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Potassium promotes yield, quality and economic returns of two sweet potato varieties in acidic loamy sand soil

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Abstract: Potassium (K) deficiency can limit growth and yield of sweet potato, particularly in sandy soils with a low pH. Most previous studies that focused on investigating rate of K applied for sweet potato did not use strongly acidic sandy soil. Therefore, the objective of this study was to investigate the effects of K on growth parameters, storage root yield, quality, and economic return over fertilizer cost of two sweet potato varieties grown in a strongly acidic loamy sand soil in Kalasin province, Northeast Thailand. An experiment with a 2 × 4 split plot design and four replications was established. The factors consisted of two sweet potato varieties (Beni Haruka and Okinawa-Kugani-Imo) and four K rates, 0 (control), 30, 60 and 90 kg K ha^{-1}. At the rate of 90 kg K ha^{-1}, storage root yield, total soluble solids, and economic return of Okinawa-Kugani-Imo variety were better than those of Beni Haruka. Storage root yield and economic return of Okinawa-Kugani-Imo were significantly increased with increasing K application rate up to 90 kg K ha^{-1}, while Beni Haruka had the same trend up to 60 kg K ha^{-1}, but had no significant differences when increasing the rate to 90 kg K ha^{-1}. Therefore, recommended K application rates for sweet potato variety Okinawa-Kugani-Imo and Beni Haruka, grown in the dry season after paddy rice harvest in the acidic loamy sand soil, were 90 and 60 kg K ha^{-1}, respectively.

Keywords: Northeast Thailand; potassium; economic return; acidic loamy sand soil; tuber crop.
Abbreviations: ANOVA_Analysis of variance; CV_Coefficient of variation; EC_Electrical conductivity; LSD_Least significant difference; N_Nitrogen; OM_Organic matter; P_Phosphorus; K - Potassium.

Introduction

Sweet potato (Ipomoea batatas (L.) Lam), a member of Convolvulaceae family, is a perennial crop usually grown as an annual and a starchy staple food crop in the tropical, sub-tropical and frost-free temperate climatic zones of the world (Cartabiano-Leite et al., 2020). In developing countries, it ranks as the seventh most important food crop in the world after rice, wheat, potato, maize, cassava, and barley (FAO, 2011). The tuberous root crop is known for its tolerance to high temperatures, poor soils, and floods, and exhibits some resistance to pests and diseases (Sapakhova et al., 2023). Sweet potato is can be planted as a monocrop or an intercrop with other food crops such as maize, cassava, yam or okra in West African countries where it is effective in suppressing weed growth in such fields (Eneji et al., 1995).

Sweet potato is valuable for its storage roots which are boiled, fried, baked or roasted for humans, or boiled and fed to livestock as a source of energy. The storage roots can also be processed into flour for bread making, starch for noodles, and used as a raw material for industrial starch and alcohol (Ukom et al., 2009). Sweet potato, other root crops and tuber crops are more important for food security in the face of climate change and a growing world population (Sapakhova et al., 2023). Although sweet potato is easy to cultivate, there have been some production and economic constraints that limit sweet potato production in Thailand. High labor costs can reduce the net income of sweet potato growers. Low soil fertility caused by long-term land use without proper land management can cause severe yield reductions, which are compounded by yield loss due to improper post-harvest practices. Low selling price is also another important constraint than reduces the incentive for potato growers to invest in the crop. Therefore, improvement of crop productivity through better management of soil nutrients is an important means to increase profitability for farmers. Sweet potato yields can be affected by several factors, such as low soil fertility, soil reaction, variety selection, planting date, weather conditions, soil type, weeds, insects, disease, and crop management practices (Onunka et al, 2012). Although sweet potatoes can grow in low-fertility soils, the application of potassium (K) can increase their growth and yield. Soil pH is a key factor in regulating nutrient availability for plants (Marschner, 1995). When the soil becomes too acidic (below pH < 5.0), the absorption of essential nutrients, such as K, can decrease, limiting plant growth and productivity (Morgan and Kadyampakeni, 2024).

The range of optimum K rates applied to sweet potato varied between 120 kg K2O ha^{-1} and 300 kg K2O ha^{-1}. In Hubei province, China, the optimum K rates varied from 150 kg K2O ha^{-1} to 300 kg K2O ha^{-1} (Jian-wei et al., 2001). In India, the mean optimun

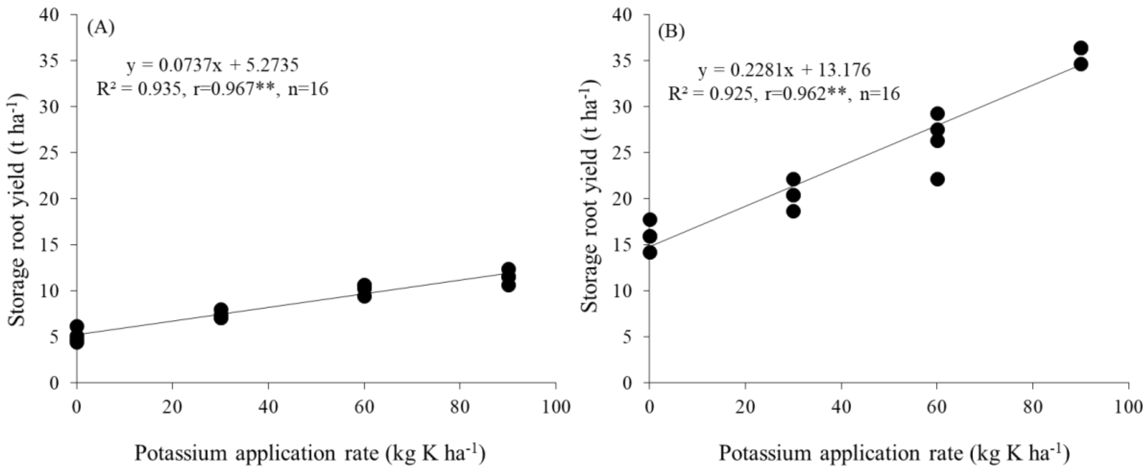

Figure 1. Relationship between potassium application rate and sweet potato storage root yield: (A) Beni Haruka and (B) Okinawa Kugani-Imo varieties.

requirement was recorded at 120 kg K2O ha^{-1}, while the maximum rate was 160 kg K2O ha^{-1}, with the highest storage root yield being 6.7 t ha^{-1} (Trehan et al., 2009). In India and Indonesia, applying K at a rate of 90 kg K ha^{-1} resulted in higher storage root yields (23 and 22 t ha^{-1}, respectively) compared to yields without K application (12 and 14 t ha^{-1}, respectively) (Nwale and Salvi, 1984; Wargiono, l98l). Sweet potato varieties responded differently to K application (Muoneke and Ukpe, 2010). The response of sweet potato varieties to K application was associated with their yield potential and the size of storage roots (Lui et al., 2023). The varieties with rapid bulking and larger storage roots had higher storage root yields those with smaller storage roots in response to K application (Trehan and Grewal, 1991).

In Thailand, sweet potato is grown as a cash crop. It is grown in the upland areas in the early and late rainy season. In the dry season, sweet potatoes are largely grown in the rice fields after the rice harvest. Information on the responses of sweet potato varieties to K application in tropical acidic loamy sandy soil is still incomplete. The study was conducted to investigate the effect of K rates on growth rate, storage root yields, and quality of two sweet potato varieties (Beni Haruka and Okinawa-Kugani-Imo) planted in tropical acidic loamy sand soil.

Results and discussion

Growth attributes of sweet potato

Sweet potato varieties were significantly different ($P \le 0.01$, $P \le 0.05$) regarding length and number of vines (Table 1). Okinawa Kugani-Imo had higher vine lengths and a greater number of vines than Beni Haruka. Potassium rates were not significantly different, and interactions between variety and K rate were not significant.

Sweet potato varieties did not give significantly different vine dry weights, but the differences among K rates were significant ($P \le 0.01$) for this trait (Table 1). Average vine dry weights were similar between the two sweet potato varieties, ranging between 906.3 and 918.7 kg ha^{-1}, and ranging between 850.0 and 975.0 kg ha^{-1} for K application rates. The higher K application rates (60 and 90 kg K ha^{-1}) resulted in higher vine dry weights than with lower K application rates (30 and 0 kg K ha^{-1}). The interaction between variety and K application rate was not significant for vine dry weight, indicating similar responses from these sweet potato varieties to the application of K.

Exchangeable K in soil prior to planting of sweet potato was at a medium level, but this soil had a very low soil pH. The low pH could affect K availability to plants, and application of K at the high rates was necessary for obtaining acceptable sweet potato yields. Uwah et al. (2013) found that the application of K at rates of 120 and 160 kg K ha^{-1} gave higher vine dry weights than the application of K at rates of 40 kg K ha^{-1}, but they were not significantly different from K at the rate of 80 kg K ha^{-1}. It seems likely that K application in this study was still low compared to other studies, and application at higher K rates should be explored.

Yield components and yield

Sweet potato varieties were significantly different ($P \le 0.01$) regarding storage root diameter, storage root number, and storage root yield, and K rates were also significantly different for these traits (Table 2). Okinawa Kugani-Imo had a larger storage root diameter (average 5.46 cm) than Beni Haruka (average 3.77 cm) (Table 2).

Average storage root lengths among different K rates varied between 10.31 cm and 14.73 cm. Storage root lengths increased with higher rates of K, being highest at a rate of 90 kg K ha^{-1}, and lowest at a rate of 0 kg ha^{-1}. Average storage root diameters among K rates varied between 3.67 cm and 5.62 cm. Storage root diameters increased with higher rates of K, being highest at a rate of 90 kg K ha^{-1}, and lowest at 0 kg ha^{-1}.

Storage root length and storage root diameter are the components of storage root size that determines storage root yield of sweet potato (Liang et al., 2023). Gobena et al. (2022) found their average storage root lengths ranged between 6.5 cm and 17.7 cm, which are similar to the results in this study. Storage root diameters of mixed varieties in a study by Tabatabaeefar (2002) varied between 5.0 cm and 8.0 cm, which are somewhat larger than the results in this study. The differences in the results are mainly due to the differences in soil fertility. Tabatabaeefar (2002) also reported a strong positive correlation between storage root diameter and storage root volume. Liang et al. (2023) pointed out that the ratio of storage root length/storage root diameter is important for quality criteria of sweet potato, and that a low ratio is required.

Okinawa Kugani-Imo had a significantly greater number of storage roots (average 3.1 roots) than Beni Haruka (average 2.2 roots), giving Okinawa Kugani-Imo higher storage root yields (24.7 t ha^{-1}) than Beni Haruka (8.6 t ha^{-1}) (Table 2). Storage root numbers increased consistently with the increasing rates of K application. Storage root numbers among K rates ranged from 2.2 to 3.7 root plant^{-1}, with a rate of 90 kg K ha^{-1} giving the highest number of storage roots (3.7 root plant^{-1}) and the rates of 0 and 30 kg K ha^{-1} giving the lowest (2.2 root plant^{-1} for both rates). Storage root yields also increased consistently with increasing rates of K application, varying from 10.6 to 23.8 t ha^{-1}. Storage root number is closely associated with storage root yield of sweet potato. According to a study by Rahman et al. (2015) on the morphological attributes and yield performance of nine genotypes of sweet potato in acidic soil in Bangladesh, the ranges for the number, length, diameter, and yield of storage roots were 2.82-6.53 root plant^{-1}, 3.81-10.80 cm, 1.26-3.35 cm, and 7.13-22.83 t ha^{-1}, respectively. There were small differences for storage root number and storage root diameter, but storage root

Table 1. Vine length, number and dry weight as influenced by different potassium application rates.

Treatment	Vine length (cm)	Vine no. (vine plant^{-1})	Vine dry weight (kg ha^{-1})
Variety (V)			
Beni Haruka (V1)	29.56 b	17.66 b	906.3
Okinawa Kugani-Imo (V2)	51.21 a	19.68 a	918.7
Potassium rate (kg K ha^{-1}) (K)			
0 (K1)	40.09	18.79	887.5 bc
30 (K2)	40.50	18.11	850.0 c
60 (K3)	40.35	18.93	937.5 ab
90 (K4)	40.59	18.85	975.0 a
V x K			
V1 x K1	30.20	17.65	896.3
V1 x K2	29.25	16.90	857.9
V1 x K3	29.03	17.90	931.0
V1 x K4	29.75	18.20	901.8
V2 x K1	49.98	19.93	882.9
V2 x K2	51.75	19.33	868.4
V2 x K3	51.68	19.95	923.7
V2 x K4	51.43	19.50	1021.8
F-test: V	**	*	ns
F-test: K	ns	ns	**
F-test: V x K	ns	ns	ns
CV (%): V	10.29	7.03	10.78
CV (%): V x K	6.15	4.97	5.54

Means in the same column followed by different lowercase letters are significantly different by LSD (P≤0.01**, ≤0.05*). ns represents not significantly different (P>0.05).

Table 2. Yield components and yield as influenced by different potassium application rates.

Treatment	Storage root length (cm)	Storage root diameter (cm)	Storage root number (tuber plant^{-1})	Storage root yield (t ha^{-1})
Variety (V)				
Beni Haruka (V1)	11.84	3.77 b	2.2 b	8.6 b
Okinawa Kugani-Imo (V2)	12.88	5.46 a	3.1 a	24.7 a
Potassium rate (kg K ha^{-1}) (K)				
0 (K1)	10.31 c	3.67 c	2.2 b	10.6 d
30 (K2)	11.20 c	4.02 c	2.2 b	13.9 c
60 (K3)	13.19 b	4.98 b	2.6 b	18.3 b
90 (K4)	14.73 a	5.62 a	3.7 a	23.8 a
V x K				
V1 x K1	9.69	3.03	1.9	5.1 g
V1 x K2	10.61	3.47	1.7	7.7 f
V1 x K3	13.39	3.95	2.1	10.3 e
V1 x K4	13.66	4.64	3.2	11.6 e
V2 x K1	10.93	4.30	2.5	16.0 d
V2 x K2	11.80	4.94	2.8	20.4 c
V2 x K3	12.99	6.00	3.0	26.4 b
V2 x K4	15.80	6.61	4.1	36.0 a
F-test: V	ns	**	**	**
F-test: K	**	**	**	**
F-test: V x K	ns	ns	ns	**
CV (%): V	13.29	10.66	3.20	4.46
CV (%): V x K	7.03	9.14	13.57	9.13

Means in the same column followed by different lowercase letters are significantly different by LSD (P≤0.01).
ns represents not significantly different (P>0.05).

yields were rated similarly. In this study, storage root length, storage root diameter, storage root number, and storage root yield increased with increasing rates of K application. Most studies reported that application of K increased storage root yield of sweet potato (Liu et al., 2023; Liu et al., 2013; Putra et al., 2018; Klipcan et al., 2020). In K deficient soils, application of K fertilizer is important for obtaining acceptable yields of sweet potato.

The interactions between variety and K application rate were not significant for storage root length, storage root diameter, or storage root number (Table 2). The results indicated that the sweet potato varieties responded to K rates in similar patterns for these traits. However, the interaction between sweet potato variety and K rate was significant (P≤0.01) for storage root yield, indicating a differential response between two sweet potato varieties. The highest storage root yields were found at the rate of 90 kg ha^{-1} in both Beni Haruka (11.6 t ha^{-1}) and Okinawa Kugani-Imo (36.0 t ha^{-1}).

Similar to our study, in India and Indonesia, application at the rate of 90 kg K ha^{-1} produced greater storage root yield (23 and 22 t ha^{-1}, respectively) than without the application of K (12 and 14 t ha^{-1}, respectively) (Nwale and Salvi, 1984; Wargiono, l98l). Uwah et al. (2013) also found that the higher K rate of 160 kg K ha^{-1} provided the highest tuber yield (39.5 t ha^{-1}), but they did not find any interaction between variety and K rate. Putra et al. (2018) found significant interaction between variety and K rate when studying Gunung Kawi and Cilembu varieties, which performed best at a KCl rate of 196 kg ha^{-1} giving the highest storage root yields of 28.7 t ha^{-1} and 16.3 t ha^{-1}, respectively.

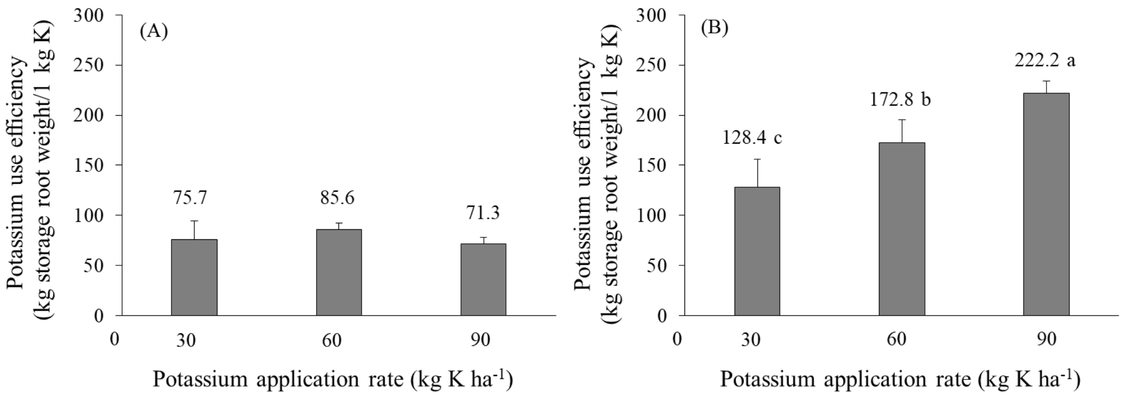

Figure 2. Effects of potassium application rate on potassium use efficiency for sweet potato storage root yield: Beni Haruka and (B) Okinawa Kugani-Imo varieties.

Table 3. Harvest index, total soluble solids and firmness of fresh tuber as influenced by applied different potassium rates.

Treatment	Harvest index	Total soluble solids (°brix)	Firmness of fresh storage roots (kg cm^{-2})
Variety (V)			
Beni Haruka (V1)	0.68 b	9.22 b	3.38 a
Okinawa Kugani-Imo (V2)	0.87 a	10.65 a	3.54 b
Potassium rate (kg K ha^{-1}) (K)			
0 (K1)	0.70 c	9.52 c	3.43
30 (K2)	0.76 b	9.82 bc	3.43
60 (K3)	0.81 a	10.14 ab	3.44
90 (K4)	0.83 a	10.27 a	3.55
V x K			
V1 x K1	0.58	10.35	3.35
V1 x K2	0.68	10.48	3.38
V1 x K3	0.73	10.93	3.33
V1 x K4	0.73	10.98	3.55
V2 x K1	0.80	8.75	3.53
V2 x K2	0.85	9.20	3.53
V2 x K3	0.90	9.40	3.53
V2 x K4	0.90	9.63	3.55
F-test: V	**	**	*
F-test: K	**	**	ns
F-test: V x K	ns	ns	ns
CV (%): V	1.67	2.53	2.84
CV (%): V x K	2.85	2.83	2.25

Means in the same column followed by different lowercase letters are significantly different by LSD (P≤0.01, ≤0.05). ns represents not significantly different (P>0.05).

Application of K at two splits (at planting and 60 days after planting) promoted a greater marketable yield (Silva et al., 2022). In our study, a single K application was used. Therefore, the effect of dosage application should be explored in further studies.
The harvest indexes were significantly different for sweet potato varieties (P≤0.01) and K rates (P≤0.01), with Okinawa Kugani-Imo having a higher harvest index (0.87) than Beni Haruka (0.68) (Table 4). Harvest indexes increased with higher rates of K application, ranging from 0.70 to 0.83. Application of K at the rate of 90 kg K ha^{-1} had the highest harvest index (0.83), and 0 kg K ha^{-1} had the lowest harvest index (0.70).
The harvest index is an important trait for selecting crop varieties with a high ratio of economic yield to biological yield. In a study conducted in Thailand, harvest indices of sweet potato ranged from 0.49 to 0.76 (Ruttanaprasert et al., 2017). Other studies reported harvest indexes of sweet potato in the range between 0.12 and 0.88 (Bhagsari and Ashley, 1990). Sweet potato has the highest harvest index compared to other root crops and tuber crops (Mazurczyk et al., 2009). Hayati et al. (2024) reported that the interaction between K rate and harvest index was significant. The differences in the results of this study and previous studies are due to the differences in the diversity of sweet potato varieties used.

Storage root quality of sweet potato

Total soluble solids and firmness of fresh storage roots changed significantly with sweet potato varieties (P≤0.01) and potassium rates (P≤0.01, P≤0.05) (Table 3). Okinawa Kugani-Imo had higher total soluble solids (10.65 °brix) than Beni Haruka (9.22 °brix), and higher firmness of fresh storage roots (3.54 kg cm-2) than Beni Haruka (3.38 kg cm-2).
Total soluble solids increased with increasing K application rates, ranging from 9.52 to 10.27 °brix (Table 3). The K rate of 90 kg K ha^{-1} had the highest total soluble solids (10.27 °brix), and the rate of 0 kg K ha^{-1} had the lowest total soluble solids (9.52 °brix).
Sweetness (total soluble solids) is one of the criteria for judging the quality of sweet potato. In a previous study, the total soluble solids were highest in purple sweet potato (10.13 °Brix), followed by orange sweet potato (8.52-9.72 °Brix) and white sweet potato (5.57 °Brix) (Šlosár et al., 2019). Coelho et al. (2024) found that K fertilizer increased total soluble solids in sweet potato, which were highest (4.3 and 15.8 °brix, depending on years) at the rate of 120 kg K2O ha^{-1}. This indicates that the range observed in the previous study aligns with the range reported in this study, and the effect of K on the sweetness of sweet potato in the previous study is consistent with the results found here. Similarly, firmness of fresh storage roots also increased with higher rates of K application. The highest firmness of fresh storage roots (3.55 kg cm-2) was recorded at the K rate of 90 kg K ha^{-1}, and the lowest (3.43 kg cm-2) was recorded at a rate of 0 kg K ha^{-1}.
Firmness is an indicator for the texture quality of sweet potato. Constantin et al. (1977) found that application of K at the rates from 0 to 140 kg ha^{-1} reduced firmness from 4.26 to 3.92 kg cm-2. This differs from our results and is thought to be due to the interactions between K and phosphorus (P). The results were not conclusive, and more studies are still required. However, the

Table 4. Means for storage root yield, yield value and economic return over fertilizer cost of two sweet potato varieties as affected by different potassium rate applications.

Potassium rate (kg K ha^{-1})	Fertilizer formula 0-0-60 cost (USD ha^{-1})	Fertilizer formula 15-15-15 cost (USD ha^{-1})	Storage root yield (t ha^{-1})		Yield value (USD ha^{-1})		Economic return over fertilizer cost (USD ha^{-1})	
			V1/1	V2/2	V1	V2	V1	V2
0	0	326.91	5.1±0.8 c	16.0±1.5 c	8576 c	26717 c	8249 c	26390 c
30	32.50	326.91	7.4±0.4 b	20.4±1.5 c	12369 b	34139 c	12010 b (46%)	33780 c (28%)
60	65.00	326.91	10.3±0.6 a	26.4±3.0 b	17152 a	44034 b	16760 a (103%)	43642 b (65%)
90	97.50	326.91	11.6±0.7 a	36.0±0.9 a	19296 a	60114 a	18872 a (129%)	59690 a (126%)
F-test			**	**	**	**	**	**
CV (%)			7.13	7.13	7.13	8.33	7.13	8.33

V1/1= Beni Haruka variety. V2/2= Okinawa Kugani-Imo variety. ± = Standard error of the mean. Means in the same column followed by different lowercase letters are significantly different by LSD (P≤0.01). The cost of the chemical fertilizer formula 0-0-60 and 15-15-15 at the time of application was 32.50 USD 50 kg^{-1} and 26.11 USD 50 kg^{-1} applied, respectively. The cost of sweet potato in 2024 was 1.67 USD kg^{-1}. Number in parenthesis is % increase of tuber yield and economic return over fertilizer costs compared to the no potassium application.

range in this study was similar to Constantin et al. (1977). Therefore, K fertilizer is important to improve the quality of sweet potato.

The interactions between variety and K rate were not significant for total soluble solids and firmness of fresh storage roots. The results indicated that both sweet potato varieties respond to K rate in a similar pattern for total soluble solids and firmness of fresh storage roots.

Relationship between potassium rate and tuber yield of sweet potato

The correlations between K rate and storage root yield were positive and significant (P≤0.01) in both Beni Haruka (r =0.967**) and Okinawa Kugani-Imo (r =0.962**) (Figure 1A, 1B). The results indicated that Okinawa Kugani-Imo was sensitive to K application, and its yield responses were higher than those of Beni Haruka.Higher storage root yields in Okinawa Kugani-Imo were associated with higher storage root length, storage root diameter and number of storage roots (Table 2). Higashikawa et al. (2024) reported a significant and strong correlation between K rate and storage root yield of sweet potato (r=0.941**), similar to the results of this study, highlighting the importance of K fertilizer in sweet potato production.

Agronomic potassium use efficiency

The responses of sweet potato varieties to K application for K use efficiency were different (Figure 2). Potassium use efficiencies in Beni Haruka were not significantly different, ranging between 71.3 and 85.6, and K use efficiency seemed to reduce at the highest rate (90 kg K ha^{-1}) (Figure 2a). However, K use efficiencies in Okinawa Kugani-Imo were increased significantly (P≤0.01) with increasing K rates, ranging from 128.4 to 222.2 (Figure 2B), indicating that the later variety is more responsive to increasing K application rates.

It is interesting to note here that the response to K of Beni Haruka, and the increase of K rates did not increase K use efficiency in this variety. However, in Okinawa Kugani-Imo, although K fertilizer was applied at the highest rate (90 kg K ha^{-1}), the efficacy was still high, and it seemed likely that the rates higher than 90 kg K ha^{-1} could be applied without significant reduction in K use efficiency, although this will need to be verified in further study.

According to Bruns and Botiwkamp (1989), K fertilizer could be applied to sweet potato as high as 260-360 kg K2O ha^{-1} to attain maximum yields, and maximum efficiency was achieved at the rate of 229 kg ha^{-1} of K2O. Higashikawa et al. (2024) also reported that maximum efficiency was achieved at 229 kg ha^{-1} of K2O, while the economically optimum rate was observed at 171 kg ha^{-1} of K2O. In this study, K rates were still low, and higher rates should be studied using Okinawa Kugani-Imo.

Economic return

Two varieties of sweet potato were separately analyzed for economic returns (Table 4). The K rates were significantly different (P<0.01) for storage root yield, gross output value and economic return over fertilizer cost in both sweet potato varieties. All K rates had significantly higher storage root yields, gross outputs and economic returns over fertilizer cost than the control (0 kg K ha^{-1}) in both sweet potato varieties. Similar to storage root yield, gross output and economic return over fertilizer cost of the two sweet potato varieties increased with higher rates of K application. In Beni Haruka, the gross output and economic return over fertilizer cost were highest at the K rate of 90 kg K ha^{-1} and lowest at the K rate of 0 kg K ha^{-1}. The K rate of 90 kg K ha^{-1} was not significantly different from the K rate of 60 kg K ha^{-1} for storage root yield, yield value and economic return over fertilizer cost. Therefore, the K rate of 60 kg K ha^{-1} was optimum for Beni Haruka.

Okinawa Kugani-Imo had significantly higher storage root yields, yield value and economic returns over fertilizer cost at the K rate of 90 kg K ha^{-1}. Therefore, the K rate of 90 kg K ha^{-1} was optimum for Okinawa Kugani-Imo.

In a previous study, both the predicted K application rate for maximum yield and maximum profitability were the same at 174 kg K2O ha^{-1} (144.5 kg K ha^{-1}) (Harvey et al., 2022). The maximum K rate in previous study was rather higher than the maximum K rate (90 kg K ha^{-1} or 108.4 kg K2O ha^{-1}) in this study although the units were not the same. The results indicated that maximum K rate for Okinawa Kugani-Imo can be higher than 90 kg K ha^{-1}. As the K rate of 90 kg K ha^{-1} was the highest rate in this study, higher rates should be explored in further studies. Based on our results, Okinawa Kugani-Imo and K rate of 90 kg K ha^{-1} are highly recommended for sweet potato production after the paddy rice harvest in acidic loamy sandy soil in Northeast Thailand.

Materials and methods

Treatments and experimental design

Field experiment was conducted in a farmer's field located in Sahatsakhan district, Kalasin province in the Northeast Thailand (16°44'39.7"N 103°35'43.2"E, 200 MASL). The average rainfall was 1364 mm yr^{-1}, and the average temperature was 27.8°C. A 2 × 4 split plot design with four replications was used. Two sweet potato varieties, Beni Haruka and Okinawa-Kugani-Imo, were assigned in main plots and four K rates, 0 (control), 30, 60 and 90 kg K ha^{-1}, were assigned in subplots. Potassium fertilizer formula 0-0-60 was applied as a K source. In all treatments, chemical fertilizer formula 15-15-15 of 313 kg ha^{-1} was applied twice: once before planting (basal fertilizer) and again two months after planting. At three months after planting, K at rates of 0, 30, 60 and 90 kg K ha^{-1} were applied to the soils according to the treatments.

Soil properties before sweet potato planting

Topsoil (0-20 cm) samples of the experimental site were collected before planting. The soil samples were analyzed for physical and chemical properties including soil texture (hydrometer method), pH (1: 2.5; soil: H2O), electrical conductivity (EC, 1: 2.5; soil: H2O), organic matter (OM) (Walkley and Black method),

Table 5. Soil properties before sweet potato planting.

Soil property	Value	Classification
Soil texture	Loamy sand	-
Soil pH (1: 2.5; soil: H_2O)	4.96	Very strongly acidic
Electrical conductivity (1: 2.5; soil: H_2O) (dS m^{-1})	0.09	Non-saline
Organic matter (%)	0.02	Very low
Available P (mg kg^{-1})	11.00	Low
Exchangeable K (mg kg^{-1})	80.00	Medium

available P (Bray II extractant) and exchangeable K (1 N NH4OAc extractant) (Jones, 2001).

The soil at the experimental site was very strongly acidic (pH=4.96) and not saline (electrical conductivity, EC=0.09 dS m^{-1}) (Table 5). Soil pH and EC are important soil properties affecting sweet potato growth. However, the soil had low organic matter (OM) (0.02%), low available phosphorus (P) (11.00 mg kg^{-1}) and medium exchangeable potassium (K) (80.00 mg kg^{-1}).

Based on the chemical properties described by Sanchez et al. (2003), the soil in this study was acidic with low fertility. Soil pH is an excellent indicator of the suitability of a soil for plant growth. Most plants grow well at a pH range of 6.0 to 7.0 (Xia et al., 2024). Soil pH levels that are too high or too low lead to a deficiency of many nutrients, especially primary nutrients N, P, and K, a decline in microbial activity, decrease in crop yields, and deterioration of soil health (Xia et al., 2024).

Due to low OM and low available P, nutrient deficiencies of N and P limit the growth and storage root yields of sweet potato, necessitating the application of sufficient N and P. Potassium availability to plants is highest at a soil pH of 6.0–7.5 (neutral), and at low pH levels, K is often deficient (Rawal et al., 2022).

Crop management

The soil was ploughed twice, and soil ridges at distances of 0.3 m and 0.6 m apart from each other were constructed after tillage. The experimental area was divided into 32 plots each with an area of 1 × 1.8 m2.

Two sweet potato varieties (Beni Haruka and Okinawa Kugani-Imo) were chosen for this study because they are popular in the studied area, namely Kalasin province. Beni Haruka has a yellow flesh color and Okinawa Kugani-Imo has an orange flesh color. The crop was planted in the dry season in the farmer's field after the rice harvest in December 2023. Vine cuttings with 25-30 cm in length and 5-6 nodes from the terminal shoots with the lower leaves removed were inserted into the soil at the depth of half cutting length and leaning angle of 45°. The cuttings were planted at a spacing of 0.3 m × 0.6 m with one plant per hill, nine plants in a plot, and a population density of 55,555 plants per hectare. Weeds were controlled manually at 1 and 2 months after planting. A furrow irrigation system was used to supply water to the crop one and two months after planting. There was no rain during crop growth. The crop used mainly stored soil water with minimum additional irrigation. The sweet potato was harvested in March 2024.

Data collection

At harvest (4 months after planting), the data were recorded for vine fresh weight, storage root number, storage root fresh weight, storage root length, storage root width, total soluble solids, and harvest index. All plants in the plot were cut at the ground surface, and storage roots of all plants in the plot were harvested. Fresh weights of shoots and storage roots were recorded in the field.

The samples of shoots with 1 kg for each sample were oven-dried at 40℃ until the weights were constant, and dry weights of the samples were recoded. Then dry weights of the samples were converted to dry weights of the plots. Harvest index was calculated by dividing storage root fresh weight by total fresh weight (both roots and shoots).

Fresh tuber samples of 1 kg in each plot were randomly sampled and used for determination of total soluble solids (°brix) using an Atago N-1E Hand Refractometer. Agronomic efficiency (AE) was calculated according to Fageria et al. (2008):

AE = (Tf - Tu / Kna) kg sweet potato root kg / Kn fertilizer applied, AE=(Tf-Tu)/Kna

where Tf is the root yield of the fertilized K plot (kg), Tu is the root yield of the unfertilized K plot (kg), and Kna is the rate of applied K fertilizer (kg).

Statistical analysis

Data for each parameter were analyzed statistically using analysis of variance (ANOVA) with Statistix 10 according to the experimental design. Means were separated by least significant difference (LSD) at 0.05 and 0.01 probability levels. The relationships between storage root yield and K rate were calculated using Pearson's correlation analysis.

Conclusions

Application of potassium to sweet potato planted in strongly acidic loamy sandy soil in the dry season after rice harvest increased vine dry weight, storage root length, storage root diameter, storage root number, storage root yield, harvest index, total soluble solids, and firmness of fresh storage roots. These parameters increased with higher rates of K application, which also increased yield value and economic return over fertilizer cost. Application of K at the rate of 60 kg K ha^{-1} was optimum for Beni Haruka, whereas application of K at the rate of 90 kg K ha^{-1} was optimum for Okinawa Kugani-Imo. Okinawa Kugani-Imo had higher storage root yields and economic returns over fertilizer cost than Beni Haruka. Okinawa Kugani-Imo variety and K rate of 90 kg K ha^{-1} are recommended for sweet potato production in the acidic loamy sand soil after the paddy rice harvest.

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