

Growth and Yield Performance of Five Purple Sweet Potato (*Ipomoea batatas*) Accessions on Colluvium Soil

Martini Mohammad Yusoff^{1*}, Siti Nurjiah Abdullah², Mohd Ridzwan Abd Halim¹,
Erwan Shah Shari³, Nur Arina Ismail¹ and Masnira Mohammad Yusoff⁴

¹Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia (UPM),
43400 Serdang, Selangor, Malaysia

²Tambunan Community College, Tambunan Village Resort Centre & Resort,
Kolam, Tandarason, 89657 Tambunan, Sabah, Malaysia

³Malaysian Agricultural Research and Development Institute (MARDI), 13200 Seberang Prai,
Pulau Pinang, Malaysia

⁴Malaysian Agricultural Research and Development Institute (MARDI), 43400 Serdang, Selangor, Malaysia

ABSTRACT

A study was conducted to evaluate the growth and yield performance of five purple sweet potato accessions on colluvium soil at Field 2, Universiti Putra Malaysia, Serdang, Selangor. The treatments comprised five purple sweet potato accessions (Accessions 1, 2, 3, 5, and 6) arranged in completely randomized design with four replications. Maximum tuber yield of purple sweet potato was highest ($p < 0.05$) in Accession 6 (34,563 kg ha⁻¹) compared to the lowest yield in Accession 3 (9,331 kg ha⁻¹). This was followed by Accession 2 (22,031 kg ha⁻¹), Accession 1 (21,094 kg ha⁻¹), and Accession 5 (22,900 kg ha⁻¹). A similar trend was observed for crop growth rate (CGR) with the highest (199 kg ha⁻¹ day⁻¹) in Accession 6 and the lowest (60 kg ha⁻¹ day⁻¹) in Accession 3 ($p < 0.05$). Accession 6 reached the critical leaf area index (LAI_{crit}) of 2.79 at 90% of intercepted radiation compared to the Accessions 1, 2, 3, and 5 that did not reach the LAI_{crit}. Unexpectedly, the highest total intercepted photosynthetically active radiation (PAR) was recorded by Accession 3 (340 MJ m⁻²), whereas Accession 6 showed the lowest (309 MJ m⁻²). In contrast, the highest radiation use efficiency (RUE) was obtained by Accession 6 with 7.58 g MJ⁻¹ and the lowest was Accession 3 (2.16 g MJ⁻¹). However, there was no significant difference in RUE among the rest of the accessions, except for Accession 6. To maximize the

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E-mail addresses:

martiniupm@gmail.com (Martini Mohammad Yusoff)

jjahabdullah5168@gmail.com (Siti Nurjiah Abdullah)

ridzwan@upm.edu.my (Mohd Ridzwan Abd Halim)

wanshah24@gmail.com (Erwan Shah Shari)

arinainmail.n@gmail.com (Nur Arina Ismail)

mmyusof@mardi.gov.my (Masnira, Mohammad Yusoff)

* Corresponding author

tuber yield, Accession 6 is the choice for cultivation in colluvium soil.

Keywords: Leaf area index (LAI), radiation use efficiency (RUE), sweet potato, total intercepted photosynthetically active radiation (PAR), tuber yield

INTRODUCTION

Sweet potato (*Ipomoea batatas*) is a dicotyledonous plant belonging to the Convolvulaceae family. The plant is a herbaceous perennial vine with alternate heart-shaped or palmate lobed leaves that is usually grown as an annual. Sweet potato ranks as the world's seventh most important food crop after wheat, rice, maize, potato, barley, and cassava (Food and Agriculture Organization of the United Nations [FAO], 2009). In Malaysia, sweet potato ranks second among the tuber crops next to cassava (Hanim, Chin, & Yusof, 2014). According to Uwah, Undie, John and Ukoha (2013), China is the largest sweet potato producer with an annual production of 100 million tonnes followed by Indonesia. The total sweet potato area in Malaysia was about 2000 ha/year (Tan et al., 2010). In the tropical, sub-tropical, and frost-free temperate climatic zones of the world, sweet potato is considered as a staple food. Hue, Chandran and Boyce (2010) reported that the varieties of sweet potato may differ in its flesh colour, storage root's skin colour, and some by origin. Its flesh ranges in colour from beige to white, purple, red, pink, violet, yellow, and orange.

Sweet potato varieties with white or pale yellow flesh are not as sweet and moist as those with red, pink, or orange flesh.

Sweet potato is rich in carbohydrate, protein, vitamin A, vitamin C, potassium, iron, fiber (Mais & Brennan, 2008), β -carotene, and anthocyanins (Bovell-Benjamin, 2007). It also helps to maintain fluid and electrolyte balance in the body (Palaniswami & Peter, 2008). It is also good for treating stress and provides important minerals that help to maintain balance throughout the body during stress (Motsa, Modi, & Mabhaudhi, 2015).

Most of the sweet potatoes produced in Malaysia are consumed as supplementary food. It is also processed as snacks. Sweet potato is served mainly in the boiled and baked forms. Besides that, the roots and leaves are widely consumed as vegetable in rural and urban areas. The harvested vines are also used as cattle feed. Usually the sweet potato is consumed fresh and only a limited quantity are used in making sweet potato flour that are mixed with wheat flour in making breads and cakes.

Many areas in the states of Perak, Kelantan, and Terengganu in Malaysia are involved in sweet potato production. The area planted with sweet potato in Malaysia was 2229 ha in 2011 with the production reaching 26,582 tonnes and increased to 2505 ha with the production of 26,688 tonnes in 2013. However, the yield was lower in 2012 with 25,417 tonnes from 2386 ha planted area (Department of Agriculture, 2013).

In sweet potato cultivation, the chosen variety for cultivation plays a significant role in yield determination and improvement (Maniyam, Gangadharan, & Susantha,

2012). Jalomas, Gendut, and VitAto are the popular varieties developed by the Malaysian Agricultural Research and Development Institute (MARDI) in Malaysia, besides other high-yielding varieties such as Madu, Telong, Pontian, Bukit Naga, Serdang, Rhu Tapai dan Kuala Linggi (Maniyam et al., 2012; Tan, 2000 ; Tan et al., 2010; Zaharah & Tan, 2006). Other local varieties such as Batu Kelantan, Biru Putih, Oren, and Indon are also planted in Malaysia (Hue et al., 2010).

Research on sweet potato by organizations such as MARDI and Universiti Putra Malaysia (UPM) focuses on developing specific sweet potato variety with high yield and quality. In Malaysia, research on orange flesh sweet potato known as VitAto has been conducted by MARDI (Zaharah & Tan, 2006). It is proven that the VitAto is a suitable variety for cultivation in Kelantan and Terengganu because VitAto sweet potato was reported to grow well on bris soil (Zaharah & Tan, 2006). In addition, VitAto tubers are of high-nutrient value with high beta carotene and vitamin C. It is also a good supplementary food for Malaysians because of low-glycemic index and high-dietary fiber content (Mahmood, Ibrahim, Mohd. Nasir, Pin, & Hamzah, 2007).

Other than VitAto, there are no new selected varieties that have been released or introduced recently. Hence, identification of other high-yielding varieties such as the purple sweet potato can attract the local farmers to grow sweet potato, thus increasing their family income. Purple sweet potato also has a high nutritional value due

to the presence of “anthocyanin” pigment derived from purple-coloured flesh variety of sweet potato. In addition, peonidins and cyanidins in anthocyanin have anti-oxidant and anti-inflammation properties that are very important for good digestion.

Other than planting on the bris soil, colluvium soil is also common for sweet potato planting in Malaysia. Furthermore, sweet potato vines of the vigorous varieties have high dry matter yield and protein content that could be used to feed cattle. Thus, the present study was conducted to identify the high-yielding accessions of purple sweet potato suitable to be planted on colluvium soil and to evaluate the yield performance of purple sweet potato accessions on colluvium soil.

MATERIALS AND METHODS

The study was conducted at Field 2, Faculty of Agriculture, Universiti Putra Malaysia (UPM), Serdang, Selangor (3° 00' N, and 101° 42' E). The soil type of the location of the study was colluvium soil with a flat terrain. Soil analysis was done at the Analytical Laboratory, Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia, Serdang, Selangor. The results of the soil analyses were soil pH was 6.18, total N was 0.11%, total P was 1.87 ppm and soil texture: sandy loam. The previous crop on the site was also sweet potato. The field experiment started on 23rd October, 2013 and ended on 23rd February, 2014. The total rainfall for the four months of the experimental period was 1040.7 mm, while the maximum and

minimum temperatures were 32.3°C and 22.8°C, respectively. The land was ploughed with a disc plough and left fallow for 14 days to ensure that the existing weeds and weed seeds in the soil were eliminated. Then a disc harrow was used to pulverize the soil followed by a rotor-ridger to loosen

the soil and planting beds were then formed. Five accessions of purple sweet potato were tested in this study that were labeled Accessions 1, 2, 3, 5, and 6. The general description of these accessions is presented in Table 1.

Table 1
General description of the accessions used as planting materials for the study

Accessions	1	2	3	5	6
Mature leaf colour	Green	Green	Green with purple veins on upper surface	Green	Green
Mature leaf shape	Lobed	Lobed	Lobed	Lobed	Lobed
Tuber shape	Round elliptic	Long elliptic	Long elliptic	Long irregular or curved	Round elliptic
Tuber skin colour	White	Dark purple	Purple red	Dark purple	Dark purple
Tuber flesh colour	Light purple	Purple red	Light purple	Dark purple	Dark purple

Stem cuttings of 30 cm in length with at least seven nodes derived from plants aged 2 months were used as planting materials. These cuttings were left under the shade for 2-3 days before planting to get better root initiation. The cuttings were dipped in Benomicide™ solution for several minutes as a prevention from soil-borne disease infection. The cuttings were planted at a distance of 0.25 m between the plants and 1 m between the ridges. There were 20 plots and each plot was 6.0 × 1.0 m in size. The planting materials were obtained from Bachok Research Station of the Malaysian Agricultural Research and Development Institute (MARDI) in Kelantan. Chicken manure was applied to the experimental

plots before planting at the rate of 5 tonnes ha⁻¹. Compound fertilizer NPK Blue with the ratio of 12:12:17:2 was applied at the rate of 266 kg ha⁻¹. The fertilizer was given in three split applications at the rate of 160 g plot⁻¹. Insects were controlled with contact insecticide Press® that contains active ingredient: profenos and organophosphate. The herbicides were used at the 37 days of planting using Roundup™ or Ecomax™ that contains active ingredient; glyphosate-isopropylammonium to control weeds in between the beds. Hand weeding was also carried out when necessary throughout the growing season. A sprinkler system was used to supply water to the plants twice a day.

Measurements

Maximum Tuber Yield and Plant Biomass. Maximum tuber yield is defined as the highest yield recorded for the whole growing season for each accession. Samples of tuber yield and plant biomass (tuber, leaves, and vines) were collected at 2-week intervals beginning at second week after planting until final harvest. Samplings were measured by taking duplicate 0.2 m² quadrats in each plot. For the final harvest, duplicate 0.5 m² quadrats were used. Samples were oven dried at 60°C to constant weight. All samples of tuber and plant biomass were weighed using a digital balance, which was examined for accurate reading prior to its use.

Total Dry Matter (TDM) Accumulation Over Time (Crop Growth Rate). Crop growth rate (CGR) is defined as $= \Delta \text{TDM} / \Delta t$, where TDM is total dry matter (kg ha⁻¹) and t is time (days after sowing) over the range of days from 5-95% of maximum TDM for all accessions.

Leaf Area Index and Radiation Interception. Leaf area index (LAI) and the fraction of radiation transmitted (I/I_0) through the canopy were measured using a Plant Canopy Analyser LAI-2000 (LI-COR Biosciences, Inc., Nebraska, USA). Measurements were taken weekly from October to February starting from 14 days after sowing (DAS) until 120 DAS at final harvest. At each session, two readings of LAI were taken on each plot and the average of the measurements was obtained. The

fraction of radiation intercepted (F_i) was calculated using the formula of Gallagher and Biscoe (1978):

$$F_i = 1.0 - (I/I_0)$$

Where, I is radiation under the canopy and I_0 is radiation above the canopy.

Daily incident solar radiation from the nearest Meteorological Station was used to determine total incident PAR and 50% of the incident solar radiation received was taken as PAR (Monteith, 1972). The amount of intercepted PAR by the crop (S_a) was calculated using the formula from Szeicz (1974): $S_a = F_i \times S_i$

In which F_i is the fraction of radiation intercepted and S_i is the total amount of incident PAR.

Total intercepted PAR was calculated as the sum daily intercepted PAR for the duration of the planting of the five accessions of sweet potato over the growing season.

Radiation Use Efficiency (RUE)

The RUE was calculated as the slope of the linear regression line between accumulated crop biomass and accumulated intercepted PAR. The regression line was forced through the origin based on the assumption that when accumulated intercepted PAR was zero, no DM was produced.

Statistical Analysis

Data of tuber yield, CGR, LAI, PAR and RUE were analyzed using analysis of variance and means separation between

accessions was determined by least significant difference (LSD) at the $p < 0.05$. Correlation analysis between TDM yield and CGR was also performed to evaluate their relationship.

RESULTS AND DISCUSSION

Maximum Tuber Yield

Among the accessions evaluated, Accession 6 had the highest maximum tuber yield at

34,563 kg ha⁻¹, followed by Accession 5 at 22,900 kg ha⁻¹, Accession 2 at 22,031 kg ha⁻¹, and Accession 1 at 21,094 kg ha⁻¹ (Figure 1). The lowest maximum tuber yield was from Accession 3 at 9331 kg ha⁻¹ while Accession 6 was significantly higher ($p < 0.01$) in maximum tuber yield compared with the other accessions. However, there was no significant difference among the other three accessions (1, 2, and 5) except for Accession 3.

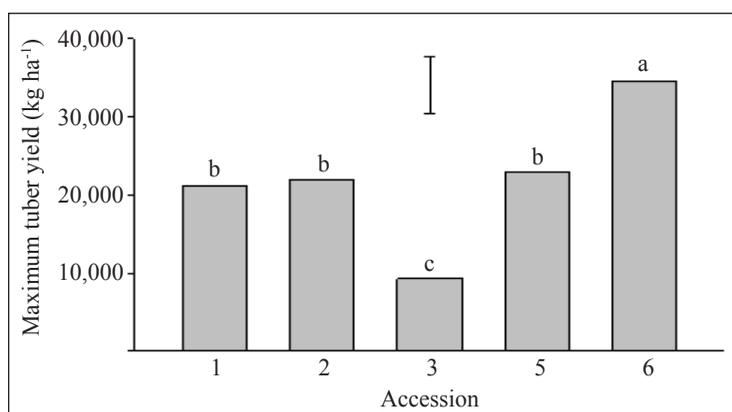


Figure 1. Maximum tuber yield of five accessions of purple sweet potato values with different letters are significantly different at $p < 0.05$

Crop Growth Rate

The pattern of TDM accumulation over time for the five accessions of purple sweet potato is shown in Figure 2. The curve fitting approximated the increase in dry matter yield over the growing period. The rapid accumulation of TDM could be seen from Accessions 6 compared with the other accessions. The highest CGR was indicated by Accession 6 with 199 kg ha⁻¹ day⁻¹ followed by Accession 2 with 117 kg ha⁻¹ day⁻¹ and Accession 1 with 106 kg ha⁻¹ day⁻¹.

While Accessions 3 and 5 gave the lowest CGR with 60 kg ha⁻¹ day⁻¹ and 82 kg ha⁻¹ day⁻¹, respectively. However, no significant difference was observed among Accessions 1, 2, 3, and 5. Tuber yield is dependent on the rate of dry matter production and the distribution of dry matter within the plant (Watson, 1952). This was shown by accumulation of TDM (CGR) (Figure 2) that indicated the highest CGR was from Accession 6 with 199 kg ha⁻¹ day⁻¹ and the lowest CGR was from Accession 3 with 60 kg ha⁻¹ day⁻¹. Van de Fliert and Braun (1999)

reported that the development cycle of sweet potato from crop establishment to harvest of the storage roots usually takes place in three phases (establishment, intermediate, and storage root bulking phase) within a time span of 90 to 120 days. The growth duration depends on the variety and environmental conditions. Accession 6 was found to form tuber earliest at 63 days after sowing (DAS) compared with Accession 3 at 78 DAS. The duration of tuber formation was considered slow since tuber could be formed as early as 4 weeks after planting. This was possibly due to the rainy season that occurred during the experimental period. The earlier formation of tuber yield in Accession 6 resulted in greater tuber yield compared to the other accessions. The variation in yield of the accessions was possibly due to genome differences among the accessions. Janssens (2001) reported that the differences in tuber yield was due to the differences in genetic constituents of genotypes of the

different sweet potato accessions. This was in agreement with Ali, Wassu and Beneberu (2015) who reported that in 114 accessions evaluated, the variation in tuber yield of sweet potato might be due to genetic differences among accessions.

Although sweet potato requires moderate temperature and well-distributed rainfall for vigorous crop growth, the rainy season that had occurred during planting affected the soil texture making it compact and wet, and tended to retard tuber formation and resulted in reduced yields as suggested by Watanabe, Ozaki and Yashiki (1968). In addition, the lower maximum tuber yield of all purple sweet potato accessions except Accession 6 was due to the plants had been attacked by army worms (*Spodoptera litura*), red cotton bugs (*Dysdercus cingulatus*), and sweet potato weevils (*Cylas formicarius*). Vines and tuber were also attacked by root knot (*Meloidogyne* spp.) and *Rotylenchulus reniformis*.

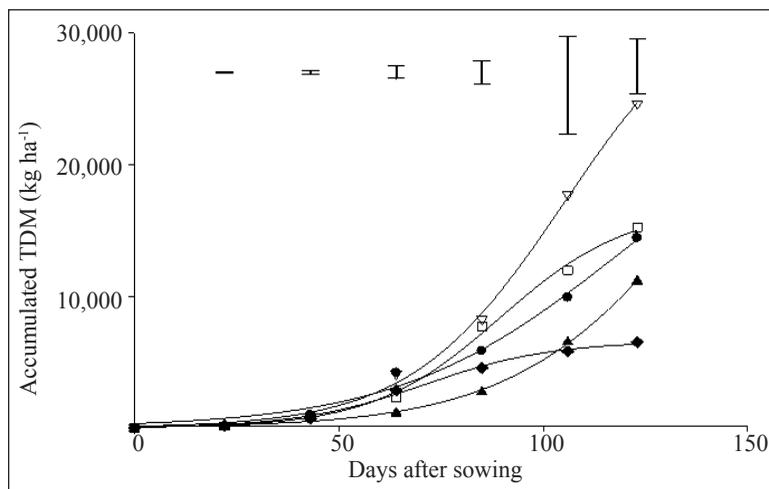
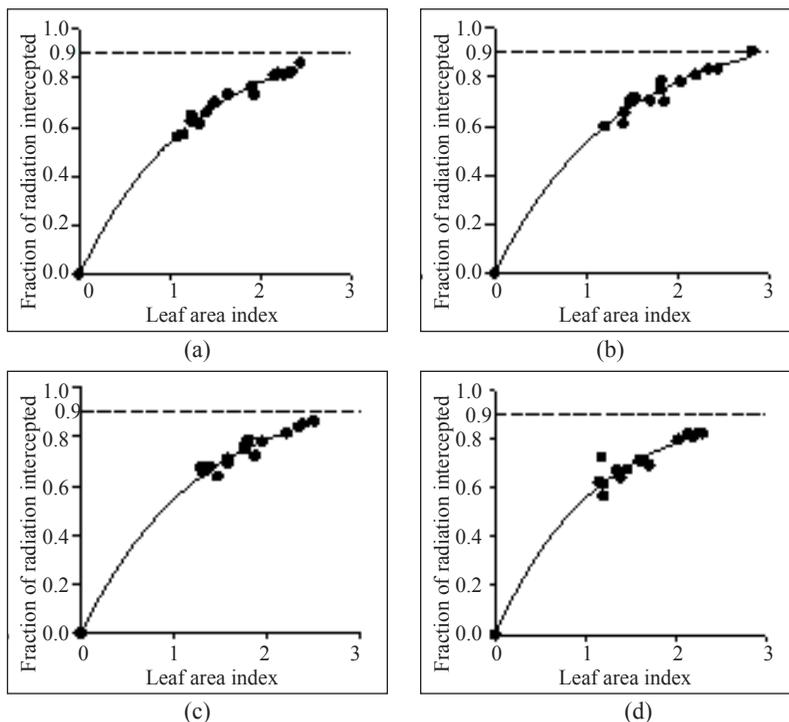


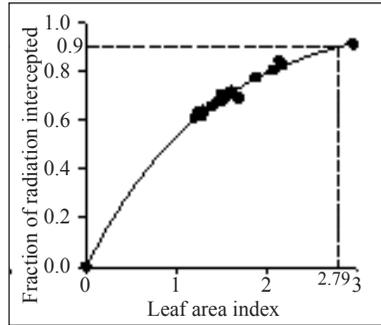
Figure 2. Accumulated total dry matter (TDM) for Accession 1 (●), Accession 2 (□), Accession 3 (◆), Accession 5 (▽), and Accession 6 (▲) of purple sweet potato.

Intercepted Radiation and Leaf Area Index (LAI)

The LAI is one of the important measurements used to determine the light interception in any crops. Light interception and photosynthesis rate are closely related to LAI (Hay & Porter, 2006). The relationship between the fraction of radiation intercepted and LAI for each accession is shown in Figure 3. From the exponential curve in Figures 3(a–e), the critical LAI (LAI_{crit}) at which 90% of intercepted PAR was calculated to be 2.79 for Accession 6 (Figure 3(e)). However, in the other accessions, radiation interception did not reach 90%, (Figures 3(a–d)), which means that they did not reach the LAI_{crit} . The LAI_{crit} for Accession 6 was achieved at 63 days after sowing (Figure 4(e)) and the other accessions could not be identified as they did not achieve the

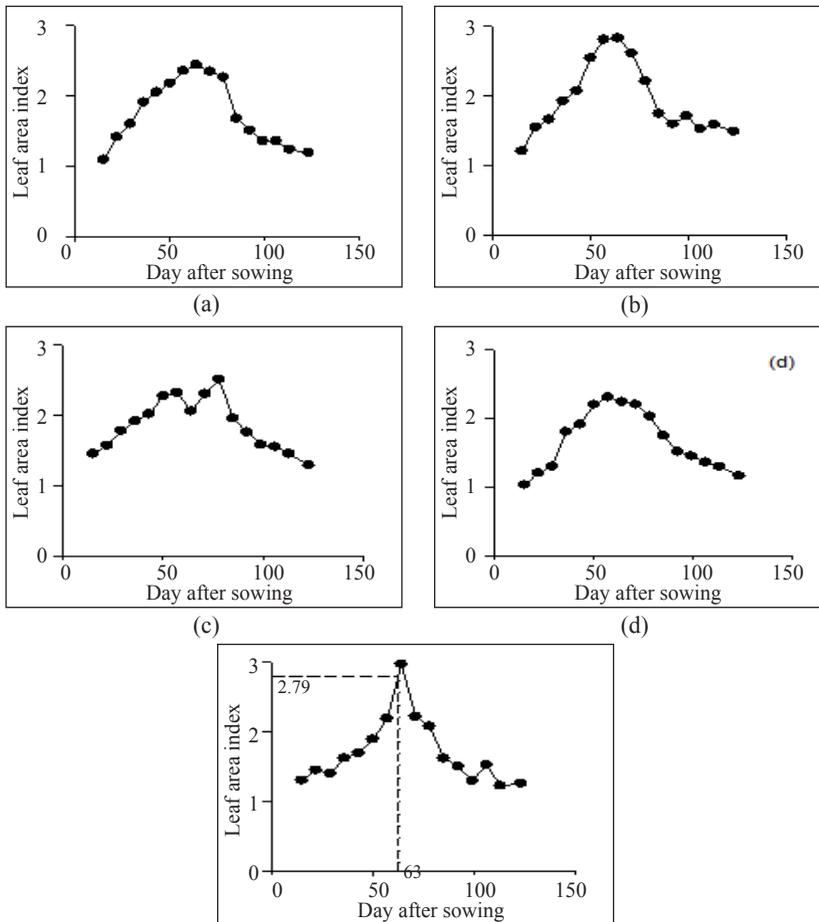
LAI_{crit} (Figures 4(a–d)). Accession 6 had the highest maximum tuber yield also due to the crop had achieved the LAI_{crit} at 2.79 (Figures 3 and 4). Critical LAI has been defined as the LAI required to intercept 90% of the incoming radiation (Brougham, 1958). Despite the ability to achieve LAI_{crit} by Accession 6, the amount of radiation intercepted by this accession was lower than the other accessions. This indicated that the amount of radiation intercepted by the crop canopy was efficiently converted to dry matter as explained by its radiation use efficiency (RUE). Radiation use efficiency is defined as crop biomass produced per unit of total solar radiation or PAR intercepted by the canopy (Monteith, 1977). Accession 6 had the highest RUE compared with the other accessions.





(e)

Figure 3. The relationship between the fractions of radiation intercepted against leaf area index of: (a) Accession 1; (b) Accession 2; (c) Accession 3; (d) Accession 5; and (e) Accession 6 of purple sweet potato



(e)

Figure 4. The relationship between the leaf area index against days after sowing of: (a) Accession 1; (b) Accession 2; (c) Accession 3; (d) Accession 5; and (e) Accession 6 of purple sweet potato

Total Intercepted Photosynthetically Active Radiation (PAR) and Radiation Use Efficiency (RUE)

Based on the analysis of variance, indicated significant differences among accessions in total intercepted PAR and RUE. Table II shows the highest total intercepted PAR was recorded for Accession 3 with 340 MJ m⁻²; however, there was no significant difference among Accessions 1 (320 MJ m⁻²), 2 (334 MJ m⁻²), and 5 (324 MJ m⁻²) except with Accession 6 (309 MJ m⁻²). Accession 6 showed the lowest total intercepted PAR. In contrast, the highest RUE was obtained by Accession 6 with 7.58 g MJ⁻¹. However, there was no significant difference in RUE among the other accessions (Table II). This finding is in agreement with Stutzel, Aufhammer and Lober (1994) who stated that RUE differed from cultivars and species. In contrast, Pilbeam, Hebblethwaite, Nyongesa and Ricketts (1991) reported that the differences in total DM yield of grain legumes were due to the differences in both RUE and the amount of light intercepted by crops.

Table 2
Total intercepted photosynthetically active radiation (PAR) and radiation use efficiency (RUE) of five accessions of purple sweet potato

Accession	Total intercepted PAR (MJ m ⁻²)	RUE (g DM MJ ⁻¹)
1	320 ^{ab}	4.08 ^b
2	334 ^a	4.36 ^b
3	340 ^a	2.16 ^b
5	324 ^{ab}	3.12 ^b
6	309 ^b	7.58 ^a

Means with different letters are significantly different at $p < 0.05$

Correlation Coefficient between CGR and Yield

There was a significant positive correlation between CGR and yield (Table 3). This indicated that when CGR increased, yield also increased.

Table 3
Correlation coefficient between CGR and yield

	Crop growth rate (kg ha ⁻¹ day ⁻¹)	TDM yield (kg ha ⁻¹)
Crop growth rate (kg ha ⁻¹ day ⁻¹)	--	0.9692***
TDM yield (kg ha ⁻¹)	0.9692***	

***Significant at $p \leq 0.001$

CONCLUSION

Based on tuber yield, CGR, and physiological parameters, Accession 6 has the highest potential among the accessions assessed. This information could form the critical criteria in assessing purple sweet potato accessions appropriate for colluvium soil. However, other information such as pest and disease tolerance and fertilizer requirement are needed to make final recommendation of the most suitable accession to be planted on colluvium soil.

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