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Organic and inorganic fertilisers influence sweet potato (*Ipomoea batatas* L.) performances under BRIS, peat, silty clay and clay soil

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Abstract

The sweet potato is one of the most economically important food crop and is recognised as a highly nutritious food. Sweet potatoes with purple flesh are richer in anthocyanins. This study evaluates the purple sweet potato, namely *Kedudut* 2, *Kedudut* 5 and *Kedudut* 6 varieties under silty clay, clay, BRIS and peat soil with three levels of organic fertiliser (0, 5 and 10 t/ha) and four levels of NPK 12:12:17 (0, 200, 400 and 600 kg/ha) on yields and total anthocyanin content (TAC). The results indicated that *Kedudut* 2 (560 mg/kg) produced the highest TAC compared to *Kedudut* 5 (276 mg/kg) and *Kedudut* 6 (252 mg/kg). Even though *Kedudut* 5 and *Kedudut* 6 had greater tuber yields, both had very low TAC, which may not be favourable to farmers and industries. Generally, *Kedudut* 2, *Kedudut* 5, and *Kedudut* 6 produced anthocyanin yields of 2.29 kg/ha, 1.24 kg/ha and 1.73 kg/ha, respectively. The tuber yields and anthocyanin yields in Bagan Datuk (silty clay) and Serdang (clay) were low. Soil with a high clay content is naturally compacted, which results in low fertiliser effectiveness and consequently reduces the tuber yield potential. It can be concluded that planting *Kedudut* 2 with a rate of 5 t/ha organic fertiliser and 200 kg/ha inorganic fertiliser (NPK 12:12:17) is recommended for sweet potato cultivation in Bachok, while 5 t/ha organic fertiliser and 600 kg/ha inorganic fertiliser are recommended in Pontian for maximum marketable yield and consequently maximise the anthocyanin yields.

Keywords: *sweet potato, nutrient management, tuber yield, Ipomoea batatas, total anthocyanin content*

Introduction

In Malaysia, sweet potatoes are grown in small areas with an estimated planted area of about 3,129 ha, producing 53,614 mt in 2021 (DOA 2022). In 2021, the trade value of Malaysian sweet potato (HS Code: 071420) exports was RM50,885,181 (USD10,848,563), equivalent to 17,299 mt of sweet potato based products. Meanwhile, in the same year, the import value was RM4,708,553 (USD1,003,849) equivalent to 2,282 mt of sweet potato-based products (Comtrade 2023). Sweet potato is considered one of the main staple foods besides wheat, rice, corn, barley, potatoes and cassava. In Malaysia, purple sweet potato is usually used to make chips and used as a base material in traditional cakes (Ishak et al. 2019). Purple sweet potatoes have a high content of anthocyanins (185 – 316 mg/L) and can be processed to produce various types of food or drinks (Tun Norbrillinda and Hasri 2019). Anthocyanins are a source of antioxidants essential for affordable health benefits that may help reduce the risk of various chronic diseases such as heart disease, stroke, and asthma (Tun Norbrillinda and Hasri 2019). Due to Malaysia's rapid economic development, which has led to an increase in agricultural land use primarily for residential, commercial, and industrial uses, the country's agricultural land usage is also continuing to decline (Alam et al. 2012) but agricultural sector is very crucial to ensure food security, employment generation, socioeconomic improvement, economic growth, poverty reduction and overall achievement of vision 2020. The palm oil industry, among industrial crops, took up the most significant portion of the nation's total land use, from only 2.1% in 1960 to 63.4% in 2005. The palm oil industry has dramatically extended its agricultural land use during the past five decades (Alam et al., 2012). Malaysia's ability to produce enough sweet potatoes to satisfy domestic demand was

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limited. More acres can enhance production, but since land is getting harder to come by in Malaysia, marginal soils will eventually need to be used for agricultural growth (Anuar and Jamal 1998). Root and tuber crops such as sweet potatoes and cassava are resilient because they are more adaptable to marginal areas. Marginal areas are characterised as edaphic and climatic conditions only suitable for root and tuber crops because they can tolerate poor soils and drought stress (Gweyi-Onyango et al. 2021). Root and tuber crops can yield high even under poor and marginal soils (Sanginga 2015; Saravaiya et al. 2019). Malaysia has a total land area of approximately 33 million ha, whereas the land area unsuitable for agriculture is reported to be higher in East Malaysia at 15 million ha. Several marginal soils, namely acid sulphate, beach ridges interspersed with swales (BRIS), tin-tailings, peat, and steep land soils are problematic soils with severe limitations for crop cultivation in Malaysia (Faridah et al. 2022). In Malaysia, BRIS and peat soils are considered suitable for agriculture if properly reclaimed and improved. Sand-textured BRIS soils are infertile, heavily leached, have low water holding capacity and have a high surface temperature. Incorporating organic matter could increase their productivity. The limitations of peat soils include low acidity, nutrient deficiency, low soil-bearing capacity, woody composition, and poor drainage. The right crops must be chosen for successful production (Othman et al. 1990). BRIS soil has a low cation exchange capacity (CEC) of 9.53 meq/100 g, a pH range of 4.3 to 4.4, and is deficient in nutrients. It also has a low capacity to hold water (Nur Amirah et al. 2015). A high percentage of sand in BRIS soil will hinder plant growth. Thus, soil amendments such as organic matter, palm oil mill effluent (POME), and compost that can increase the soil's health, water holding capacity, and nutrient status have shown benefits to a few crops, such as coconut and sweet potato (Jahan et al. 2014). Peat soils in Malaysia can be considered poor in nutrient contents with a pH range of 3.0 to 4.5 and there is very low available nitrogen (Abu Bakar et al. 1981). CEC is also high at a range of 29.6 – 41.3 meq/100 g which indicates the ability of peat soil to retain or release nutrients (Lulie 2016). With adequate fertiliser and good management practices, possible crops such as sweet potato, cassava, maize, tomato, sorghum, ginger, and watermelon are suitable for peat soil (Abu Bakar et al. 1981).

In Malaysia, sweet potato cultivation is based on a small and medium commercial scale for the fresh market. The cultivation of sweet potatoes in Malaysia is also run commercially, especially in the area of rubber and palm oil replanting as cash crops and conventionally using a sprinkler irrigation system (Yaseer et al. 2023). Farmers in the agricultural sector are left mainly with aged farmers and sweet potato is a prime example of a labour intensive crop. One ha of crop requires up to 750 man-hours to cultivate and harvest. The only option with a labour shortage is to switch to machines in the hope of increasing productivity and maximising the profit margin (Md Akhir et al. 2012). Sweet potatoes are suitable for planting in sandy loam soils or soils rich in organic matter with a reasonable water absorption rate. It is also suitable to grow in peat soils with a good drainage system (Nur Izalin et al. 2014). Heavy clay soils are less suitable because excessive soil moisture does not quickly drain from the upper soil profile. In these soils, tuber shape tends to be less regular, which is a consideration for marketed produce (Bourke 2005).

Several studies have been carried out on the use of commercial NPK fertilisers and organic fertilisers to increase the yield of tuber crops. Yeng et al. (2012) suggested the combination of organic and chemical fertiliser as a better option than either organic or chemical input applied alone. An integrated combination of organic and inorganic fertiliser supplies nutrients and improves the soil's physicochemical properties, thereby significantly enhancing the yield and quality of sweet potatoes (Boru et al. 2017). In potatoes, the integrated use of organic and commercial chemical fertilisers significantly enhanced potato tuber yield compared to using each fertiliser source separately. This is because organic manure releases nutrients very slowly and the released nutrients in the year of application may not satisfy the crop's nutrient demand so chemical fertilisers are essential to provide nutrients for potato growth development (Balemi 2012). According to Darko et al. (2020) inorganic fertiliser applied to sweet potatoes did not significantly impact the growth and yield under different environments. However, the yield between varieties was influenced by different locations, which could be attributed to differences in soil conditions, rainfall patterns, temperatures, and relative humidity. The use of organic fertiliser has a considerably favourable effect on cotton growth and production by improving the root's structure (Zhang et al. 2020) and increasing yam tuber yield by improving soil porosity, water content and a relatively better C/N ratio (Agbede et al. 2013). In contrast, chemical fertiliser (NPK) alone increased the yield of yam but degraded the tuber quality (Tiama et al. 2018). As a result, organic manure has been utilised to boost soil fertility and crop productivity. Performance of organic fertilisers compared to inorganic fertiliser applications, implying that in the absence of inorganic fertilisers, either due to cost or availability, organic fertilisers, which are relatively more accessible to farmers, could be used to achieve comparable yield levels (Esan et al. 2021).

Adequate manure application improved the soil's physical, chemical, and physical qualities, increasing potato production. Because of the crumb and loose soil atmosphere created, this allows plant roots to develop appropriately. Suppose the soil's physical qualities are good. In that case, root development will be deeper and more expansive, allowing for better absorption of nutrients and water (Kantikowati et al. 2019). According to Mishra (2018) inadequate soil fertility is one of the causes contributing to low crop production. Plants require several elements for growth and development, the most significant of which are N, P and K. In addition, Roba (2018) mentioned that the use of only inorganic or organic fertiliser has both beneficial and adverse effects on plant growth, nutrient availability and soil health. Organic fertiliser increases the physical and biological activity of the soil, but it has a low nutritional content. Thus a more significant quantity is necessary for plant growth. On the other hand, inorganic fertiliser is usually immediately and quickly available, providing nutrients that are directly accessible to plants. However, the prolonged use of inorganic fertilisers causes soil organic matter degradation. Thus, adopting integrated nutrient management is the best strategy for increasing yield while maintaining soil fertility. The present research aims to evaluate the influence of organic and inorganic fertilisers on the yield and quality of purple sweet potatoes under different soil types.

Materials and method

Experimental design

Field experiments were conducted on BRIS soil in MARDI Bachok Station, Kelantan, peat soil in MARDI Pontian Station, Johor, silty clay soil in MARDI Bagan Datuk Station, Perak and clay soil in MARDI Headquarters, Selangor. Soil samples were collected at a depth of 0 – 20 cm before planting. The collected soil samples were air-dried, crushed, and sieved to pass through a 2 mm sieve and stored at room temperature under dark conditions until analysis. The results of the soil analysis are presented in *Table 1*.

The experimental design was 3 x 4 x 3 factorials in a randomized complete block design with two replications. These comprise three levels of organic manure (0, 5 and 10 t/ha), four levels of inorganic fertiliser (0, 200, 400 and 600 kg/ha) and three purple accessions of sweet potato. The use of superior accessions is one of the most accessible and appropriate technologies to increase crop yields. Sweet potato accessions (variety), namely *Kedudut 2, Kedudut 5* and *Kedudut 6* were used in this study. This accessions are breeding line developed by the MARDI Bachok Research Centre and are based on the most promising selections from the preliminary yield trials in terms of potential yield and total anthocyanin. The control treatment does not apply organic manure or inorganic fertiliser.

Field establishment and treatment application

Slashing, ploughing and harrowing with a tractor were followed by ridge preparation with hoes. Each plot was 1.2 m wide x 5 m long and 0.60 m in height, with a 0.60 m spacing between plots. Fresh sweet potato vines were harvested at the age of two and a half months old, and the long vines were cut to a size of 30 cm. Each planting material gives 5 – 6 nodes and was planted at 45° with 3 – 4 nodes into the soil to optimise establishment. Hand weeding was done throughout the experiment, whereas other cultural practices were carried out as per the recommended industrial standard. Each plot contained a row of 20 cuttings at 25 cm x 25 cm.

Fertiliser sources were poultry manure and N: P_2O_5: K_2O: Mg (12:12:17:2). Poultry manure was applied ten days before planting. The total NPKMg nutrient content was 24:24:34:4 (200 kg/ha), 48:48:68:8 (400 kg/ha), and 72:72:102:12 (600 kg/ha) and applied as equal to three split applications at the third, fifth and eighth weeks after planting. The nutrient contents were based on an approximate nutrient removal rate for a crop yielding 12 t/ ha of storage root for an average global sweet potato root production with minimum NPK requirements of 26:6:60 (O'Sullivan et al. 1997).

Root yield

Root data taken includes the number of roots per plant, the number of tubers produced per plant, and the tuber yield (marketable and unmarketable tubers). The root (tuber) numbers and yield were calculated based on all the plants in each of the plot treatments that were harvested. The weight was taken using a precision balance and extrapolated per hectare using the equation below:

$$\text{Yield (t/ha)} = \frac{\text{Tuber weight}}{\text{Area harvested}} \times \frac{10{,}000\ m^2}{1000}$$

Table 1. Soil chemical characteristic on four locations before planting

Parameter	Bachok (BRIS)	Pontian (peat)	Bagan Datuk (silty clay)	Serdang (clay)
Soil chemical				
pH	6.2	4.3	4.7	4.6
CEC ($cmol_{(+)}$ /kg)	1.89	114	12.9	8.8
Electrical conductivity (dS/m)	1.47	0.24	0.05	0.07
Total N (%)	0.08	1.58	0.12	0.17
Total P (%)	0.05	0.04	0.03	0.02
Exchangeable K ($cmol_{(+)}$ /kg)	0.05	0.78	0.75	0.14
Exchangeable Ca ($cmol_{(+)}$ /kg)	1.32	31.39	6.4	0.98
Exchangeable Mg ($cmol_{(+)}$ /kg)	0.18	7.46	8.45	0.2

A marketable tuber is the weight of clean, uninfected tubers that fall in the size range of ≥150 g, while a tuber weighing <150 g/tuber was considered un-marketable. Total yield (t/ha) is the sum total of both marketable and unmarketable tuber yields obtained from the harvestable plot.

Total anthocyanin content (TAC) determination

The total anthocyanin content (TAC) was determined using a pH differential method based on the property of anthocyanin pigments to change colour with different pH (Lapornik et al. 2005). Fresh tubers were cut into small pieces, and approximately 50 g of the sample were extracted with 100 ml of methanolic (70%) solution in a blender for 1 min. The samples were allowed to shake for 24 hours in the dark at room temperature. Then, 1.0 mL aliquots were pipetted into two test tubes (A1 and A2). One mL of ethanol HCl (0.01%) was added to each test tube. After that, 10 mL of 2% HCl (pH 0.8) was added to the first tube (A1), while 10 mL of citric buffer solution (prepared from 0.2 M Na_2HPO_4 and 0.1 M citric acid; pH 3.5) was added to the second tube (A2). The mixture in both tubes was carefully mixed. After equilibration at room temperature for 20 min, their absorbance was measured at 520 nm against a blank (70% methanol) using a UV-Vis spectrophotometer (Agilent Cary 60). The TAC was expressed as cyanidin-3-glucoside and calculated using the following equation:

$$\text{TAC (mg/L)} = (\text{A1} - \text{A2}) \times f$$

A1 is absorbance at 2% HCl, A2 is absorbance at citric buffer solution, and f is constant (396.598). The TAC was then calculated and expressed in mg cyanidin-3-glucoside kg^{-1} fresh weight (FW).

Statistical analysis

The analysis of variance was based on Moore and Dixon (2015), using Statistical Analysis Software (SAS 9.3) with Proc Mixed procedure. LSMEANS was used to estimate the differences in means between treatment groups and SLICE statement was used to test for simple effects within an interaction. *P*-values of less than 0.05 were regarded as statistically significant.

Results and discussion

There was a significant main effect of location and variety on the number of tubers of the sweet potatoes (*Table 2*). However, there was a significant interaction between location and variety in the total number of tubers produced. Generally, a very low number of tubers were produced in Bagan Datuk and Serdang compared to Bachok and Pontian (*Figure 1*). Bachok and Pontian showed that *Kedudut 6* produced the highest number of tubers, and both were significantly higher than *Kedudut 2*. Also, in Bachok, the total number of tubers was the same between *Kedudut 6* and *Kedudut 5*. High bulk density benefited sweet potato tuberization because low soil porosity and soil compaction enhanced tuber development (Adekiya et al. 2022). The current findings suggest that the compactness of heavy clayey soils limits root development and may lead to an unfavourable condition because root systems grow preferentially in loose versus dense soil. Thus, sweet potatoes under BRIS (Bachok) and peat soil (Pontian) performed better than those under Serdang (clay) and Bagan Datuk (silty clay) because of different soil porosities. The present study also found that organic and inorganic (NPK) fertilisers did not influence the total number of tubers. According to Bekele and Boru (2022), farmyard organic manure at a rate of 9.0 t/ha influenced the number of tubers compared to the control, but nitrogen fertiliser did not promote a greater number of tubers. A study by Rahmawati et al. (2022) showed that the application of vermicompost as high as 30 t/ha on different sweet potato varieties did not influence the number of tubers. In addition, Sidiky et al. (2019) reported that a combination of organic manure at a range of 5 t/ha to 15 t/ha with 200 kg/ha to 500 kg/ha of either NPK 12:12:12 or NPK 15:15:15 did not influence the number of tubers for two different varieties. The present study may explain that the use of organic and inorganic fertilisers does not play a role in the formation of tubers, even though the combination of these two fertilisers could contribute a significant amount of nutrients. Thus, the number of tubers is likely controlled by genotypes and soil types rather than nutrients.

There was a significant main effect of location and variety on tuber yield (*Table 2*). However, there was a significant interaction between location and variety (*Figure 2*) and between location and organic fertiliser (*Figure 3*). The results showed that planting sweet potatoes in silty clay (Bagan Datuk) and clay (Serdang) only produced an unsatisfactory tuber yield. There was no difference in the tuber yield of *Kedudut 2*, *Kedudut 5* and *Kedudut 6* in Bagan Datuk, with an average yield of 2.54 t/ha. Slightly different in Serdang, *Kedudut 2* (2.96 t/ha) and *Kedudut 5* (2.99 t/ha) had no difference in tuber yield, but both were significantly higher than *Kedudut 6* (1.35 t/ha). Interestingly, the potential of sweet potato cultivation can be seen in BRIS (Bachok) and peat (Pontian) soils. In Bachok, *Kedudut 5* (15.22 t/ha) showed the highest tuber yield but was comparable to *Kedudut 6* (13.76 t/ha) and both significantly had greater tuber yield than *Kedudut 2* (10.08 t/ha). While in Pontian, the highest tuber yield was *Kedudut 6* (15.93 t/ha), followed by *Kedudut 5* (12.09 t/ha) and *Kedudut 2* (8.69 t/ha). The use of organic fertiliser was seen to give a response on BRIS soil (Bachok) and peat (Pontian) compared to silty clay (Bagan Datuk) and clay soil (Serdang). The tuber yield was not significantly different for sweet potatoes grown in Bagan Datuk and Serdang (*Figure 3*), with an average of 2.53 t/ha and 2.43 t/ha, respectively. On the other hand, a higher tuber yield could be achieved by applying 5 t/ha of

Table 2. Analysis of variance of means square on yield parameter and quality of sweet potato grown on different locations, organic and inorganic fertiliser

Source	DF	Mean square					
		Total number of tuber (ha)	Tuber yield (t/ha)	Marketable tuber yield (t/ha)	Unmarketable tuber yield (t/ha)	TAC (mg/kg)	Anthocyanin yield (kg/ha)
Location (L)	3	*	*	*	*	ns	*
Variety (V)	2	**	*	ns	**	**	**
L x V	6	*	**	**	*	**	ns
Organic (OM)	2	ns	ns	*	ns	*	*
L x OM	6	ns	*	*	ns	ns	*
V x OM	4	ns	ns	ns	ns	ns	ns
L x V x OM	18	ns	ns	ns	ns	ns	ns
NPK rate (NPK)	3	ns	ns	ns	ns	*	ns
L x NPK	9	ns	ns	*	ns	ns	ns
V x NPK	6	ns	ns	ns	ns	ns	ns
OM x NPK	6	ns	ns	ns	ns	ns	ns
L x Var x NPK	18	ns	ns	ns	ns	ns	ns
L x OM x NPK	18	ns	ns	ns	ns	ns	ns
V x OM x NPK	12	ns	ns	ns	ns	ns	ns
L x V x OM x NPK	36	ns	ns	ns	ns	ns	ns
Error	140						
Corrected total	287						

TAC = Total anthocyanin content. ** = significant at <0.001, * = significant at <0.05

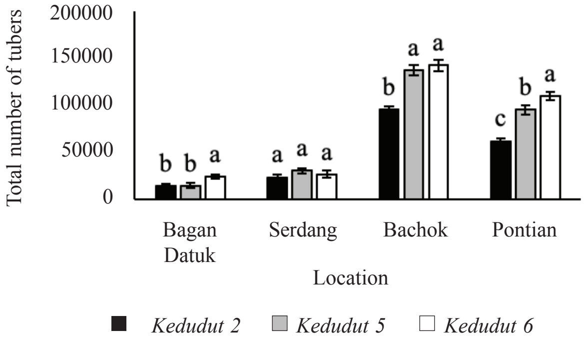

Figure 1. Total number of tuber production as affected by variety and location. Bagan Datuk = silty clay, Serdang = clay, Bachok = BRIS, Pontian = peat.

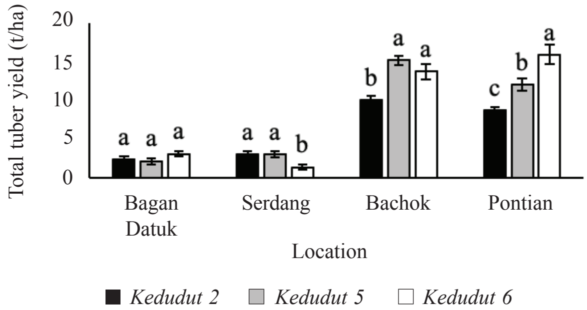

Figure 2. Yield of sweet potato tuber as affected by location and variety. Bagan Datuk = silty clay, Serdang = clay, Bachok = BRIS, Pontian = peat.

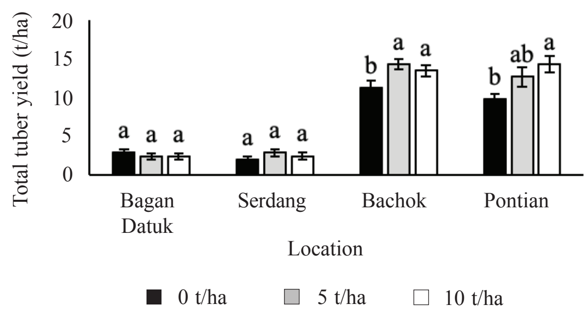

Figure 3. Yield of sweet potato tuber as affected by organic fertiliser application and location. Bagan Datuk = silty clay, Serdang = clay, Bachok = BRIS, Pontian = peat

organic fertiliser to sweet potatoes grown in Bachok, with an average yield of 14.31 t/ha. Contrary to this, in Pontian, a similar yield of 14.31 t/ha could only be achieved by applying 10 t/ha of organic manure, which was statistically no different from 5 t/ha of organic manure (13.46 t/ha of tuber yield). Soil amendments through high concentrations of organic fertilisers have a great potential to improve soil quality, and the effects of organic fertiliser amendments on organic matter content improvement are generally better than those of commercial inorganic fertilisers in terms of soil fertility (Li et al. 2022). Mohd Yusoff et al. (2017) reported that although the BRIS (beach ridges interspersed with swales) are regarded as problematic lowland soils for agriculture, as are peat soils in Malaysia, it is believed that an appropriate combination of chemical fertiliser and manure input can overcome inherent soil fertility. In addition, Bhatt et al. (2019) and Xiu-rong et al. (2003) also reported that organic and inorganic fertilisers improve soil fertility. While, Pahalvi et al. (2021) and Dubey et al. (2012) reported that chemical fertiliser alone could sustain high crop yields but also soil fertility. Montagu et al. (2001) reported that the soil determined how the root system as a whole responded. The growth of roots in compact soil was always slowed. However, when the root axis grew through loose soil into a shallow or deep compact subsoil, compensatory root growth in the loose soil maintained total root length, and thus shoot growth was unaffected. In addition, wet soils, particularly those high in silt and clay, appear to be the most susceptible to compaction, which directly limits root growth, reduces canopy development and thereby certain crop yields (Johansen et al. 2015). According to Ahad et al. (2015) there was a direct relationship between bulk density and sand content and an indirect relationship between bulk density and clay content, which means that more sand and less clay content in soil means higher bulk density and vice versa. The porosity of soil decreases as its bulk density increases. According to Oleszczuk and Truba (2013), increasing bulk density values causes a decrease in porosity in peat soils but according to Arabia et al. (2020) it is common for peat soil to have very low bulk density. In this study, soil with a high clay content, such as in Bagan Datuk and Serdang, was the limiting factor for tuber production compared to Bachok and Pontian. High clay content decreases the soil bulk density and increases soil porosities, which could limit tuber production undergroud. Even though a decrease in soil bulk density and an increase in soil porosity improved the nutrient uptake by the plant, it also improved the aeration of the soil and nutrient availability (Ogbodo 2005; Nadeem Shah et al. 2023). The present findings suggest that the effect of location and variety on total tuber yield may be determined by soil-genotype interaction. Purple sweet potato varieties have a specific tendency to grow better under soil with low bulk density, which means the soil has to have fewer clay contents. The present study also revealed that *Kedudut 6* is slightly advantageous in peat soil, but *Kedudut 5* has more potential in BRIS soil. Soil that receives organic fertiliser is less compacted and has better soil arrangement, texture, and airing, which increases the soil's capacity to hold onto water and encourages the growth of strong roots (Assefa and Tadesse 2019). Significantly increased soil bulk density, water holding capacity, and capillary porosity (Liu et al. 2023) and can control how soil nutrients build up and move through the soil (Fan et al. 2023). Thus, it could explain the significant effect of location and organic fertiliser on total tuber yield production which depends on the soil type. The use of high amount of organic fertilisers may negate the ability of inorganic fertilisers (NPK fertilisers) to increase tuber yield production because organic fertilisers provide soil structural conditions more conducive to sweet potato rooting. However, high clay content in soils such as Serdang (clay) and Bagan Datuk (silty clay) which naturally increase the soil compaction, may not benefit from organic application for sweet potatoes in this study. This is in line with Vos et al. (2018) who recommended that the best soils for sweet potato cultivation should be loose, well-draining, and, most importantly, have a low clay content.

There was a significant interaction between location and variety, location and organic fertiliser, and location and inorganic fertiliser on the marketable tuber yield (*Table 2*). Sweet potatoes planted in Bagan Datuk (silty clay soil) had no difference in marketable yield regardless of the varieties planted, with an average yield of 1.76 t/ ha (*Figure 4*). In Serdang (clay soil), the marketable tuber yields of *Kedudut 2* (1.85 t/ha) and *Kedudut 5* (1.70 t/ha) had a comparable yield but were significantly higher than *Kedudut 6* (0.49 t/ha). On the other hand, the performance of sweet potatoes in Bachok (BRIS) and Pontian (peat soils) was remarkable in terms of marketable tuber yield production (*Figure 4*). In Bachok, *Kedudut 5* (7.23 t/ha) produced the highest marketable tuber yield but was significantly comparable to *Kedudut 6* (7.09 t/ha). Also, *Kedudut 6* had comparable marketable tuber yields to *Kedudut 2* (4.78 t/ha). In Pontian, *Kedudut 5* and *Kedudut 6* also had comparable marketable tuber yields of 9.05 t/ha and 11.56 t/ha, respectively but significantly higher than *Kedudut 2* (6.22 t/ha). Generally, the average yield in Pontian (8.95 t/ha) was higher by 41% than in Bachok (6.37 t/ha). Organic fertiliser applications did not influence the marketable yield of three sweet potato varieties grown in Bagan Datuk and Serdang but significantly improved the marketable yields in Bachok and Pontian (*Figure 5*). In Bachok (4.33 t/ha) and Pontian (6.28 t/ha), without organic applications (0 t/ha), both show lower marketable tuber yields than sweet potatoes applied with 5 t/ha and 10 t/ha. In Bachok, applying 5 t/ ha and 10 t/ha produced 7.15 t/ha and 7.62 t/ha of marketable tuber yield, respectively with differences of only 6.6%. However, applications of 5 t/ha and 10 t/ha were significantly comparable. On the other hand, in Pontian, applying 5 t/ha and 10 t/ha produced 9.34 t/ha and 11.2 t/ ha of marketable tuber yield, respectively with differences of 20%. Also, these two rates were comparable in terms of marketable yield. Thus, the present study indicates that 5 t/ha of organic fertiliser is optimum for marketable sweet potato yields. Sweet potato grown in Bagan Datuk was not influenced by inorganic fertiliser, but in Serdang, the increase in inorganic fertiliser significantly reduced sweet potato marketable tuber yield (*Figure 6*). On the other hand, higher rates of NPK significantly increased marketable tuber yields in Bachok and Pontian. Applying NPK (12:12:17) in Bachok at the rates of 0 kg/ha, 200 kg/ha, 400 kg/ha, and 600 kg/ha produced marketable tuber yields of 4.67 t/ha, 5.97 t/ha, 7.41 t/ha and 7.44 t/ha, respectively. However, no significant difference was observed between the three higher rates. This gave 27.8%, 58.7% and 59.3% yield advantages over the control, respectively. Thus, applying 200 kg/ha of inorganic fertiliser (NPK 12:12:17) could be sufficient for sweet potatoes in Bachok in terms of producing marketable tuber yields. While the application of 0 kg/ha, 200 kg/ha, 400 kg/ha, and 600 kg/ha produced 7.61 t/ha, 8.44 t/ha, 9.18 t/ha and 10.55 t/ha, of marketable tuber yields, respectively in Pontian (*Figure 6*). However, no significant difference was noted between the three lower rates and between the three higher rates. Generally, this gave a 10.8%, 20.6% and 38.6% yield advantage over the control, respectively. Thus, NPK fertiliser at the rate of 600 kg/ha for marketable tuber yield in Pontian could be recommended. Hayati et al. (2020) reported that yield in sweet potatoes increased by NPK application because N is a component of proteins and nucleic acids that plays an essential role in photosynthetic activity. Sufficient N contributes to an increase in tuber weight, length and diameter and consequently increases the yield of sweet potato tubers (Pushpalatha et al. 2017). According to Tang and Ngome (2022), the total N in the soil is the limiting factor determining the sweet potatoes' growth and yield because it is directly involved in amino acid synthesis, total starch synthesis and photosynthesis; thus, low N could limit the growth of the sweet potato. However, excessive N will favour vine and leaf formation because it could contribute more to the photosynthesis supply that scarifies storage root formation (Bourke 1985; Darko et al. 2020; Tang and Ngome 2022). The optimal range of total N (%) in the soil for sweet potato cultivation is 0.2% and 0.5% (Darko et al. 2020) and for exchangeable K, 0.51 cmol/kg - 1.02 cmol/kg (Vos et al. 2018). A study conducted on seed potato minitubers under nutrient solution recorded that the highest tuber productivity was observed in a range of 2.2 dS/m - 2.2 dS/m (Calori et al. 2017), 1.0 dS/m and 2.0 dS/m (Sumarni et al. 2019). A similar report on sweet potato tuber yields under nutrient solution was found to be optimal at 2.0 dS/m (Rodríguez-Delfina et al. 2012), 2.6 dS/m (Sakamoto and Suzuki 2020). A study conducted under field conditions showed that sweet potato growth and yield reduced 50% after the salinity reached 8 dS/m (Begum et al. 2015). Soil electrical conductivity is directly proportional to the nutrient concentration level. Higher soil EC values indicate a high level of salts or a high amount of nutrient concentration in the soil, but also a high level of salts. High soil EC indicates a low to medium fertilisation requirement, but high EC could also damage the plant root system (Che Othman et al. 2019). The current study revealed that nitrogen status in the studied soils at the initial stage was less fertile than the recommended range, except for Pontian (peat soil). While only Pontian and Bagan Datuk were in the acceptable range for exchangeable K. High nitrogen elements in peat soil are mostly in organic forms, which are less available for plants due to the high C/N ratio, resulting in N immobilisation because soil microbes use inorganic N for the decomposition of organic matter before being utilised by plants (Sulandjari et al. 2019; Choo et al. 2022). In addition, high CEC in peat soil also has very low base saturation, which leads to low availability of K, Ca and Mg (Choo et al. 2022). The EC values found in this work at the initial stage were too low in Bagan Datuk (silty clay soil) and Serdang (clay soil)

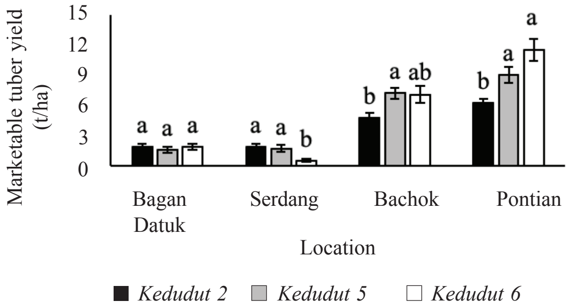

Figure 4. Marketable tuber yield of three sweet potato varieties as affected by location. Bagan Datuk = silty clay, Serdang = clay, Bachok = BRIS, Pontian = peat

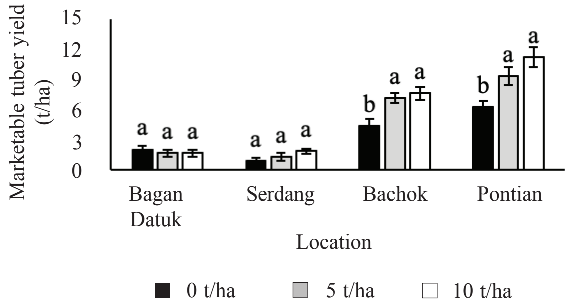

Figure 5. Marketable tuber yield as affected by organic fertilizer and location. Bagan Datuk = silty clay, Serdang = clay, Bachok = BRIS, Pontian = peat.

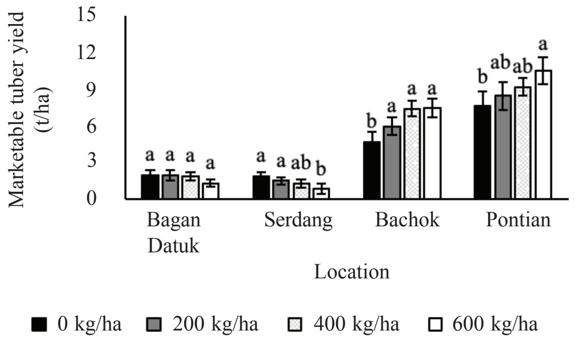

Figure 6. Marketable tuber yield (t/ha) as affected by inorganic fertiliser and location. Bagan Datuk = silty clay, Serdang = clay, Bachok = BRIS, Pontian = peat.

but according to U.S. Department of Agriculture (2021) it it normal for non-saline soils to have a range within 0 – 2 dS/m. However, too low EC in soils reduces crop growth because the transport rate of nutrients to the roots is limited (Heinen et al. 2002). The present study suggests that purple sweet potato marketable tuber yield response varied remarkably with organic and inorganic fertiliser levels, as well as soil types. Marketable tuber yields regardless of the varieties applied with organic and inorganic fertilisers were not performed under silty clas (Bagan Datuk) and clay soils (Serdang) because heavy clay soils restrict storage development due to compactness (Nedunchezhiyan et al. 2012), decrease in root growth and rooting depth, severe root stunting and a decrease in the availability of nutrients (Shaheb et al. 2021). In addition, added organic and inorganic fertilisers did not improve the marketable tuber yields, which could be due to high soil compaction (naturally high clay content in soils) decreased permeability, drainage, aeration, water availability, absorption of nutrients by plants, and a higher amount of inorganic fertiliser significantly increasing the soil compactness (Massah and Azadegan 2016). Moreover, similar to clayey soils, fine sand and silty soils are frequently slowly permeable and therefore subject to compaction naturally, and where roots in compact soil are confined to macrospores, the rate at which they can extract water and nutrients from the soil could be limited (Batey 2009). Due to soil compaction, there is high penetration resistance, less infiltration, high runoff, more soil erosion, and consequently less nutrient uptake by the plant (Shah et al. 2017). On the other hand, loose-soil such as BRIS and peat soil promote greater marketable tuber yields. Even though BRIS and peat soils have low nutrient content and poor soil structure, applying organic and inorganic fertilisers could increase the ability of soil structural support, water and nutrient movement, microbial life movement and soil aeration, thus consequently improving the root's development for tuber formation. According to Correa et al. (2019) crops are planted in loose soil, the root system expresses its full potential under an ideal soil condition that is neither too hard nor too loose, in which the roots could maximise the nutrient uptake per unit root length. Improved marketable tuber yields through NPK and inorganic fertilisers could be attributed to the increased nutrient contents, as the inherent N, P and K levels were categorised as low. Thus, applications of both fertilisers enable rapid nutrient uptake by plants and consequently improve growth and yields (Siose and Kader 2021).

Location and variety had a significant main effect on unmarketable tuber yield (*Table 2*). However, there was a significant interaction between location and variety. There was no significant effect of organic and inorganic fertilisers. Due to the low number of tubers, total tuber yield weight and marketable tuber yields in Bagan Datuk and Serdang, it can be observed that the unmarketable tuber yield was also low (*Figure 7*). Interestingly, in Bachok, the unmarketable tuber yield was significantly highest in *Kedudut 5* (7.99 t/ha), followed by *Kedudut 6* (6.67 t/ha) and the lowest in *Kedudut 2* (5.30 t/ha). On the other hand, in Pontian, the highest unmarketable tuber yield was in *Kedudut 6* (4.37 t/ha), followed by *Kedudut 5* (3.04 t/ha) and *Kedudut 2* (2.47 t/ha) but statistically there was no difference between *Kedudut 2* and *Kedudut 5.*

There was a significant effect of variety on total anthocyanin content (TAC). However, there was a significant interaction between location and variety in TAC (*Table 2*). This study showed that TAC content was significantly highest in *Kedudut 2* for all locations (*Figure 8*). This result is interesting because *Kedudut 2* shows the lowest tuber yield, but vice versa for TAC content. There is no difference in TAC between *Kedudut 5* and *Kedudut 6*, except in Bachok, where *Kedudut 6* had a higher TAC than *Kedudut 5*. Generally, the average TAC in *Kedudut 2*, *Kedudut 5* and *Kedudut 6* was 560 mg/kg, 276 mg/kg, and 252 mg/kg, respectively. There was no significant effect of organic fertiliser on TAC. However, there was a significant main effect of inorganic fertiliser on TAC. TAC showed inconsistent results among different inorganic fertiliser levels (*Figure 9*). TAC showed the highest without inorganic fertiliser (192 mg/kg) but did not differ with 400 kg (183 mg/kg). These two rates of inorganic fertiliser rates were significantly higher than 200 kg (163 mg/kg) and 600 kg (166 mg/kg) applied to sweet potatoes. Kurata and Kobayashi (2023) reported that the changes in anthocyanin in purple sweet potato content varied due to location on the basis of soil temperature, where a lower temperature could increase anthocyanin content. Zha and Koffas (2017) reported that anthocyanin fluctuates based on seasonal and environmental factors. Mattoo et al. (2022) explained that differences in geographical locations influence anthocyanin contents in potatoes and sweet potatoes due to variations in light intensity, temperature, soil fertility, stress levels and tuber formation stage. The present study suggests the TAC in three purple sweet potatoes (*Kedudut 2, Kedudut 5*, and *Kedudut 6*) is strongly influenced by genetic factor because *Kedudut 2* is remarkably high at all locations despite different soil types and a similar trend was also observed for *Kedudut 5* and *Kedudut 6* across all locations.

Anthocyanin yield (t/ha) is the product of marketable tuber yield (t/ha) and TAC in sweet potatoes. There was a significant effect of variety on anthocyanin yield (*Table 2*). There was a significant effect of variety on anthocyanin yield (*Table 2*). In this study, *Kedudut 2* produced the highest anthocyanin yield compared to *Kedudut 5* and *Kedudut 6*, which were 2.29 kg/ha, 1.24 kg/ha, and 1.73 kg/ha, respectively (*Figure 10*). There was a significant effect of organic fertiliser on anthocyanin yield. However, there was a significant interaction between location and organic fertiliser (*Table 2*). Silty clay and clay soils produced a low marketable yield, which directly contributed to the low anthocyanin yield in Bagan Datuk and Serdang. In Bagan Datuk, application of 0 t/ha, 5 t/ha, and 10 t/ha organic fertiliser produced insignificant anthocyanin yields of 0.88 kg/ha, 0.71 kg/ha, and 0.71 kg/ha (*Figure 11*). Also in Serdang, application of 0 t/ha, 5 t/ha, and 10 t/ha organic fertiliser produced insignificant anthocyanin yields of 0.69 kg/ha, 0.67 kg/ha, and 0.51 kg/ha, respectively. While, in Bachok, for maximum anthocyanin yield, application of 10 t/ha organic fertiliser produced the highest anthocyanin yield of 2.41 kg/ha. Application of 5 t/ha organic fertiliser produced 1.88 kg/ha anthocyanin yield and there was no difference with 0 t/ha organic fertiliser (1.71 kg/ha). Also, statistically, there was no difference between 5 t/ha and 10 t/ha organic fertiliser. Meanwhile, in Pontian, the highest anthocyanin yield was produced at 10 t/ha (4.6 kg/ha), followed by 5 t/ha (3.33 kg/ha), and 0 t/ha (2.22 kg/ha). The present study indicates that the application of organic fertiliser improved the anthocyanin yield, but it also depends on soil types. BRIS (Bachok) and peat soil (Pontian) have

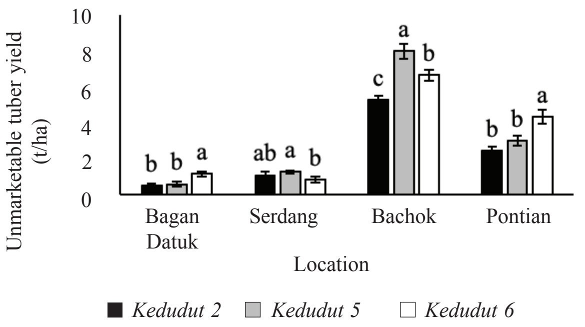

Figure 7. Unmarketable tuber yield of sweet potato as affected by location and variety. Bagan Datuk = silty clay, Serdang = clay, Bachok = BRIS, Pontian = peat

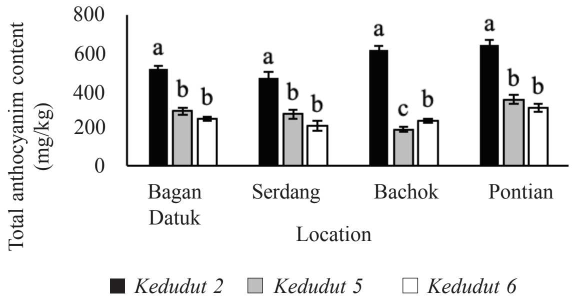

Figure 8. Total anthocyanin content (mg/kg) as affected by locations and variety. Bagan Datuk = silty clay, Serdang = clay, Bachok = BRIS, Pontian = peat

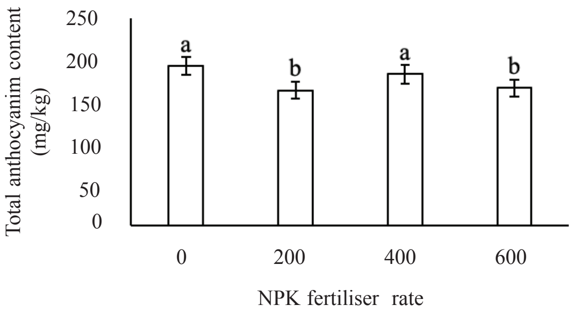

Figure 9. Total anthocyanin content (mg/kg) in tuber of sweet potato as affected by NPK fertiliser (12:12:17).

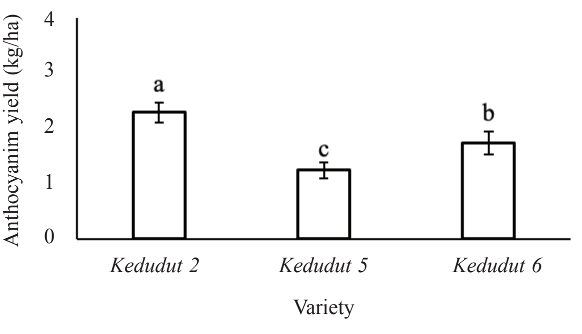

Figure 10. Anthocyanin yield (kg/ha) produced by Kedudut 2, Kedudut 5 and Kedudut 6

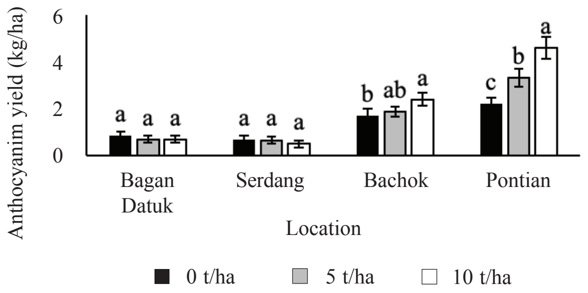

Figure 11. Anthocyanin yield (kg/ha) as affected by locations and organic fertiliser. Bagan Datuk = silty clay, Serdang = clay, Bachok = BRIS, Pontian = peat

been shown to benefit from organic application compared to silty clay (Bagan Datuk) and clay soil (Serdang).

Marketable tuber yield is the most important trait that influences the economics of sweet potato production. In the case of cassava, farmers in Thailand have two pricing schemes: either weight based or starch content based. With weight based pricing, the harvest is sold according to its weight, whereas with starch content based pricing, the quality of the harvest is evaluated at the factory gate. When the cassava has lower starch content, the buyer decreases the buying price, depending on the measured starch content of the harvest and the standard of minimum starch content in cassava (Pannakkong et al. 2022). The purpose of cultivation of purple sweet potatoes' is because of their high anthocyanin and carotenoid content, which is responsible for their potent antioxidant capacity that can neutralise free radicals and help prevent lipid peroxidation activity, providing defence against harm brought on by hepatotoxins (Laveriano-Santos et al. 2022). Additionally, eating sweet potatoes high in anthocyanins has been linked to improved cognitive function and a reduced risk of diabetes, cancer, and cardiovascular disease (Laveriano-Santos et al. 2022). Therefore, TAC in purple sweet potatoes is the most important trait, as it could be the price-limiting factor even though they have a lower yield. The present study indicates that regardless of the soil types, *Kedudut 2* outperformed *Kedudut 5* and *Kedudut 6* in terms of anthocyanin yield. Significantly high TAC in the purple sweet potatoes gives advantages even though they have a slightly lower yield because the primary final product is the variety that could produce the highest anthocyanin yield. In order to maximise *Kedudut 2* anthocyanin yields by increasing the marketable tuber yield (in the case farmers prefer to sell weight-based), a rate of 5 t/ha organic fertiliser and 200 kg/ha of inorganic fertiliser (NPK 12:12:19) is recommended for sweet potato cultivation in Bachok (BRIS soil), while 5 t/ha organic fertiliser and 600 kg/ha of inorganic fertiliser are recommended in Pontian (peat soil).

Conclusion

The purple sweet potato is an important food crop with health effects attributed to its anthocyanin content. The TAC in the purple sweet potato could be the limiting market price factor, as it determines the potential anthocyanin yields. *Kedudut* 2 produced the highest TAC compared to *Kedudut* 5 and *Kedudut* 6. Even though *Kedudut* 5 and *Kedudut* 6 had greater tuber yields, both had very low TAC, which may not be favourable to farmers and industries. Generally, *Kedudut* 2, *Kedudut* 5 and *Kedudut* 6 produced anthocyanin yields of 2.29 kg/ha, 1.24 kg/ha and 1.73 kg/ha, respectively. The tuber yields and anthocyanin yields in Bagan Datuk (silty clay) and Serdang (clay) were low. Soil with a high clay content is naturally compacted, which results in low fertiliser effectiveness and consequently reduces the tuber yield potential. It can be concluded that planting *Kedudut* 2 with a rate of 5 t/ha organic fertiliser and 200 kg/ha inorganic fertiliser (NPK 12:12:17) is recommended for sweet potato cultivation in Bachok, while 5 t/ha organic fertiliser and 600 kg/ha inorganic fertiliser are recommended in Pontian for maximum marketable yield and consequently maximise the anthocyanin yields. Further study needs to be carried out to determine the other suitable agronomic practices in marginal soils for sweet potato cultivation.

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References

Abu Bakar, M. Z., Nafis, A. W., Chaang, T. C. & Mohamad, A. R. (1981). Distribution, characterization and utilization of problem soils in Malaysia - A country report. *Tropical Agriculture Research Series*, *15*, 41–61.

Adekiya, A. O., Adebiyi, O. V., Ibaba, A. L., Aremu, C. & Ajibade, R. O. (2022). Effects of wood biochar and potassium fertilizer on soil properties, growth and yield of sweet potato (*Ipomea batata*). *Heliyon*, *8*(11). doi.org/10.1016/j.heliyon.2022.e11728

Agbede, T. M., Adekiya, A. O. & Ogeh, J. S. (2013). Effects of organic fertilizers on yam productivity and some soil properties of a nutrient-depleted tropical Alfisol. *Archives of Agronomy and Soil Science*, *59*(6), 803–822. doi.org/10.1080/03650340.2012.683423

Ahad, T., Kanth, T. A. & Nabi, S. (2015). Soil bulk density as related to texture, organic matter content and porosity in Kandi soils of district Kupwara (Kashmir valley), India. *International Journal of Scientific Research*, *4*(1), 198–200.

Alam, M. M., Morshed, G., Siwar, C. & Murad, M. W. (2012). Initiatives and challenges of agricultural crop sector in East Coast Economic Region (ECER) development projects in Malaysia. *American-Eurasian Journal of Agricultural & Environmental Sciences*, *12*(7), 922–931.

Anuar, A. R. & Jamal, T. (1998). Continuos production of sweet potato on an acidic soil. *UPM Research Report*, *2*.

Arabia, T., Basri, H., Manfarizah, Z. & Mukhtaruddin. (2020). Physical and chemical characteristics in peat lands of Aceh Jaya District, Indonesia. *International Symposium on Wetlands Environmental Management*, *499*. doi.org/10.1088/1755-1315/499/1/012004

Assefa, S., & Tadesse, S. (2019). The principal role of organic fertilizer on soil properties and agricultural productivity -A Review. *Agricultural Research & Technology*, *22*(2), 46–50. doi.org/10.19080/ARTOAJ.2019.22.556192

Balemi, T. (2012). Effect of integrated use of cattle manure and inorganic fertilizers on tuber yield of potato in Ethiopia. *Journal of Soil Science and Plant Nutrition*, *12*(2), 253–261. doi.org/10.4067/S0718-95162012000200005

Batey, T. (2009). Soil compaction and soil management - A review. *Soil Use and Management*, *25*(4), 335–345. doi.org/10.1111/j.1475-2743.2009.00236.x

Begum, F., Azizul Haque, M., Alam, M. S. & Mohanta, H. C. (2015). Volume 40 Number 2 June 2015. *Bangladesh Journal of Agricultural Research*, *40*(2), 249–258.

Bekele, D. & Boru, M. (2022). Effect of farmyard manure and inorganic nitrogen fertilizers rates on the yield and yield traits of sweet potato (*Ipomoea batatas* L.) at Assosa District. *International Journal of Ecotoxicology and Ecobiology*, *7*(3), 32–36. doi.org/10.11648/j.ijee.20220703.11

Bhatt, M. K., Labanya, R. & Joshi, H. C. (2019). Influence of long-term chemical fertilizers and organic manures on soil fertility - A review. *Universal Journal of Agricultural Research*, *7*(5), 177–188. doi.org/10.13189/ujar.2019.070502

Boru, M., Tsadik W, K. & Tana, T. (2017). Effects of application of farmyard fanure and inorganic phosphorus on tuberous root yield and yield related traits of sweet potato [*Ipomoea batatas* (L.) Lam] at Assosa, Western Ethiopia. *Advances in Crop Science and Technology*, *5*(4). doi.org/10.4172/2329-8863.1000302

Bourke, R. M. (2005). Sweet potato in Papua New Guinea: the plant and people. In *The sweet potato in Oceania: A reappraisal* (1st Editio, Issue October, pp. 15–24). Oceania Publications and University of Pittsburgh.

Bourke, R. Michael. (1985). Influence of nitrogen and potassium fertilizer on growth of sweet potato (*Ipomoea batatas*) in Papua New Guinea. *Field Crops Research*, *12*, 363–375. doi.org/10.1016/0378-4290(85)90081-4

Calori, A. H., Factor, T. L., Feltran, J. C., Watanabe, E. Y., de Moraes, C. C. & Purquerio, L. F. V. (2017). Electrical conductivity of the nutrient solution and plant density in aeroponic production of seed potato under tropical conditions (winter/spring). *Bragantia*, *76*(1), 23–32. doi.org/10.1590/1678-4499.022

Che Othman, N. N., Md Isa, M. N., Ismail, R. C., Ahmad, M. I. & Hui, C. K. (2019). Factors that affect soil electrical conductivity (EC) based system for smart farming application. *The 2nd International Conference on Applied Photonics and Electronics 2019*, *020055*. doi.org/doi.org/10.1063/1.5142147

Choo, L. N. L. K., Ahmed, O. H., Razak, N. A. & Sekot, S. (2022). Improving nitrogen availability and Ananas comosus L. Merr var. Moris productivity in a tropical peat soil using clinoptilolite zeolite. *Agronomy*, *12*(2750). doi.org/10.3390/agronomy12112750

Comtrade. (2023). *United Nations Statistics Division, UN COMTRADE. International Merchandise Trade Statistics. HSCode 071420.*

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. doi.org/10.1093/jxb/erz383

Darko, C., Yeboah, S., Amoah, A., Opoku, A. & Berchie, J. N. (2020). Productivity of sweet potato (*Ipomoea batatas* (L) Lam) as influenced by fertilizer application in different agro-ecologies in Ghana. *Scientific African*, *10*. doi.org/10.1016/j.sciaf.2020.e00560

DOA. (2022). Booklet statistik tanaman (sub-sektor tanaman makanan). In *Jabatan Pertanian Malaysia*.

Dubey, V., Patel, A. K., Shukla, A., Shukla, S. & Singh, S. (2012). Impact of continuous use of chemical fertilizer. *International Journal of Engineering Research and Development*, *3*(11), 13–16.

Esan, V. I., Omilani, O. O. & Okedigba, I. (2021). Effects of organic and inorganic fertilizers on sweet potato production in Iwo, Nigeria. *African Journal of Plant Science*, *15*(5), 131–137. doi.org/10.5897/AJPS2021.2130

Fan, H., Zhang, Y., Li, J., Jiang, J., Waheed, A., Wang, S., Rasheed, S. M., Zhang, L. & Zhang, R. (2023). Effects of organic fertilizer supply on soil properties, tomato yield, and fruit quality: A global meta-Analysis. *Sustainability*, *15*(2556). doi.org/10.3390/su15032556

Faridah, M., Norziana, Z. Z. & Liza Nuriati, L. K. C. (2022). Soil fertility management for sustainable plant Production in Malaysia. *Role of Healthy Soil-Plant Interactions towards Achieving Resilient Agriculture in the Asian and Pacific Regio*, 1–8.

Gweyi-Onyango, J. P., Sakha, M. A. & Jefwa, J. (2021). Agricultural interventions to enhance climate change adaptation of underutilized root and tuber crops. In W. L. Filho (Ed.), *African Handbook of Climate Change Adaptation* (pp. 62–81). doi.org/10.1007/978-3-030-45106-6

Hayati, M., Zakaria, S., Efendi, & Anhar, A. (2020). The effect of nitrogen, phosphorus, and potassium fertilizer on the yield and quality of sweet potato (*Ipomoea batatas* L.) clones in the highlands of Indonesia. *Systematic Reviews in Pharmacy*, *11*(2), 309–316. doi.org/10.5530/srp.2020.2.48

Heinen, M., Marcelis, L. F. M., Elings, A., Figueroa, R. & Del Amor, F. M. (2002). Effects of EC and fertigation strategy on water and nutrient uptake of tomato plants. *Acta Horticulturae*, *593*(June 2014), 101–107. doi.org/10.17660/ActaHortic.2002.593.12

Ishak, K., Noor Ismawaty, N., Zaulia, O., Nur Syafini, G. & Nurul Afza, A. K. (2019). Kajian kesan pengawetan dan tanpa pengawetan ke atas penyimpanan persekitaran pengudaraan biasa terhadap kualiti tekstur ubi keledek unggu varieti K6. In Azman Hamzah, H. C. Man, M. H. Hamzah, N. Khairudin, M. Z. M. Nor, & R. Shamsudin (Eds.), *National Convention of Agricultural and Food Engineering* (pp. 81–85). Malaysian Society of Agricultural Engineers.

Jahan, S. M., Muslianie, I. & Khandaker, M. M. (2014). Effects of soil amendments on BRIS soil health, crop physiology and production. *International Journal of Research and Innovations in Earth Science*, *1*(1), 1–8.

Johansen, T. J., Thomsen, M. G., Løes, A. K. & Riley, H. (2015). Root development in potato and carrot crops – influences of soil compaction. *Acta Agriculturae Scandinavica Section B: Soil and Plant Science*, *65*(2), 182–192. doi.org/10.1080/09064710.2014.977942

Kantikowati, E., Karya, Yusdian, Y. & Suryani, C. (2019). Chicken manure and biofertilizer for increasing growth and yield of potato (Solanum tuberosum l.) of Granola varieties. *IOP Conference Series: Earth and Environmental Science*, *393*. doi.org/10.1088/1755-1315/393/1/012017

Kurata, R. & Kobayashi, T. (2023). Effect of cultivation temperature on yield and anthocyanin content of purple sweet potato (*Ipomoea batatas* L.). *The Horticulture Journal*, *92*(3), 290–298. doi.org/10.2503/hortj.qh-044

Lapornik, B., Prošek, M. & Wondra, A. G. (2005). Comparison of extracts prepared from plant by-products using different solvents and extraction time. *Journal of Food Engineering*, *71*, 214–222. doi.org/10.1016/j.jfoodeng.2004.10.036

Laveriano-Santos, E. P., López-Yerena, A., Jaime-Rodríguez, C., González-Coria, J., Lamuela-Raventós, R. M., Vallverdú-Queralt, A., Romanyà, J. & Pérez, M. (2022). Sweet potato is not simply an abundant food crop: A comprehensive review of its phytochemical constituents, biological activities, and the effects of Processing. *Antioxidants*, *11*(1648). doi.org/10.3390/antiox11091648

Li, X., Li, D., Lu, Q., Wang, D., Ren, X., Lv, L., Ahmed, T., Yan, J. & Li, B. (2022). Effects of different organic fertilizers on sweet potato growth and rhizosphere soil properties in newly reclamation land. *Agronomy*, *12*(1649). doi.org/https://doi.org/ 10.3390/agronomy12071649

Liu, Z., Song, Y., Ge, L., Pan, X., Zhao, Y., Cheng, L., Li, Y., Wang, W. & Liu, X. (2023). Impact of various organic fertilizers on the growth, yield, and soil environment of peanuts subjected to continuous cropping obstacles. *Polish Journal of Environmental Studies*, *32*(4), 3683–3693. doi.org/10.15244/pjoes/164404

Lulie, M. (2016). Peatland in Malaysia. In Osaki, M. & Tsuji N. (Eds.), *Tropical Peatland Ecosystems* 59–73. Springer. doi.org/10.1007/978-4-431-55681-7

Massah, J. & Azadegan, B. (2016). Effect of chemical fertilizers on soil compaction and degradation. *Agricultural Mechanization in Asia, Africa and Latin America*, *47*(1), 44–50.

Mattoo, A. K., Dwivedi, S. L., Dutt, S., Singh, B., Garg, M. & Ortiz, R. (2022). Anthocyanin-rich vegetables for human consumption—focus on potato, sweetpotato and tomato. *International Journal of Molecular Sciences*, *23*(2634). doi.org/10.3390/ijms23052634

Md Akhir, H., Desa, A. & Ibni Hajar, R. (2012). Farm layout and planting system for sweet potato production in Malaysia. *Agricultural Mechanization in Asia, Africa and Latin America*, *43*(1). doi.org/10.13140/RG.2.1.4242.4803

Mishra, N. (2018). Effect of fertilizers on growth and productivity of potato. A Review. *International Journal of Agriculture Sciences*, *10*(4), 5183–5186. doi.org/10.9735/0975-3710.10.4.5183-5186

Mohd Yusoff, K. H., Abdu, A., Sakurai, K., Tanaka, S. & Kang, Y. (2017). Influence of agricultural activity on soil morphological and physicochemical properties on sandy beach ridges along the east coast of Peninsular Malaysia. *Soil Science and Plant Nutrition*, *63*(1), 55–66. doi.org/10.1080/00380768.2016.1255127

Montagu, K. D., Conroy, J. P. & Atwell, B. J. (2001). The position of localized soil compaction determines root and subsequent shoot growth responses. *Journal of Experimental Botany*, *52*(364), 2127–2133. doi.org/10.1093/jexbot/52.364.2127

Moore, K. J. & Dixon, P. M. (2015). Analysis of combined experiments revisited. *Agronomy Journal*, *107*(2), 763–771. doi.org/10.2134/agronj13.0485

Nadeem Shah, M., Wright, D. L., Hussain, S., Koutroubas, S. D., Seepaul, R., George, S., Ali, S., Naveed, M., Khan, M., Tanveer Altaf, M., Ghaffor, K., Dawar, K., Syed, A., & Eswaramoorthy, R. (2023). Organic fertilizer sources improve the yield and quality attributes of maize (*Zea mays* L.) hybrids by improving soil properties and nutrient uptake under drought stress. *Journal of King Saud University - Science*, *35*(4). doi.org/10.1016/j.jksus.2023.102570

Nedunchezhiyan, M., Byju, G. & Jata, Susantha, K. (2012). Sweet potato agronomy. *Fruit, Vegetable and Cereal Science and Biotechnology*, *6*(1). doi.org/10.1079/9781789243369.0157

Nur Amirah, Y., Alias, A. A. & Wan Zaliha, W. S. (2015). Growth and water relations of roselle grown on bris soil under partial root zone drying. *Malaysian Applied Biology*, *44*(1), 63–67.

Nur Izalin, M. Z., Siti Meriam, A. & Hasri, H. (2014). Penghasilan tepung pracampuran hasilan bakeri berasaskan ubi keledek VitAto. *Buletin Teknologi MARDI*, *6*, 9–16.

O'Sullivan, J. N., Asher, C. J. & Blamey, F. P. C. (1997). Nutrient disorders of sweet potato. In *ACIAR Monograph* (Vol. 48). Australian Centre for International Agricultural Research.

Ogbodo, E. (2005). Effect of depth of tillage on soil physical conditions, growth and yield of sweet potato in an Ultisol at Abakaliki, Southeastern Nigeria. *Journal of Agriculture and Social Research*, *5*(1), 41–47. doi.org/10.4314/jasr.v5i1.2827

Oleszczuk, R. & Truba, M. (2013). The analysis of some physical properties of drained peat-moorsh soil layers. *Annals of Warsaw University of Life Sciences - SGGW. Land Reclamation*, *45*(1), 41–48. doi.org/10.2478/sggw-2013-0004

Othman, A. B., Aminuddin, Y., Ghulam, M. H. & Abdul Razak, H. (1990). Soil constraints on sustainable plant production in Malaysia. *Tropical Agriculture Research Series*, 60–68.

Pahalvi, H. N., Rafiya, L., Rashid, S., Nisar, B. & Kamili, A. N. (2021). Chemical fertilizers and their impact on soil health. In G. H. Dar, R. A. Bhat, M. A. Mehmood, & K. R. Hakeem (Eds.), *Microbata and Biofertilizers Vol 2*. Springer, Cham. doi.org/doi.org/10.1007/978-3-030-61010-4_1

Pannakkong, W., Parthanadee, P. & Buddhakulsomsiri, J. (2022). Impacts of harvesting age and pricing schemes on economic sustainability of cassava farmers in Thailand under market uncertainty. *Sustainability*, *14*(7768). doi.org/10.3390/su14137768

Pushpalatha, M., Vaidya, P. H. & Adsul, P. B. (2017). Effect of graded levels of nitrogen and potassium on yield and quality of sweet potato (*Ipomoea batatas* L.). *International Journal of Current Microbiology and Applied Sciences*, *6*(5), 1689–1696. doi.org/10.20546/ijcmas.2017.605.183

Rahmawati, N., Sitepu, F. E. T. & Pasaribu, M. Y. (2022). Vermicompost application to increase sweet potato local genotype yield to support sustainable agriculture. *IOP Conference Series: Earth and Environmental Science*, *977*. doi.org/10.1088/1755-1315/977/1/012027

Roba, T. B. (2018). Review on: The effect of mixing organic and inorganic fertilizer on productivity and soil fertility. *Open Access Library Journal*, *5*(e4618). doi.org/10.4236/oalib.1104618

Rodríguez-Delfína, A., Posadas, A., León-Velarde, C., Mares, V. & Quiroz, R. (2012). Effect of salt and water stress on the proline and total chlorophyll content and nutrients uptake on two sweet potato cultivars grown on soilless culture. In F. C. Gomez-Merino (Ed.), *Proceedings of the II International on Soiless Culture and Hydroponics* (Vol. 947, pp. 55–62). Acta Horticulture. doi.org/10.17660/actahortic.2012.947.4

Sakamoto, M. & Suzuki, T. (2020). Effect of nutrient solution concentration on the growth of hydroponic sweetpotato. *Agronomy*, *10*(1708). doi.org/10.3390/agronomy10111708

Sanginga, N. (2015). Root and tuber crops (cassava, yam, potato and sweet potato). *An Action Plan for African Agricultural Transformation*, 29.

Saravaiya, S. N., Desai, K. D. & Desai, G. B. (2019). Problems and prospects of tropical tuber crops in tribal areas of South Gukarat region. *Gujarat Journal of Extension Education Special Issue on National Seminar*, *June*, 170–172.

Shah, A. N., Tanveer, M., Shahzad, B., Yang, G., Fahad, S., Ali, S., Bukhari, M. A., Tung, S. A., Hafeez, A. & Souliyanonh, B. (2017). Soil compaction effects on soil health and cropproductivity: an overview. *Environmental Science and Pollution Research*, *24*(11). doi.org/10.1007/s11356-017-8421-y

Shaheb, M. R., Venkatesh, R. & Shearer, S. A. (2021). A Review on the effect of soil compaction and its management for sustainable crop production. *Journal of Biosystems Engineering*, *46*, 417–439. doi.org/10.1007/s42853-021-00117-7

Sidiky, B., Zoumana, K., Brice, D. K. E. & Martial, K. J. H. (2019). Effect of the organic and NPK fertilizers on the growth and yield of sweet potato (*Ipomoea batatas* (L) Lam) in the Centre of Côte d'Ivoire. *Asian Journal of Soil Science and Plant Nutrition*, *4*(3), 1–14. doi.org/10.9734/ajsspn/2019/v4i330047

Siose, T. K. & Kader, M. A. (2021). Determination of optimum level of NPK for cultivation of sweetpotato in Samoa. *Journal of South Pacific Agriculture*, *24*, 12–22.

Sulandjari, Sakya, A. T., Syamsiyah, J. & Panji, D. (2019). The application of amendments to increase nutrients absorption of *Petiveria aleaceae* L. (Singawalang) in peat soils. *IOP Conference Series: Earth and Environmental Science*, *250*(012017). doi.org/10.1088/1755-1315/250/1/012017

Sumarni, E., Farid, N., Darjanto, D., Ardiansyah, A. & Soesanto, L. (2019). Effect of electrical conductivity (EC) in the nutrition solution on aeroponic potato seed production with root zone cooling application in tropical Lowland, Indonesia. *Agricultural Engineering International*, *21*(2), 70–77.

Tang, E. N. & Ngome, F. A. (2022). The integrated effects of fertilizer on sweet potato (*Ipomea Batatas*, Lam.) in Andosol and Nitisol soils. *International Journal of Sustainable Agricultural Research*, *9*(1), 28–45. doi.org/10.18488/ijsar.v9i1.2962

Tiama, D., Sawadogo, N., Traore, R. E., Yolou, M., Bationo-Kando, P., Zoundihekpon, J., Sawadogo, M. & Zongo, J. D. (2018). Effect of chemical fertilizers on production of yams (Nyù) o'f Passore in farmers' environment. *Agronomie Africaine*, *30*(1), 99–105.

Tun Norbrillinda, M. & Hasri, H. (2019). Potensi ubi keledek Anggun dalam pemprosesan produk makanan: Biskut bar. *Buletin Teknologi MARDI*, *15*, 35–40.

U.S. Department of Agriculture, N. R. C. S. (2021). *National Soil Survey Handbook, Soil properties and qualities.*

Vos, C., Arancon, N & Mathews, B. (2018). Nutrient management on commercial Okinawan sweet potato farms on the Hamakua Coast of Hawaii Island. *Pacific Agriculture and Natural Resources*, *8*, 1–7.

Xiu-rong, L., Wei-hong, S., Zhen, W., Yan-ru, H. & Chang-ai, Z. (2003). Effect of matching use of straw and chemical fertilizer on soil fertility. *Acta Pedologica Sinica*, *40*(4), 618–623.

Yaseer, S. M., Izyani, R., Noor Ismawaty, N., Rawaida, R., Nur Khairani, A. B., Razean Haireen, M. R., Bee, T. S., Siti Nurzahidah, Z. A., Muhamamad Faidhi, T., Zakry Al-asyraf, A. L., Fatin Nurliyana, A., Noor Safura, S., Hanim, A. & Mazidah, M. (2023). Planting sweet potato using fertigation system. *Buletin Teknologi MARDI*, *35*, 55–63.

Yeng, S. B., Agyarko, K., Dapaah, H. K., Adomako, W. J. & Asare, E. (2012). Growth and yield of sweet potato (*Ipomoea batatas* L.) as influenced by integrated application of chicken manure and inorganic fertilizer. *African Journal of Agricultural Research*, *7*(39), 5387–5395. doi.org/10.5897/AJAR12.1447

Zha, J. & Koffas, M. A. G. (2017). Production of anthocyanins in metabolically engineered microorganisms: Current status and perspectives. *Synthetic and Systems Biotechnology*, *2*, 259–266. doi.org/10.1016/j.synbio.2017.10.005

Zhang, Z., Dong, X., Wang, S. & Pu, X. (2020). Benefits of organic manure combined with biochar amendments to cotton root growth and yield under continuous cropping systems in Xinjiang, China. *Scientific Reports*, *10*(4718). doi.org/10.1038/s41598-020-61118-8