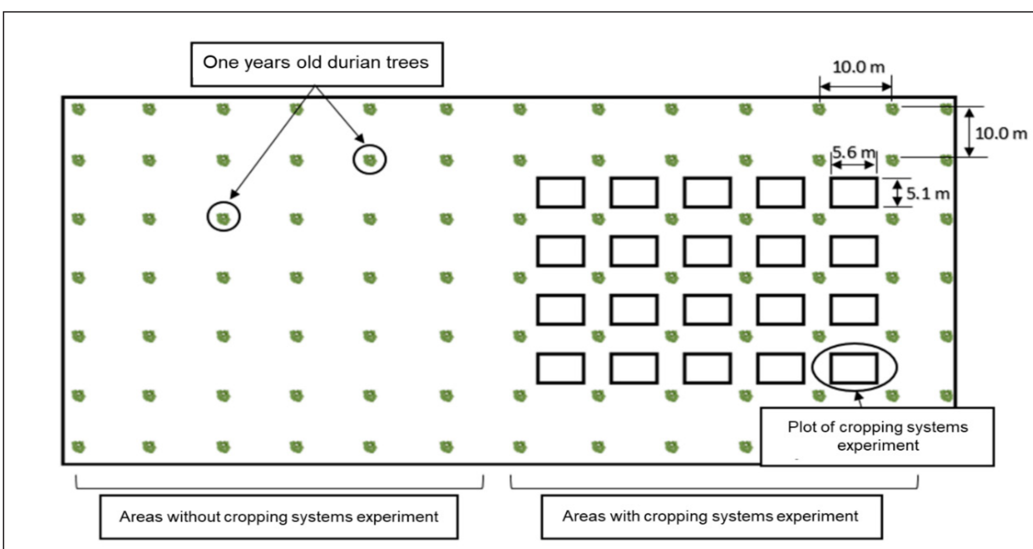

Figure 1. General plot layout

away from each durian seedling. The durian seedlings in this orchard were not planted specifically for this experiment but had been planted one year earlier. All routine activities and general field maintenance, such as weeding, manuring and liming were managed by PPP, UPM Puchong, and carried out on a scheduled basis.

Durian Seedlings Growth Parameters

Plant Height, Canopy Diameter, Main Stem Diameter and Girth

The growth parameters of durian, such as plant height, canopy diameter, main stem diameter, and main stem girth, were measured both before the commencement of the cropping systems experiment in season 1 and after the conclusion of season 2 was based on the works of Yaacob et al. (1978) and, Hoe and Palaniappan (2013). Plant height, canopy diameter, and main stem diameter were measured using a measuring tape, while the main stem girth was measured using a vernier calliper. A permanent marker was used to denote the base of the trunk at ground level. Plant height was measured from this mark to the top of the canopy, while main stem diameter and girth were measured 10 cm from the mark. The canopy diameter was determined by measuring the longest spread of the canopy from left to right. The values obtained were expressed in cm plant^{-1}.

Root Weight

Root weight measurements were done based on the method outlined by Masri (1991). Two soil core samples were extracted for each selected durian seedling using an aluminium tube with a diameter of 3 cm. To ensure unbiased sampling, the samples were taken at 50 cm (approximately half of the canopy radius) from the base of the main stem. The aluminium tubes were gently hammered into the soil until a depth of 50 cm was reached. The soil and root-containing samples were then washed through a 2 mm sieve to separate the roots from the soil. Smaller roots that passed through the sieve were collected and suspended on a fine nylon mesh. The collected roots were subsequently dried in the oven at 72ºC for 2 days before being weighed using an analytical digital balance (Radwag AS 220-R2, Torunska, Poland). The values obtained were expressed in g plant^{-1}.

Leaf Parameters

Five fully mature leaves per plant (leaves number 6 – 7 from the plant apex) were selected for the measurement of several leaf parameters, including SPAD data, chlorophyll ‘a’, ‘b’, and total chlorophyll content, as well as nitrogen concentration. SPAD values were assessed using the SPAD meter (502Plus Chlorophyll Meter, Minolta Camera Co., Osaka, Japan) in the field. Subsequently, the leaves were punched using a paper hole puncher to obtain approximately 200 mg of small leaf cuts for chlorophyll determination, following the method described by Srivastava (2009). Similar leaves were harvested, dried in the oven at 72ºC for 2 days, ground into powder using a pulverizer and passed through a 0.7 mm sieve. The ground leaf samples were then used for the determination of total nitrogen concentration, following the method outlined by Horneck and Miller (1998).

Chlorophyll Content

Chlorophyll content measurements were done based on the method outlined by Srivastava (2009). The small pieces of leaves, approximately 200 mg per sample per plant, were ground together with 10 ml of 80% acetone in a pestle and mortar. The homogenate was then transferred into a 25 ml volumetric flask through a filter funnel covered with filter paper (Whatman Filter Paper No. 1). The pestle was washed with 5 ml of 80% acetone before transferring the remaining homogenate into the same volumetric flask. This process was repeated 2 to 3 times. The final volume of homogenate in the volumetric flask was adjusted with 80% acetone. The filtrate was then filled into the cuvette up to three-quarters of its total volume, and its absorbance was measured by a spectrophotometer (UV-3101PC UV-VIS-NIR, Shimadzu, Japan) at wavelengths of 645 and 663 nm against the solvent. Acetone with 80% concentration served as a blank. The amount of chlorophyll was calculated based on the formula below:

- Chlorophyll 'a' = $[(12.7 \times A663) - (2.69 \times A645)] \times V / 1000 \text{ x } W$
- Chlorophyll 'b' = $[(22.9 \times A645) - (4.68 \times A663)] \times V / 1000 \text{ x } W$
- Total Chlorophyll = $[(8.02 \times A663) + (20.2 \times A645)] \times V / 1000 \text{ x } W$

Where A is the absorbance at the given wavelength (663 or 645 nm), V is the total volume of the extract (ml), and W is the weight of the sample (g). The value obtained is expressed as mg of chlorophyll per gram of fresh weight sample (mg g^{-1}).

Leaf Total Nitrogen Concentration

The leaf samples, approximately 0.25 g were weighed. They were then mixed with 5 ml of 98% sulfuric acid (H_2SO_4) and one Kjeldahl tablet in a 100 ml digestion tube. The mixture was mixed using a vortex mixer for 15 seconds to thoroughly wet the sample with acid. The digestion tube was heated in a block digester at 150ºC for one and a half hours before further heating at 400ºC until the digestion became clear or colourless. After cooling down, the mixture was transferred into a 100 ml volumetric flask through a filter funnel covered with filter paper (Whatman Filter Paper No. 1). The digestion tube was rinsed with 10 ml of distilled water to collect the remaining sample solution, which was also transferred into the same volumetric flask. This rinsing process was repeated 2 to 3 times. The solution was then adjusted to a volume of 100 ml using distilled water before being transferred into a 100 ml plastic vial. The sample solution was pipetted into the distillation flask, mixed with 10 ml of 30% NaOH solution, and attached to the distillation unit. The condensate from the solution was collected in a 10 ml trap containing 2% boric acid mixed with an indicator dye (bromocresol green + methyl red) in a conical flask. The conical flask was removed from the distillation unit when the solution turned from purplish red to green, and the volume increased to approximately 50 ml. It was then slowly titrated with 0.01N hydrochloric acid (HCl) from a 100 ml glass burette attached to a stand until the colour returned to purplish red. The initial and final volumes of HCl in the burette were recorded and used for the determination of total nitrogen using the formula below:

$$\text{Tot. N concentration} = \frac{(Y_{HCl} - Z_{HCl}) \times HCl_{concentration} \times 14}{1000} \times \frac{V_{sam.}}{W_{sam.}} \times \frac{1}{10} \times 100\%$$

Where Tot. N concentration is total nitrogen concentration, Y_{HCl} and Z_{HCl} is final and initial volume of HCl (ml) respectively, $HCl_{concentration}$ is concentration of hydrochloric acid used (0.01N), $V_{sam.}$ is volume of sample solution (ml) and $W_{sam.}$ is weight of sample (g). The value obtained was expressed in %.

The values of nutrient concentrations obtained from the instrument were based on the sample weight. All samples used were standardized to a common or constant weight before being statistically analysed using the formula below:

$$N_{concentration(0.25)} = (N_{concentration\ (sam.)} \times W_{0.25} / W_x$$

Where, $N_{concentration(0.25)}$ is nitrogen concentration in % per 0.25 g, $N_{concentration(sam.)}$ is value of leaf nitrogen concentrations based on the sample weight, $W_{0.25}$ is sample weight of 0.25 g and W_x is sample weight (g) of measured for N concentration analysis. The same method of calculation was applied to all analysis to standardize all samples to a constant weight.

Soil Parameters

Soil Penetration Resistance

Soil penetration resistance data were obtained using Penetrologger 6.0, a portable electronic penetrometer equipped with a built-in data logger (Royal Eijkelkamp, Nijverheidsstraat, Giesbeek, The Netherlands). Two data points were measured for each selected durian seedling area at 50 cm from the base of the main stem. This measurement was conducted using a load cell connected to a cone screwed onto the bottom end of a bipartite probing rod. The cone utilized in this study has a 60° angle and a base area of 1 cm^2. The penetration speed was set at 2 cm s^{-1}. By exerting equal pressure on both electrically insulated grips, the cone is vertically pushed into the soil. An internal ultrasonic sensor accurately records the vertical distance above the soil surface, while the load cell calculates the readings at each depth. The device stores data up to a depth of 80 cm in the profile. However, to ensure consistent measurement points at each location, only resistance readings at every 10 cm up to a maximum soil penetration depth of 70 cm were utilized. Pressure measurements were expressed in MPa, and the measurement method was based on Royal Eijkelkamp (2022).

Soil pH, Cation Exchange Capacity and Organic Matter

Soil Sample Collection and Preparation

The soil sample collection and preparation were based on Van Reeuwijk (2002). Soil samples were collected from the orchard at four points around the durian seedlings, within a depth of 15.00 to 30.00 cm and at 1.00 m from the base of the main stem, using a soil probe. The soil probe ensured uniform soil volume throughout the sample depth (Sullivan et al., 2019). These samples were placed in plastic bags before being transferred to plastic trays for air-drying. Each plastic tray was labelled according to the area where the samples were collected. Large soil clods were broken up to expedite drying, and plant residue was removed. Once dried, the soil was sieved through a 2 mm sieve. Any remaining clods that did not pass through the sieve were crushed using a pestle and mortar and sieved again. The fine soil samples were then stored in Ziploc bags before analysis.

Soil pH

The soil pH was measured potentiometrically in the supernatant suspension of a 1:2.5 liquid (soil: liquid mixture). Distilled water was used as the liquid. Approximately 20 g of soil sample was weighed and placed into a 100 ml plastic vial and mixed with 50 ml of distilled water. The plastic vial was then sealed with a bottle cap and shaken for 2 hours using an orbital shaker at a speed of 180 rpm. The vial was manually shaken once or twice before taking the pH reading using a pH Benchtop meter (HI-2211, Hanna Instruments SRL, Romania), which had been calibrated beforehand. The reading was considered stable when it did not change by more than 0.1 unit per 30 seconds. The pH meter electrode was rinsed with distilled water and cleaned with a soft tissue before taking readings from another sample (Van Reeuwijk, 2002).

Cation Exchange Capacity

Cation exchange capacity determination was performed according to Ross & Ketterings (1995) and Purnamasari et al. (2021). The 10 g soil sample was weighed using an analytical digital balance (Radwag AS 220-R2, Torunska, Poland) and placed in a 150 ml leaching tube clipped to the rack after ashless floc and 3 cm diameter filter paper were placed at the bottom of the leaching tube. The soil sample was then levelled, and a 5 cm diameter filter paper was placed on top of the sample and levelled as well. Subsequently, 100 ml of 1N ammonium acetate (NH_4OAc) buffered at pH 7 was added into the funnel to leach out the exchangeable cations (K^+, $Ca2^+$, Mg^{2+}, and Na^+) and to saturate the exchange material with ammonium. Following this, 100 ml of 95% ethyl alcohol was added to the leaching tube to remove excess or non-adsorbed ammonium ions and prevent the hydrolysis process from taking place. The soil, saturated with NH_4^+ ions, was then leached with 100 ml of 0.1N K_2SO_4 to remove the adsorbed NH_4^+ ions. The collected leachates containing NH_4^+ were determined by distillation and titration techniques. The CEC was determined using calculations based on the formula below:

$$CEC = \frac{(Y_{HCl} - Z_{HCl}) \times HCl_{concentration}}{W_{sam.}} \times \frac{100\ ml}{10\ ml} \times \frac{1000\ g}{1\ kg} \times \frac{1 cmol}{10\ mmol}$$

Where, CEC is cation exchange capacity, Y_{HCl} and Z_{HCl} are final and initial volume of hydrochloric acid (ml) respectively, $HCl_{concentration}$ is concentration of hydrochloric acid (0.01N), $W_{sam.}$ is the weight of sample (g). The value obtained was expressed in cmol (+)/kg of soil.

Soil Organic Matter

Soil organic matter determination followed the method outlined by Konaré et al. (2010). The porcelain crucible was heated for 1 hour at 400ºC in a muffle furnace, then cooled down in the open to about 150ºC before being further cooled in a desiccator for 30 minutes before being weighed. Thereafter, the soil sample was oven-dried at 105ºC for 24 hours and placed in the desiccator. Ten grams of the soil sample were then placed in the crucible. The weight of the crucible plus the weight of the soil sample is considered the pre-ignition weight. The crucible containing samples was placed in the muffle furnace at 400ºC for at least 16 hours or overnight. The furnace temperature was then adjusted to 150ºC to cool down the sample for approximately 3 hours. The crucible was then placed in the desiccator using tongs for 30 minutes and weighed to obtain the post-ignition weight. Soil organic matter was calculated using the following formula:

$$SOM = \frac{Wpre. - Wpost.}{W_{pre.}} \times 100\%$$

Where, SOM is soil organic matter, $W_{pre.}$ is pre-ignition weight, W_{post}. is post-ignition weight of soil sample + crucible before and after heated at 400ºC respectively. The value obtained was expressed in %.

Soil Nutrient Concentrations

Nitrogen (N) Concentration

Soil nitrogen concentration was prepared and determined following the method outlined by Horneck and Miller (1998). The same method was used for leaf samples; however, the weight of the soil sample used was 1.0 g.

Phosphorus, Potassium, Calcium, and Magnesium Concentrations (P, K, Ca, Mg)

Soil phosphorus, potassium, calcium, and magnesium concentration determination were based on Campbell and Plank (1998). A 1.0 g soil sample was placed in a 100 mL digestion tube, to which 5 mL of concentrated sulfuric acid (H_2SO_4) was added. The mixture was vortexed until all plant material was fully moistened and then allowed to stand overnight, or for at least 2 hours. The digestion tube was subsequently heated using a block digester at 285°C in a fume chamber for approximately 45 minutes. After heating, the tube was removed from the block digester, allowed to cool, and 2 mL of 50% hydrogen peroxide (H_2O_2) was added. This process, involving heating and the addition of H_2O_2, was repeated until the digestate became clear or colourless. The resulting solution was then transferred into a volumetric flask before being stored in a plastic vial. Nutrient concentrations were determined using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES), Optima 7300 DV (PerkinElmer, Massachusetts, United States). The nutrient values obtained from the instrument were subsequently converted into percentages using appropriate calculations. Typically, the values measured by ICP-OES are expressed in units of μg/mL, mg/kg, or ppm, where 1 μg/mL is equivalent to 1 mg/kg, 1 ppm, or 0.0001%.

Statistical Analysis

Statistical analysis was conducted using Minitab version 16 (Minitab Inc., State College, PA, USA). An independent t-test was used to compare the means between treatments. A significance level of $p \leq 0.05$ was considered statistically significant.

RESULTS

Growth of Durian Seedlings

Plant Height, Canopy Diameter, Main Stem Diameter and Girth

Generally, no significant differences were observed in above-ground durian growth parameters such as plant height, canopy diameter, main stem diameter, and main stem girth for the two cropping systems at the end as affected by the intercropping experiments from pre-season 1 to post-season 2 (Figure 2).

Root Weight

The root weight of durian seedlings was not significantly affected by the intercropping with sweet corn and groundnut after two seasons (Figure 3).

Durian Leaf Chlorophyll Content

Chlorophyll a and b contents, total chlorophyll, and carotenoid contents of durian seedlings leaves in the intercropping plot were significantly higher compared to the monocropping

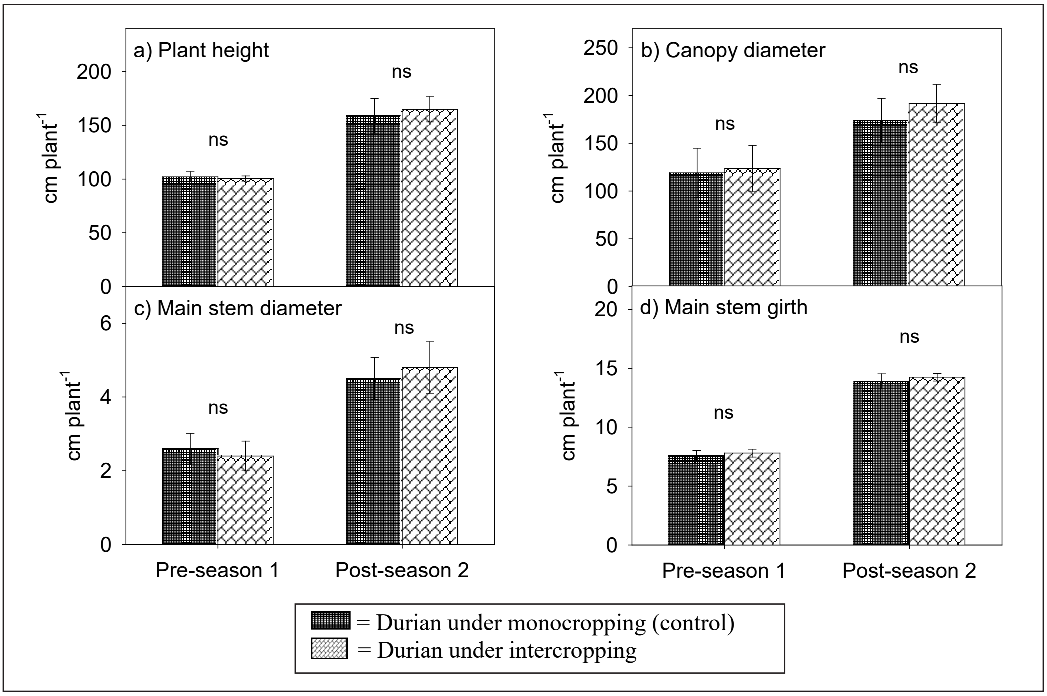

Figure 2. Plant height, canopy diameter, main stem diameter, and main stem girth of durian seedlings as affected by intercropping with sweet corn and groundnut from pre-season 1 to post-season 2. Different letters assigned to various treatments indicate a significant difference at $P \leq 0.05$, while 'ns' denotes no significance. The values represent the means of six replicates

plot. However, SPAD values and N concentration were not significantly affected by the intercropping experiments (Table 2). The values of leaf chlorophyll a, chlorophyll b, total chlorophyll, and carotenoid content of durian under intercropping were 1.04, 0.64, 2.09, and 0.08 mg/g fresh weight (FW), respectively. In contrast, the values for similar parameters for durian under monocropping were 0.87, 0.57, 1.79, and 0.06 mg/g FW, respectively.

Soil Nutrient Content

Soil Strength

At soil depths of 0, 10, 20, and 30 cm, soil strength in the monocropping plot was significantly higher than in the intercropping plot during post-season 2. In contrast, intercropping had no significant effect on soil strength at depths of 40 to 70 cm (Figure 4).

Soil pH, Cation Exchange Capacity and Organic Matter

Soil pH, cation exchange capacity (CEC), and organic matter (OM) increased from pre-season 1 to post-season 2, except for OM in the intercropping plot, where it remained constant (Table 3). In pre-season 1, soil pH in the monocropping plot was significantly higher

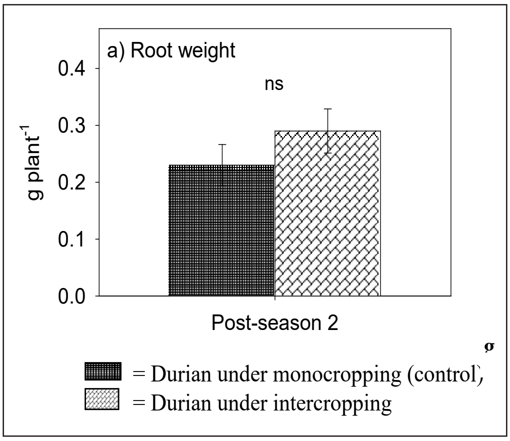

Figure 3. Illustrates the root weight of durian seedlings as affected by intercropping with sweet corn and groundnut post-season 2. Different letters assigned to various treatments indicate a significant difference at P ≤ 0.05, while 'ns' indicates no significance. The values represent the means of six replicates

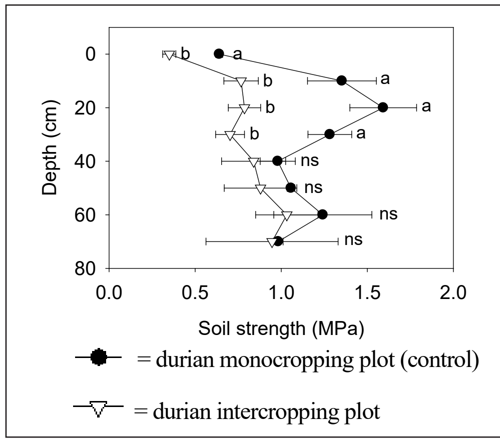

Figure 4. Soil strength in durian cultivation plots at the durian planting points as affected by intercropping with sweet corn and groundnut post-season 2. Different letters assigned to various treatments indicate a significant difference at P ≤ 0.05, while 'ns' indicates no significance. The values represent the means of six replicates

Table 2
Leaf parameters of durian seedlings as affected by intercropping with sweet corn and groundnut post-season 2

Parameters	Plot		P value
	Durian under monocropping	**Durian under intercropping**	
Nitrogen concentration (N conc.) (%)	2.66a±0.02	2.72a±0.08	0.48
SPAD (SPAD unit)	47.00a±1.30	50.48a±2.49	0.24
Chlorophyll a content (mg/g FW)	0.87b±0.02	1.04a±0.03	0.002
Chlorophyll b content (mg/g FW)	0.57b±0.01	0.64a±0.01	0.04
Total chlorophyll content (mg/g FW)	1.79b±0.04	2.09a±0.05	0.01
Carotenoid content (mg/g FW)	0.06b±0.001	0.08a±0.002	0.01

Note. FW = fresh weight. Different letters assigned to various treatments indicate a significant difference at P ≤ 0.05, while 'ns' denotes no significance. The values represent the means of six replicates

than in the intercropping plot. However, by post-season 2, soil pH in the intercropping plot had increased significantly and became higher than in the monocropping plot. Meanwhile, CEC and OM in the intercropping plot were significantly higher than in the monocropping plot throughout the study period, from pre-season 1 to post-season 2.

Soil Nutrient Concentrations

Soil nutrient concentrations are presented in Figure 5. The soil N and Fe concentrations decrease, while P concentration remains consistently low from pre-season 1 to post-season

Table 3
Soil pH, cation exchange capacity, and organic matter in durian cultivation plots as affected by intercropping with sweet corn and groundnut

Parameters	Plot		P value
	Durian under monocropping	Durian under intercropping	
pH			
Pre-season 1	4.61a ± 0.01	4.35b ± 0.03	0.02
Post-season 2	5.28b ± 0.003	5.38a ± 0.003	0.003
Cation exchange capacity (CEC)			
Pre-season 1	10.60a ± 0.87	11.60a ± 0.35	0.17
Post-season 2	11.60a ± 0.12	12.15a ± 0.55	0.25
Organic matter (OM)			
Pre-season 1	0.94a ± 0.10	1.18a ± 0.04	0.11
Post-season 2	0.95b ± 0.02	1.18a ± 0.05	0.01

Note. Different letters assigned to various treatments indicate a significant difference at $P \leq 0.05$, while 'ns' denotes no significance. The values represent the means of six replicates

2. The K concentration decreases in the monocropping plot but increases in the intercropping plot. Soil Ca, Mg, Zn, and Cu concentrations increase in both plots. The soil N and P concentrations in the intercropping plot are significantly higher than in the monocropping plot during pre-season 1, but no significant differences are observed thereafter. The concentrations of K, Mg, Fe, Zn, and Cu were not significantly affected by the intercropping treatments throughout the study. The soil Ca concentration did not differ significantly between plots before the start of season 1 however, Ca concentration in the intercropping plot is significantly higher than in the monocropping plot by post-season 2.

DISCUSSION

Growth of Durian Seedlings

The intercropping activities of corn and groundnut did not significantly affect the plant height, canopy diameter, main stem diameter, main stem girth, or root weight of young durian seedlings. However, the trend indicated that the growth of durian seedlings in intercropping plot showed improvement compared to those in monocropping plot after the experiment concluded, with increases of 3.65% in plant height, 9.74% in canopy diameter, 6.45% in main stem diameter, 2.56% in main stem girth, and 23.08% in root weight. This suggests that intercropping activities with annual or cash crops can be beneficial in young durian orchards without negatively affecting the growth of durian seedlings, as also observed by Susiloadi et al. (1994). A similar trend was observed in rubber (Paisan, 1996) plantations and young oil palm (Putra et al., 2012). Growing annual crops alongside perennial crops, which typically take 4-5 years to bear fruit, offers various benefits. It can help meet household food needs while generating income through sales to ready markets.

Consequently, it can narrow the income gap between planting and the first oil palm harvest (typically 3-5 years), enabling farmers to sell produce while waiting for palms to mature (Ecological Trends Alliance and Tropenbos International, 2021).

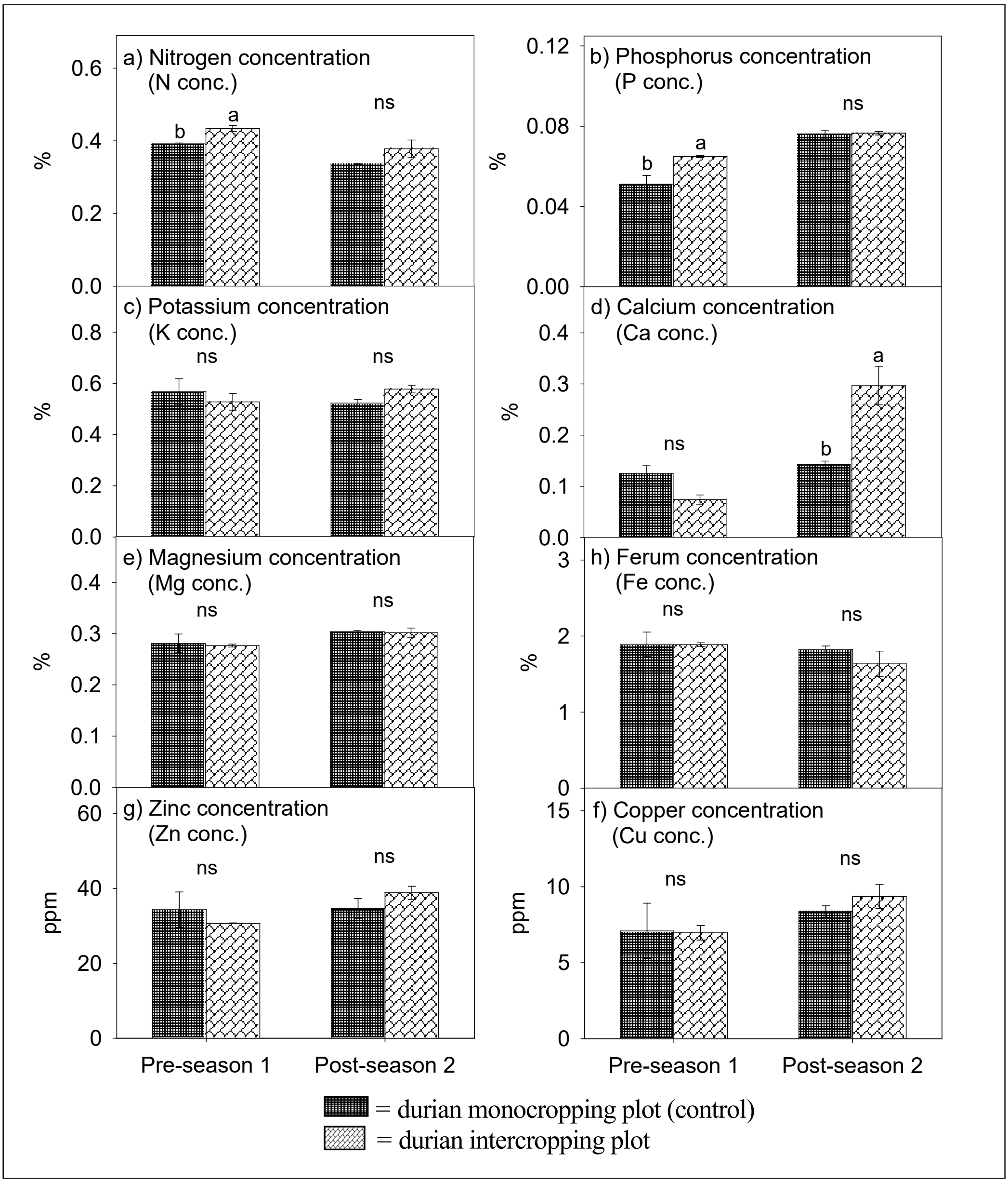

Figure 5. Soil nutrient concentrations in durian cultivation plots as affected by intercropping with sweet corn and groundnut from pre-season 1 to post-season 2. Different letters assigned to various treatments indicate a significant difference at $P \leq 0.05$, while 'ns' indicates no significance. The values represent the means of six replicates

Leaf Chlorophyll Content

Among durian leaf parameters, chlorophyll a, b, total chlorophyll, and carotenoid content exhibited a positive response in intercropping compared to monocropping plots. Leaf N concentration and SPAD value also showed a similar trend, although no significant difference was observed. Durian seedlings in the intercropping plot have chlorophyll a, b, total chlorophyll, and carotenoid content significantly higher by 17.80%, 11.57%, 15.46%, and 28.57% respectively, than those in the monocropping plot. Chlorophyll, a green pigment in leaves, absorbs light energy and converts it into chemical energy during photosynthesis (Rabinowitch, 1965; Kurniawan et al., 2021). The chlorophyll content in leaves reflects photosynthetic function and capacity, thus indicating plant growth and health (Li et al., 2018; Shi, 2019; Kurniawan et al., 2021). The growth of perennial crops within intercropping activities tends to improve compared to those grown in monoculture (Paisan, 1996; Putra et al., 2012).

Soil Strength

The soil strength from 0 to 30 cm depth exhibited a positive response in the monocropping plot. In contrast, no significant difference was observed for soil strength from 40 to 70 cm, although the trend was similar. The greatest differences in soil strength between monocropping and intercropping plots occurred at soil depths of 10 to 30 cm. This area is within the durian root zone, especially during the vegetative stage of durian seeding (Masri, 1991; DoA, 2012). However, the high soil strength in the monocropping plot was probably not a result of greater durian root. It could be due to the nature of the soil in the monocropping plot being harder than in the intercropping plot. In the monocropping plot, at a depth of 20 cm, the penetration resistance was 1.59 MPa, as indicated in Figure 4. The growth rates of roots in numerous crops decrease by around 50% when the penetration resistance reaches 1.5 MPa (Van den Akker et al., 2023). Soil strength restricts root growth and may slow down root system development (Correa et al., 2019).

Intercropping activities seemed to contribute to the improved growth of durian, not only above ground with stems and leaves but also below ground with roots. Supporting this observation is the higher root weight of durian in the intercropping plot compared to the monocropping plot, even though no significant difference was observed (Figure 3). The lower soil strength in the intercropping plot may be attributed to root penetration, which reduces soil hardness. The penetration resistance in the intercropping plot ranges from 0.70 to 0.78 MPa at depths of 10 to 30 cm, falling within the maximum axial root growth pressure range of 0.4 to 1.4 MPa (Misera et al., 1986). Mechanical energy investment per unit length increases with larger plant root diameters, while mechanical energy per unit of displaced soil volume decreases with larger diameters (Ruiz et al., 2015). The factors contributing to the weaker soil strength in the intercropping plot may also be due to watering activities in the intercropping plot for corn and groundnut between the rows of durian seedlings, leading to increased soil water content. Soil strength decreases with higher soil water content, resulting in reduced soil-root bond strength and facilitating root growth (Fan et al., 2021). Root penetration was observed to be 80% of the maximum or greater when the average soil strength was 0.75 MPa or less and when the average matric potential was 0.77 MPa or greater (Yapa et al., 1988).

Soil pH and Nutrient Concentration

The intercropping activities resulted in significant differences in soil pH and Ca concentration. In terms of soil pH, it responded positively to the intercropping plot, increasing from 4.35 to 5.38, approximately a 21.17% increment. In contrast, in a monocropping plot, it increased from 4.61 to 5.28, with approximately a 13.55% increment. After the intercropping experiment ended, soil pH in the intercropping plot was significantly higher than in the monocropping plot by 1.88%. Soil in durian cultivation areas is generally strongly acidic. Liming is a common practice to mitigate soil acidification, enhance soil quality, and improve crop productivity on many agricultural soils (Daba et al., 2021; Kalkhoran et al., 2019). However, the amount of lime used may not be adequate to increase the soil pH, as demonstrated in the monocropping plot. Additionally, the use of nitrogen-based fertilizers applied together with lime can slow down the process of increasing soil pH. Nitrogen fertilizers themselves can lower soil pH through the nitrification process (Nasedjanov, 2012; Hart et al., 2013). In the intercropping plot, the rapid increase in soil pH is probably due to increased liming activity performed before planting sweet corn and groundnut in the intercropping experiment. This suggests that a high amount of lime application can accelerate the increment of soil pH, as demonstrated in experiments conducted by Nasedjanov (2012), Bossolani et al. (2023) and Ejigu et al. (2023).

The Ca concentration responded positively in the intercropping plot following the completion of the intercropping experiment. The Ca concentration in the intercropping plot was significantly higher at 70.74% compared to the monocropping plot. This rapid increase in Ca concentration could be attributed to the substantial quantity of lime utilized in the intercropping plot. Moreover, the type of lime employed is dolomite, a double salt comprising calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$), with the chemical composition $CaMg(CO_3)_2$ (Sholicha et al., 2019; Sanz et al., 2022). Dolomite is added to the growing medium to elevate pH to the range of 5.5 to 6.5 and to provide plants with calcium and magnesium essential for healthy growth (Conover et al., 1995). However, the significant effect observed was on calcium, as calcium is the primary element contained in this type of lime, as described by Peters et al. (1996). Although no significant differences were observed, the plant height, canopy diameter, main stem diameter, main stem girth, and root weight of young durian seedlings in the intercropping plot were enhanced compared to the monocropping plot, possibly due to the high soil calcium content. In oil palm, growth parameters such as total, shoot, and root dry mass, as well as plant height of oil palm seedlings, were improved by calcium amendment treatment (Husain et al., 2021). However, calcium-deficient crops exhibited significant reductions in shoot length, shoot and trunk fresh weights, leaf area, and chlorophyll, eventually leading to drooping, yellowing, and chlorosis of leaves. Roots were less dense and primarily dark and necrotic, as shown in grapevines (Duan et al., 2022).

CONCLUSION

In conclusion, intercropping with annual or cash crops in young durian orchards does not negatively affect the growth of durian seedlings. It offers benefits such as reducing soil compaction and increasing soil pH, likely due to irrigation and liming activities. The increase in calcium concentration in the soil, resulting from liming, positively contributes to the improvement of physical growth parameters of durian seedlings.

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REFERENCES

Bossolani, J. W., Crusciol, C. A. C., Mariano, E., Moretti, L. G., Portugal, J. R., Fonseca, M., & Cantarella, H. (2023). Higher lime rates for greater nitrogen recovery: A long-term no-till experiment labeled with 15N. *Field Crops Research, 299*, Article 108971. https://doi.org/10.1016/j.fcr.2023.108971

Campbell, C. R., & Plank, C. (1998). Preparation of plant tissue for laboratory analysis. In Y. P. Kalra (Ed.), *Handbook of reference methods for plant analysis* (pp. 37–49). CRC Press Taylor & Francis Group.

Conover, C. A., Steinkamp, R. J., & Steinkamp, K. (1995). *Effects of dolomite source, dolomite rate, and fertilizer rate on change in pH of growing medium leachate* (Research Report RH-95-4). University of Florida, IFAS, CFREC-Apopka.

Correa, J., Postma, J. A., Watt, M., & Wojciechowski, T. (2019). Soil compaction and the architectural plasticity of root systems. *Journal of Experimental Botany, 70*(21), 6019–6034. https://doi.org/10.1093/jxb/erz383

Daba, N. A., Li, D., Huang, J., Han, T., Zhang, L., Ali, S., Numan Khan, M., Du, J., Liu, S., Legesse, T. G., Liu, L., Xu, Y., Zhang, H., & Wang, B. (2021). Long-term fertilization and lime-induced soil pH changes affect nitrogen use efficiency and grain yields in acidic soil under wheat–maize rotation. *Agronomy, 11*(10), 2069. https://doi.org/10.3390/agronomy11102069

Department of Agriculture. (2000). *Pakej teknologi tanaman pisang (Banana crop technology package).* Department of Agriculture Peninsular of Malaysia.

Department of Agriculture. (2012). *Pakej teknologi durian (Durian crop technology package).* Ministry of Agriculture and Agro-based Industries.

Department of Agriculture. (2016). *Pelan strategik Jabatan Pertanian 2016–2020 (Strategic plan of the Department of Agriculture).* Department of Agriculture Malaysia.

Department of Agriculture. (2021). *Fruit crops statistic in Malaysia, 2021.* Department of Agriculture Malaysia.

Duan, S., Zhang, C., Song, S., Ma, C., Zhang, C., Xu, W., … Wang, S. (2022). Understanding calcium functionality by examining growth characteristics and structural aspects in calcium-deficient grapevine. *Scientific Reports, 12*(1), Article 3233. https://doi.org/10.1038/s41598-022-06867-4

Ejigu, W., Selassie, Y. G., Elias, E., & Molla, E. (2023). Effect of lime rates and method of application on soil properties of acidic Luvisols and wheat (*Triticum aestivum* L.) yields in northwest Ethiopia. *Heliyon, 9*(3), Article e14783. https://doi.org/10.1016/j.heliyon.2023.e14783

Ecological Trends Alliance, & Tropenbos International. (2021). *Intercropping in oil palm plantations: A technical guide.* Ecological Trends Alliance (Kampala, Uganda) and Tropenbos International (Ede, the Netherlands).

Fan, C. C., Lu, J. Z., & Chen, H. H. (2021). The pullout resistance of plant roots in the field at different soil water conditions and root geometries. *Catena, 207*, 105593. https://doi.org/10.1016/j.catena.2021.105593

Hart, J. M., Sullivan, D. M., Anderson, N. P., Hulting, A. G., Horneck, D. A., & Christensen, N. W. (2013). *Soil acidity in Oregon: Understanding and using concepts for crop production.* Oregon State University Extension Service.

Hoe, T. K., & Palaniappan, S. (2013). Performance of a durian germplasm collection in a Peninsular Malaysian fruit orchard. *Acta Horticulturae, 975*, 127–137. https://doi.org/10.17660/ActaHortic.2013.975.13

Horneck, D. A., & Miller, R. O. (1998). Determination of total nitrogen in plant tissue. In Y. P. Kalra (Ed.), *Handbook of reference methods for plant analysis* (pp. 75–83). CRC Press.

Husain, S. H., Mohammed, A., Ch'ng, H. Y., & Khalivulla, S. I. (2021). Residual effects of calcium amendments on oil palm growth and soil properties. In *IOP Conference Series: Earth and Environmental Science, 756*(1), Article 012060. IOP Publishing. https://doi.org/10.1088/1755-1315/756/1/012060

Issarakraisila, M., Lamers, H., Yoovatana, M. C., & Somsri, S. (2014). Empowering a community to conserve tropical fruit trees by the utilization of their products and agro-tourism. In *XXIX International Horticultural Congress on Horticulture: Sustaining Lives, Livelihoods and Landscapes (IHC2014): 1128* (pp. 323–326). International Society for Horticultural Science. https://doi.org/10.17660/ActaHortic.2016.1128.48

Kalkhoran, S. S., Pannell, D. J., Thamo, T., White, B., & Polyakov, M. (2019). Soil acidity, lime application, nitrogen fertility, and greenhouse gas emissions: Optimizing their joint economic management. *Agricultural Systems, 176*, Article 102684. https://doi.org/10.1016/j.agsy.2019.102684

Konaré, H., Yost, R. S., Doumbia, M., McCarty, G. W., Jarju, A., & Kablan, R. (2010). Loss on ignition: Measuring soil organic carbon in soils of the Sahel, West Africa. *African Journal of Agricultural Research, 5*(22), 3088–3095.

Kurniawan, N. S. H., Kirana, I. A. P., Abidin, A. S., Jupri, A., Widyastuti, S., Hernawan, A., Nikmatullah, A., Sunarpi, H., Prasedya, E. S. (2021). Analysis of leaf chlorophyll content of paddy plants during vegetative stage grown in soil media containing macroalgae organic fertilizer. In *IOP Conference Series: Earth and Environmental Science, 913*(1), Article 012025. IOP. https://doi.org/10.1088/1755-1315/913/1/012025

Li, Y., He, N., Hou, J., Xu, L., Liu, C., Zhang, J., Wang, Q., Zhang, X., & Wu, X. (2018). Factors influencing leaf chlorophyll content in natural forests at the biome scale. *Frontiers in Ecology and Evolution, 6*, Article 64. https://doi.org/10.3389/fevo.2018.00064

Malaysian Meteorological Department. (2022). Unpublished meteorological data. F.R.I. Petaling Jaya Station.

Masri, M. (1991). Root distribution of durian, Durio zibethinus Murr. cv D24. *MARDI Research Journal, 19*(2), 183–189.

Misera, R. K., Dexter, A. R., & Alson, A. M. (1986). Maximum axial and radial growth pressures of plant roots. *Plant and Soil, 95*, 315–388. https://doi.org/10.1007/bf02374612

Ministry of Agriculture. (2019). *Agrofood statistics book.* http://www.moa.gov.my/penerbitan

Mohd Jelani, B., Jamadon, B., Nik Aziz, N. M., Abdullah, O., & Denamany, G. (1992, August 13). The integration of cocoa with other plants to increase the income of small scale cocoa growers. Paper presented at the *Seminar Perdagangan Koko*, Ipoh, Perak Darul Ridzuan, Malaysia. Universiti Putra Malaysia.

Nasedjanov, M. (2012). *The effects of lime on pH values of soil at different pH levels* [Final project report]. United Nations University Land Restoration Training Programme. https://www.grocentre.is/static/gro/publication/403/document/nasedjanov-2012.pdf

Paisan, L. (1996). Intercropping of young rubber. *Suranaree Journal of Science & Technology, 3*, 171–179.

Pamplona, P. P., & Garcia, M. E. (1997). Intercropping durian with 'Lakatan' banana and/or in coconut. In *PCARRD Highlights 1996* (pp. 51–52). Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD).

Peters, J. B., Schulte, E. E., & Kelling, K. A. (1996). *Choosing between liming materials* (A3671). University of Wisconsin—Extension.

Purnamasari, L., Rostaman, T., Widowati, L. R., & Anggria, L. (2021). Comparison of appropriate cation exchange capacity (CEC) extraction methods for soils from several regions of Indonesia. *IOP Conference Series: Earth and Environmental Science, 648*(1), 012209. IOP Publishing. https://doi.org/10.1088/1755-1315/648/1/012209

Putra, E. T. S., Simatupang, A. F., Waluyo, S., & Indradewa, D. (2012). The growth of one-year-old oil palms intercropped with soybean and groundnut. *Journal of Agricultural Science, 4*(5), 169. https://doi.org/10.5539/jas.v4n5p169

Rabinowitch, E. I. (1965). The role of chlorophyll in photosynthesis. *Scientific American, 213*(1), 74–83. https://doi.org/10.1038/scientificamerican0765-74

Radchanui, C., & Keawvongsri, P. (2017). Pattern and potential production of durian in Saikhao Community, Kokpho district, Pattani province. *International Journal of Agricultural Technology, 13*(6), 791–812.

Radziah, O., Lusi, M., & Anuar, A. R. (2006). Isolation of IAA producing rhizobacteria for enhanced growth of sweetpotato. *Malaysian Journal of Soil Science, 10*(April), 1–11.

Ratanarat, S., Pimsarn, S., & Ratanapratoom, K. (1997). Soil improvement for peanut intercropping in durian orchard. In *12th Thailand National Peanut Meeting*, Udon Thani.

Ross, D. S., & Ketterings, Q. M. (1995). Recommended methods for determining soil cation exchange capacity. In *Recommended soil testing procedures for the northeastern United States* (pp. 62–69). Northeastern Regional Publication No. 493.

Royal Eijkelkamp. (2022). *Penetrologger: User manual.* https://www.royaleijkelkamp.com/media/nrwjyah3/m-0615saepenet%20rologger.pdf

Ruiz, S., Or, D., & Schymanski, S. J. (2015). Soil penetration by earthworms and plant root mechanical energetics of bioturbation of compacted soils. *PLOS ONE, 10*(6), Article e0128914. https://doi.org/10.1371/journal.pone.0128914

Rushidah, W. Z., Jamil, Z. A., & Zaki, M. M. (2006). Effects of different sizes of planting material on the establishment and precocity of durian. *Journal of Tropical Agriculture and Food Science*, *34*(1), 7–14.

Salma, I., Masrom, H., & Mohd. Nor, A. (2018). *Durian clones.* Malaysian Agricultural Research and Development Institute (MARDI).

Sanz, J., Tomasa, O., Jimenez-Franco, A., & Sidki-Rius, N. (2022). Dolomite. In *Elements and mineral resources* (pp. 987–999). Springer Textbooks in Earth Sciences, Geography, and Environment. Springer.

Shi, L. (2019). Changes of chlorophyll value and plant height in leaves of different soil materials. In *IOP Conference Series: Earth and Environmental Science, 300*(5), Article 052010. IOP Publishing. https://doi.org/10.1088/1755-1315/300/5/052010

Sholicha, S. P., Setyarsih, W., Sabrina, G. J., & Rohmawati, L. (2019). Preparation of CaCO3/MgO from Bangkalan's dolomite for raw biomaterial. In *Journal of Physics: Conference Series*, 1171(1), Article 012034. IOP Publishing. https://doi.org/10.1088/1742-6596/1171/1/012034

Solpot, T. C., & Cumagun, C. J. R. (2022). Phylogenetic analyses and cross-infection studies of *Phytophthora* species infecting cacao and durian in South-Central Mindanao, Philippines. *Journal of Phytopathology*, *170*(1), 41–56.

Srivastava, G. C. (2009). *Modern methods in plant physiology*. New India Publishing.

Sullivan, D. M., Moore, A. D., & Brewer, L. J. (2019). *Soil organic matter as a soil health indicator: Sampling, testing, and interpretation* (EM 9251). Oregon State University Extension Service. https://extension.oregonstate.edu/sites/extd8/files/ documents/em9251.pdf

Susiloadi, A. P., Budiwibowo, Soegito, & Wahyudi, T. (1994). Pengaruh tata tanam durian dengan tanaman sela palawija terhadap pertumbuhan dan produktivitas lahan. *Penelitian Hortikultura*, *1*(6), 71–78.

Van den Akker, J. J. H., ten Damme, L., Lamandé, M., & Keller, T. (2023). Compaction. In M. J. Goss & M. Oliver (Eds.), *Encyclopedia of soils in the environment* (2nd ed., Vol. 5, pp. 85–99). Elsevier. https://doi.org/10.1016/B978-0-12-822974-3.00225-1

Van Reeuwijk, L. P. (2002). *Procedures for soil analysis* (6th ed.). International Soil Reference and Information Centre (ISRIC)

Yaacob, O., Ismail, M. N., & Talib, A. H. (1978). Observations on growth and early production of some durian (*Durio zibethinus* Murr) clones at Universiti Pertanian Malaysia orchard. *Pertanika*, *1*(1), 47–52.

Yapa, L. G. G., Fritton, D. D., & Willatt, S. T. (1988). Effect of soil strength on root growth under different water conditions. *Plant and Soil*, *109*(1), 9–16. https://doi.org/10.1007/BF02197574