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Effects of interaction between nitrogen and potassium on the growth and yield of cassava

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Abstract Nitrogen and potassium are necessary nutrients for cassava and are generally deficient in soil, particularly nitrogen. High nitrogen fertilizer applications may induce greater a potassium requirement. The results showed that increasing nitrogen rates significantly increased plant height, SPAD value of the upper and lower leaf, the fresh and dry weight of leaf blade, stem+petiole, tuber and total weight. Increasing potassium rates was decreased the SPAD value of lower leaves. Nitrogen uptake in OSC and tuber was significantly affected by interaction between N and K, but N uptake in the leaf blade and the total N uptake were affected by increasing N rates. Potassium uptake in tuber and total K uptake were significantly affected by interaction between N and K but K uptake in stem+petiole and OSC affected by increasing K rates. Furthermore, the total uptake of N and K gave a high positive correlation with the fresh and dry weight of all plant parts except OSC. The correlation coefficient between uptake N and K in the leaf blade, stem+petiole, OSC, and tuber were 0.85**, 0.83**, 0.35* and 0.87**, respectively.

Keywords: cassava, nitrogen, potassium, interaction

Introduction

Cassava (*Manihot esculenta* Crantz) is the fifth most important food crop in the world (Somwhang, 2007) and is a major food crop in tropical countries in Africa, America and Asia. Global cassava production in 2016 was 202.65 million tonnes (Food Intelligence Center Thailand, 2016). Cassava is the fourth most abundant crop in Thailand after rice, rubber and sugarcane, respectively. Approximately 31.16 million tonnes of cassava products were exported from Thailand in 2016, equal to 14.86% of total world cassava production (Food Intelligence Center Thailand, 2016). Around one and a half million hectares of agricultural area is used for cassava cultivation in Thailand (Office of Agricultural Economics, 2017) and most of the soil used is a coarsely textured with low fertility. Moreover, repeated cassava cultivation in low fertility soil may decrease soil nutrients, meaning that fertilizer is necessary to increase yield and maintain soil fertility.

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Nitrogen (N) and potassium (K) are required nutrients for cassava and are always deficient in the coarse-textured soils that are most commonly used for cassava cultivation in Thailand. Nitrogen is an essential component of protein, chlorophyll, enzymes, hormones, and vitamins. It's also essential for cyanogenic glycosides linamarin and lotaustralin which produce hydrocyanic acid (HCN) when cells are damaged (Howeler, 2014). Cardoso *et al.* (2005) showed that nitrogen is a necessary nutrient for tuber crops. Sangakkara and Wijesinghe (2014) reported that applying nitrogen fertilizer increased root numbers and yield. Meanwhile, Howeler (2014) found that nitrogen deficiencies in cassava reduced plant growth and yield. Potassium plays an important role in metabolism, stimulates net photosynthetic activity, and increases the translocation of photosynthates to tuberous roots (Howeler, 2014).

It is well known that N and K have synergistic interactions (Rietra *et al.,* 2015). Baligar *et al.* (2001) observed the synergetic effect between nitrogen and potassium in plant tissue, finding that low applications of N resulted in low plant tissue potassium concentration, while high applications of N resulted in high potassium concentration. Johnston and Milford (2012) reported that yield responses to applied N fertilizer decreased when the exchangeable K content of a soil is below a critical target level. In addition, the application of high N fertilizer rate at high K rates increased the yields of spring barley, potatoes, winter wheat and maize (Stromberger *et al.*, 1994; Johnston and Milford, 2012). Nevertheless, there is less information on the interaction between nitrogen and potassium on cassava growth and yields. The objective of this study was therefore to study the interaction effects between nitrogen and potassium on the growth of cassava.

Materials and methods

Experimental set up

The experiment was conducted in a greenhouse at the Faculty of Agriculture at King Mongkut's Institute of Technology Ladkrabang in Bangkok, Thailand from July 7, - October 22, 2017. The cassava stem cutting, Kasetsart 50 (KU50) cultivar was planted in 37 liter pots. Uniform cassava stems were selected before cutting them to 25 cm and immersing them in 2% thiamethoxam for 30 minutes before planting to prevent Mealybug damage. The pots were filled with 3 cm^3 sponges and the cassava stem cuttings were individually planted in them. Each pot was provided with an individual supply of water and nutrient solutions by a drip irrigation system throughout the 108-day experiment period. The 108-days experiment period enough for study effect of plant nutrient on cassava growth (Howeler, 2014).

The experimental design was a 3×3 factorial arrangements in randomized complete block design (RCBD) with 4 replications. Three different nitrogen rates consisting of 500 (N1), 1000 (N2) and 1500 (N3) µmol/L combined with three different potassium rates consisting of 500 (K1), 1000 (K2) and 1500 (K3) µmol/L were used. Other nutrients were also provided to all the treatments (Table 1) and the concentration of the other nutrient solutions were adequate for cassava growth, based on the experiment in Howeler *et al*. (1981). The nutrient solution concentration was maintained every two weeks by adding new solution which was collected to measure pH, electric conductivity (EC) and nutrient concentrations a day after replacement. Nutrient solution pH and EC was maintained at 5.96 - 6.04 and 0.64 – 1.04 mS/cm, respectively during the experiment.

Samples collection and analysis

The height and SPAD values of the upper and lower leaves were determined every week after planting. One hundred and eight days after planting, the cassava plants were collected and separated into four parts i.e. leave blades, stem, original stem cutting (OSC) and tuber. All plant parts were washed with distilled water, half-dried, and then dried at 70 °C for 48 hours, or until the weight of the plant was constant. Plant samples were ground, and the total nitrogen content was analyzed by a CNS analyzer (LECO, TruMac CNS analyzer) (LECO Corporation, 2016). The total potassium in the plant samples was measured by dissolving plant ash residue in aqua regia after drying the ash at 550 ℃ for 5 hours (Bryson and Mill, 2015). The total potassium was determined by inductively coupled plasma optical emission spectrometry (Perkin, Optima 4300DV) (Chongpradithnun, 2001). Nitrogen and potassium uptakes were calculated by multiplying the dry weight with total nitrogen and total potassium concentration in each plant part.

Table 1. Concentration and source of the plant nutrients solution

No.	nutrients	concentration (µmol/L)	source
1	Nitrogen (N)	depend on treatment	$Ca(NO_3)_2.4H_2O$
2	Phosphorus (P)	100	$Ca(H_2PO_4)_2.H_2O$
3	Potassium (K)	depend on treatment	K_2SO_4, KCl
4	Sulfur (S)	500	Na_2SO_4
5	Magnesium (Mg)	200	$MgSO_4.7H_2O$, $MgCl_2.6H_2O$
6	Calcium (Ca)	825	$CaCl_2.2H_2O$
7	Iron (Fe)	20.0	Fe-EDTA
8	Zinc (Zn)	0.50	$ZnSO_4.7H_2O$, $Zn(NO_3).6H_2O$
9	Manganese (Mn)	2.00	$MnCl_2.4H_2O$
10	Copper (Cu)	0.10	$CuSO_4.5H_2O$, $Cu(NO_3)_2$
11	Nickel (Ni)	0.02	$NiCl_2.6H_2O$
12	Molybdenum (Mo)	0.02	$Na_2MoO_4.2H_2O$
13	Boron (B)	3.00	$Na_2B_4O_7.10H_2O$

Source: Howeler *et al.* (1981)

Data analysis

The analysis of variance (ANOVA) was measured by statistical package and determined the mean significant difference at a 0.05 significance level using Duncan's multiple range test (DMRT). Total N was related to total K to determine the correlation coefficient between both nutrients at a 0.05 significance level. Total N and total K in all plant parts were also correlated with fresh and dry weight at a 0.05 significance level.

Results

Effect of nitrogen and potassium on cassava growth

The results showed that the different nitrogen rates affected the cassava height (Figure 1) which with increased rates of N. The maximum cassava height in the N3 treatment was 206.92 cm, followed by N2 and N1 at 185.58 and 147.67 cm, respectively. Meanwhile, there was no significant difference of cassava height under the different potassium rates.

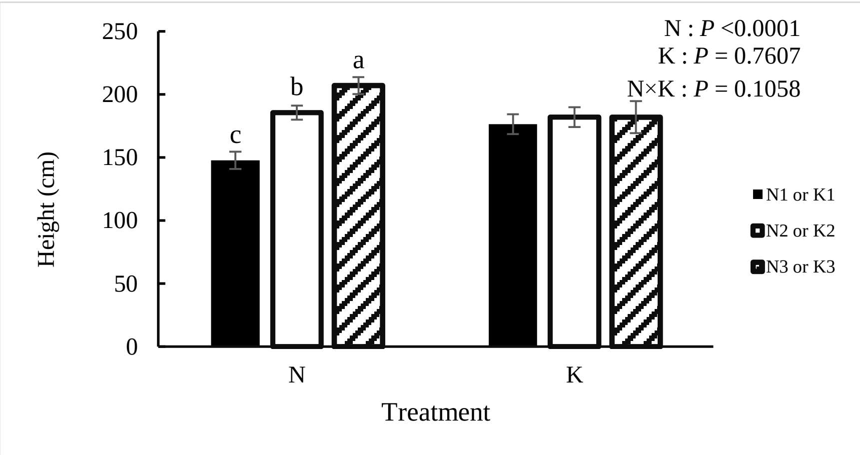

Figure 1. Height of cassava at 108 days after planting, as affected by three nitrogen rates (N1, N2, and N3) combined with three potassium rates (K1, K2, and K3). Statistical comparisons between the treatments are presented for each variable which are indicated by the different letter on the bar. Error bars indicate the standard error of mean (S.E.). ns: not significant, * and ** significance at $P<0.05$ and 0.01 levels, respectively

The different nitrogen rates affected the SPAD values in the upper and lower cassava leaves (Table 2). The SPAD values in the upper leaves of N1 were the lowest and significantly different to N2 and N3, with SPAD values at 38.04, 41.31 and 42.34, respectively. SPAD values in the lower leaves of N3 were the highest with a value of 34.64, which was significantly different to N1 and N2 with values of 30.39 and 32.09, respectively (Table 2). By contrast, different potassium rates were not found to affect the SPAD values in the upper cassava leaves. However, the SPAD values of the lower leaves in K3 were the lowest and were significantly differed from K2 (Table 2). Nonetheless, no interactive effect was found between nitrogen and potassium rates on the SPAD values in both the upper and lower leaves.

Table 2. SPAD value in the upper and lower cassava leaves at 108 days after planting, as affected by three nitrogen rates (N1, N2, and N3) combined with three potassium rates (K1, K2, and K3)

Factor	**SPAD value**			
	Upper leave		**Lower leave**	
	mean	**SE**	**mean**	**SE**
Nitrogen (N)				
N1	38.04b	0.56	30.39b	0.60
N2	41.31a	0.39	32.09b	0.57
N3	42.34a	0.42	34.64a	1.10
Potassium (K)				
K1	40.94	0.59	32.13AB	0.58
K2	40.82	0.53	33.75A	1.17
K3	39.92	0.93	31.23B	0.86
F-test				
N	**		**	
K	ns		*	
N×K	ns		ns	
CV (%)	3.70		7.30	

SE = standard error of mean, *significant at $p \leq 0.05$, **significant at $p \leq 0.01$, ns= not significant, values followed by the same uppercase and lowercase letter in column of each factor are not significantly different at $p \leq 0.05$.

The fresh and dry weights responded to the different N and K rates similarly (Table 3 and 4). Increased nitrogen rates had a highly significant increase to the fresh and dry weights of stem+petio, tuber and total weight (Table 3 and 4). The total fresh weights of N1, N2 and N3 were 451.00, 749.90 and 900.62 g/plant, respectively (Table 3), while the total dry weights were 190.26, 279.00 and 321.86 g/plant, respectively (Table 4). The fresh and dry weights of the leaf blades of N1 were the lowest and significantly different in comparison to N2 and N3. The values of N1, N2 and N3 were 78.80, 153.10 and 146.67 g/plant, respectively for fresh weight (Table 3), while 17.59, 32.55 and 41.32 g/plant, respectively for dry weight (Table 4). However, the fresh and dry weights of OSC were not significantly different (Table 3 and 4). The different potassium rates were not found to affect either the fresh or and dry weights of all the plant parts. The interaction between N and K rates was found only in the fresh weight of leaf blades, where the fresh weight of leaf blades was highest with high rates of N and K (Table 3).

Table 3. Fresh weight of leaf blade, stem, old stem cutting (OSC), tuber and total cassava fresh weight at 108 days after planting, as affected by three nitrogen rates (N1, N2 and N3) combined with three potassium rates (K1, K2 and K3)

Factor	Fresh weight (g/plant)									
	Leave blade		Stem+Petio		OSC		Tuber		Total	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Nitrogen (N)										
N1	78.80b	7.38	118.11c	6.00	152.83	5.09	101.27c	11.66	451.00c	15.43
N2	153.10a	16.47	213.01b	10.13	161.66	6.30	222.13b	23.47	749.90b	27.01
N3	146.67a	16.83	276.24a	8.01	169.87	5.43	307.84a	31.09	900.62a	34.85
Potassium (K)										
K1	118.25	15.34	198.96	21.28	156.43	6.41	212.26	34.81	685.89	66.31
K2	129.49	14.44	210.02	21.56	162.71	5.70	206.01	31.30	708.24	54.23
K3	130.82	17.29	198.37	20.72	165.22	5.57	212.97	37.65	707.39	65.84
F-test										
N	**		**		ns		**		**	
K	ns		ns		ns		ns		ns	
N×K	*		ns		ns		ns		ns	
%CV	30.3		14.9		12.5		33.7		14.0	

SE = standard error of mean, *significant at $p \leq 0.05$, **significant at $p \leq 0.01$, ns= not significant, values followed by the same uppercase and lowercase letter in the column of each factor are not significantly different at $p \leq 0.05$.

Table 4. Dry weight of leaf blade, stem, old stem cutting (OSC), tuber and total cassava dry weight at 108 days after planting plants, as affected by three nitrogen rates (N1, N2, and N3) combined with three potassium rates (K1, K2, and K3)

Factor	Dry weight (g/plant)									
	Leave blade		Stem+Petio		OSC		Tuber		Total	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Nitrogen (N)										
N1	17.59b	1.83	47.72c	1.49	70.55	2.19	54.40b	3.55	190.26c	5.80
N2	32.55a	3.60	70.76b	3.51	70.02	3.23	105.68a	10.33	279.00b	15.54
N3	41.32a	3.11	87.38a	2.76	74.83	1.96	128.33a	10.39	321.86a	10.92
Potassium (K)										
K1	32.14	3.90	70.44	5.99	68.25	3.04	91.08	12.06	261.91	20.28
K2	29.57	4.15	68.53	5.62	73.72	2.12	86.91	9.84	258.72	17.42
K3	29.57	4.40	66.89	5.11	73.42	2.20	100.42	13.58	270.49	22.18
F-test										
N	**		**		ns		**		**	
K	ns		ns		ns		ns		ns	
N×K	ns		ns		ns		ns		ns	
%CV	27.4		14.1		12.7		27.2		15.5	

SE = standard error of mean, *significant at $p \leq 0.05$, **significant at $p \leq 0.01$, ns= not significant, values followed by the same uppercase and lowercase letter in the column of each factor are not significantly different at $p \leq 0.05$.

Effect of nitrogen and potassium on plant nutrient uptake

Cassava nitrogen uptake differed between different the plant parts. The sequence of N uptake was leaf blade > tuber > OSC > stem+petiole (Table 5). Nitrogen uptake in leaf blade, OSC, tuber and the total uptake increased markedly with increasing nitrogen rates, which is clearly shown in the total N uptake (Table 5). The total N uptake of cassava was 14.54, 23.14 and 27.70 g/plant in N1, N2 and N3, respectively (Table 5). Nitrogen uptake in the leaf blade and tuber of N1 was the lowest and significantly different to N2 and N3 (Table 5). Nitrogen uptake in OSC was also lowest in N1 as 0.37 g/plant and was significantly different only to N3. The different potassium rates affected nitrogen uptake in OSC and tuber, but no significant difference was found with the other plant parts and total N uptake (Table 5). Nitrogen uptake by OSC and tuber were highest in K3 and was significantly different to K2 and K1 (Table 5).

Table 5. Nitrogen uptake in leaf blade, stem+petio, old stem cutting (OSC), tuber and total cassava nitrogen uptake at 108 days after planting, as affected by three nitrogen rates (N1, N2, and N3) combined with three potassium rates (K1, K2, and K3)

Factor	Nitrogen Uptake (g/plant)									
	Leave blade	SE	Stem+Petio	SE	OSC	SE	Tuber	SE	Total	SE
Nitrogen (N)										
N1	0.52b	0.04	0.08	0.01	0.37b	0.02	0.25b	0.01	14.54c	0.45
N2	1.07a	0.09	0.07	0.01	0.38b	0.01	0.51a	0.05	23.14b	1.15
N3	1.11a	0.09	0.07	0.01	0.46a	0.01	0.59a	0.04	27.70a	0.82
Potassium (K)										
K1	0.80	0.10	0.07	0.01	0.41AB	0.02	0.40B	0.05	21.69	1.87
K2	0.93	0.09	0.07	0.01	0.37B	0.02	0.43B	0.04	21.32	1.64
K3	0.97	0.13	0.08	0.01	0.43A	0.01	0.52A	0.06	22.38	2.02
F-test										
N	**		ns		*		**		**	
K	ns		ns		**		*		ns	
N×K	ns		ns		ns		ns		ns	
%CV	28.14		35.41		12.77		24.43		13.72	

SE = standard error of mean, *significant at $p \leq 0.05$, **significant at $p \leq 0.01$, ns= not significant, values followed by the same uppercase and lowercase letter in the column of each factor are not significantly different at $p \leq 0.05$.

Potassium uptake by cassava changed with different plant parts and the sequence of K uptake was stem+petiole > tuber > OSC > leaf blade (Table 5). Potassium uptake in N1, N2 and N3 of leaf blade was 0.21, 0.42 and 0.47 g/plant, respectively, while K uptake in N1 was significantly different with N2 and N3 (Table 6). Nitrogen rates also affected K uptake in the same way for tuber. The total K uptake of cassava was 12.55, 17.78 and 20.27 g/plant in N1, N2 and N3, respectively, which the three different N rates were significantly different. Potassium uptake in stem+petiole, OSC, tuber and total K uptake significantly increased with increasing K rates (Table 6). The total cassava K uptake was 14.21, 17.27 and 19.12 g/plant in K1, K2 and K3, respectively, which were significantly different (Table 6). Interaction between N and K affected tuber and the total K uptake. High application rates of N and K produced high tuber and total K uptake (Table 6).

Table 6. Potassium uptake in leaf blade, stem+petio, old stem cutting (OSC), tuber and total cassava potassium uptake at 108 days after planting as affected by three nitrogen rates (N1, N2, and N3) combined with three potassium rates (K1, K2, and K3)

Factor	Potassium Uptake (g/plant)									
	Leave blade	SE	Stem+Petio	SE	OSC	SE	Tuber	SE	Total	SE
Nitrogen (N)										
N1	0.21b	0.02	1.14	0.12	0.71	0.03	0.55b	0.04	12.55c	0.40
N2	0.42a	0.04	0.92	0.11	0.72	0.05	1.03a	0.14	17.78b	0.88
N3	0.47a	0.07	0.98	0.13	0.79	0.06	1.07a	0.14	20.27a	1.05
Potassium (K)										
K1	0.30	0.04	0.76B	0.11	0.61C	0.03	0.62B	0.07	14.21C	0.72
K2	0.37	0.04	1.01AB	0.11	0.72B	0.03	0.85B	0.09	17.27B	1.05
K3	0.42	0.08	1.26A	0.13	0.89A	0.04	1.17A	0.16	19.12A	1.46
F-test										
N	**		ns		ns		**		**	
K	ns		**		**		**		**	
N×K	ns		ns		ns		*		**	
%CV	47.65		35.45		15.74		33.33		9.89	

SE = standard error of mean, *significant at $p \leq 0.05$, **significant at $p \leq 0.01$, ns= not significant, values followed by the same uppercase and lowercase letter in the column of each factor are not significantly different at $p \leq 0.05$.

Correlation between fresh and dry weight and nutrient uptake

Total nitrogen uptake was positively correlated with the fresh weight of stem+peito, OSC, tuber, the total fresh weight, with correlation coefficients of 0.79**, 0.85**, 0.35**, 0.86** and 0.97**, respectively (Table 7). The total potassium uptake was also positively correlated with the fresh weight of leaf blade, stem+peito, OSC, tuber and the total fresh weight, with correlation coefficients of 0.61**, 0.74**, 0.36*, 0.69**, and 0.80**, respectively (Table 7).

Total nitrogen uptake was positively correlated with the dry weight of leaf blade, stem+peito, tuber and the total dry weight, with correlation coefficients at 0.86**, 0.86**, 0.89** and 0.98**, respectively (Table 7). The total potassium uptake was also positively correlated with the dry weight of leaf blade, stem+peito, tuber and the total dry weight, with correlation coefficients of 0.70**, 0.68**, 0.74** and 0.82**, respectively (Table 7).

Table 7. Correlation coefficient (*r*) between fresh and dry weight of leaf blade, stem+petio, old stem cutting (OSC), tuber, total dry weight with total N uptake and total K uptake of cassava at 108 days after planting, as affected by three nitrogen rates (N1, N2, and N3) combined with three potassium rates (K1, K2, and K3)

Parameter	N $uptake_{Total}$	K $uptake_{Total}$
Leave blade fresh weight	0.79**	0.61**
Stem+petio fresh weight	0.85**	0.74**
Old stem cutting fresh weight	0.35*	0.36*
Tuber fresh weight	0.86**	0.69**
Total fresh weight	0.97**	0.80**
Leave blade dry weight	0.86**	0.70**
Stem+petio dry weight	0.86**	0.68**
Old stem cutting dry weight	0.21	0.29
Tuber dry weight	0.89**	0.74**
Total dry weight	0.98**	0.82**

*Significant at $p \leq 0.05$, **significant at $p \leq 0.01$.

Nitrogen uptake in the leaf blades were positively correlated with nitrogen and potassium uptake in tuber and the total K uptake (Table 8). However, N uptake by stem+peito and OSC was positively correlated with K uptake in the plant parts, with correlation coefficients of 0.84** and 0.35*, respectively. Nitrogen uptake by tuber was positively correlated with K uptake by leaf blade, tuber and the total K uptake, with correlation coefficients of 0.47**, 0.87** and 0.82**, respectively (Table 8). Total N uptake was positively correlated with K uptake by leaf blade, tuber and total K uptake, and the correlation coefficients were 0.60**, 0.65** and 0.84**, respectively. There was a positive correlation for the relationship between potassium uptake by leaf blade and OSC and K uptake by tuber and the total K uptake. Total K uptake had a highly significant correlation with K uptake in tuber (Table 8).

Table 8. Correlation coefficient (*r*) between N uptake and K uptake in leaf blade, stem+petio, old stem cutting (OSC), tuber and total uptake of cassava at 4 months after planting, as affected by three nitrogen rates (N1, N2, and N3) combined with three potassium rates (K1, K2, and K3)

Parameter	N uptake $_{Leave\ blade}$	N uptake $_{Stem+petio}$	N uptake $_{OSC}$	N uptake $_{Tuber}$	N uptake $_{Total}$	K uptake $_{Leave\ blade}$	K uptake $_{Stem+petio}$	K uptake $_{OSC}$	K uptake $_{Tuber}$	K uptake $_{Total}$
N uptake $_{Leave\ blade}$	1.00									
N uptake $_{Stem+petio}$	-0.23	1.00								
N uptake $_{OSC}$	0.22	0.32	1.00							
N uptake $_{Tuber}$	0.67**	0.02	0.33	1.00						
N uptake $_{Total}$	0.69**	-0.19	0.32	0.80**	1.00					
K uptake $_{Leave\ blade}$	0.86**	-0.22	0.13	0.47**	0.60**	1.00				
K uptake $_{Stem+petio}$	-0.18	0.84**	0.26	-0.06	-0.32	-0.08	1.00			
K uptake $_{OSC}$	0.27	0.12	0.35*	0.33	0.17	0.31	0.41*	1.00		
K uptake $_{Tuber}$	0.51**	0.07	0.18	0.87**	0.65**	0.35*	0.07	0.44**	1.00	
K uptake $_{Total}$	0.68**	-0.03	0.29	0.82**	0.84**	0.66**	0.06	0.56**	0.79**	1.00

*Significant at $p \leq 0.05$, **significant at $p \leq 0.01$.

Discussion

Effect of nitrogen and potassium on cassava growth

As result, it showed that nitrogen plays an important role on the growth of cassava. Higher nitrogen rates increased height as well as the fresh and dry cassava weights, while the effect of different potassium rates was unclear. Uwah *et al.* (2013) found that the highest application rates of nitrogen significantly increased plant height. Cenpukdee and Fukai (1991) showed that branch production, leaf area and plant height were promoted by N application, and this enhanced assimilation sink in the tops reduced partitioning and simulated to tubers. Nitrogen fertilizer is the most limiting factor to growth and yield, so the most commonly used nitrogen fertilizer must be applied to maintain productivity (Sangakkara and Wijesinghe, 2014). From their experiment, Cenpukdee and Fukai (1991) reported that nitrogen increased the height and canopy size of cassava when compared to not applying nitrogen fertilizer. Low SPAD values in the lower and upper leaves of N1 were consistent with symptoms of chlorosis which was found in N1. Howeler (2014) showed that in some cassava cultivars, nitrogen deficiency affected the uniform chlorosis of leaves, beginning with lower leaves, but soon spreading throughout the plant. Nitrogen increases the leaves chlorophyll which thereby promotes the photosynthetic capacity of the plant, plays a part in the manufacture of proteins and is also responsible for high plant yields (Uwah *et al*., 2013).

Howeler (2014) reported that potassium deficiency affected chlorotic upper leaves, but in some cultivars lower leaves were subject to yellowing and border necrosis. Potassium deficiencies in yam result in the leaves usually show chlorosis symptoms the most distinctly. However, chlorosis patterns may be diffusely interveinal (Sullivan, 2010). Meanwhile, potassium deficiency symptoms were not found in the lower and upper leaves of all the treatments in the experiment. In addition, different potassium rates did not affect the fresh and dry cassava weights (Table 3 and 4). Usually, potassium fertilizer affects to cassava tuber weight because K importance to cassava tuberization (Imas and John, 2013). But the effect of K on the fresh and dry weight in this study were not found. It might because 108 days after planting, the cassava plants were at an initial stage of tuberization. This finding is consistent with Panique *et al.* (1997) experiment which found no evidence for significant differences in tuber yield based on the application of K fertilizer. Contradictorily, Carsky and Toukourou (2005) reported that potassium fertilizer increased the dry and fresh weights of tuber, but both weights were highest with the application of NPK fertilizer. The positive growth response to the applied potassium is attributable to their role in cell multiplication and photosynthesis which increased the size and length of the leaves and stems (Uwah *et al*., 2013).

No interactive effect was found between the nitrogen and potassium rates on the fresh and dry cassava weights. This result is in harmony with the findings of Uwah *et al*. (2013) which showed no interactive effect between nitrogen and potassium on the growth of cassava. Nitrogen and potassium deficiencies mainly resulted in reduced plant height and vigor (Howeler, 2014). Sufficient plant nutrients were attributable to their role in cell multiplication and photosynthesis, which gave rise to increases in the size and length of the leaves and stems (Uwah *et al.,* 2013).

Effect of nitrogen and potassium on plant nutrient uptake

The different rates of N affected the uptake of N and K in all the plant parts besides the uptake of N in stem+petiole and the uptake of K for stem+petio and old stem cutting. Whereas the different K rates affected the N uptake in old stem cutting and tuber, while it affected the K uptake of all plant parts except leaf blade. It seems that nitrogen highly affected the N and K uptake of cassava in all plant parts except stem+petiole. Potassium, however, was more affected to N uptake in belowground than aboveground but did not affected to K uptake in leaf blade. It might be suggest that interactive effect between N and K may affected to cassava tuberization. Imas and John (2013) reported that only N did not affect cassava tuberization but significant increased the numbers of tuberous roots. Conversely, cassava tuber fresh weight, size, number, and dry matter were all significantly higher in plants supplied with either K alone or in combination with N. It might be due to the activity of starch synthase, enzyme that catalyze glucose to starch, depend on K ion as activates enzyme (Hawkesford *et al.*, 2012).

Moreover, the interaction effect between N and K was affected to the K uptake in tuber and the total K uptake. The positive correlation between the total N and K uptakes with the fresh and dry cassava weights confirms that N and K affected cassava growth. Furthermore, the positive correlation between N and K uptake in each plant part was found (Table 8), confirming the synergistic effect of N and K on cassava nutrient uptake. Application of K fertilizer increases the N content in the yield and the total N uptake of the crops, leading to improved nitrogen use efficiency (Aulakh and Malhi, 2005). The effect of increasing N bioavailability on tissue K concentrations depended on K bioavailability in the soil solution. Then, under the conditions of high K availability, increasing the N supply increases K concentration and uptake (Aulakh and Malhi, 2005).

It concluded that the experiment findings showed that nitrogen and potassium affect the growth and nutrient uptake of cassava. Height and the fresh and dry cassava weights increased in turn with increasing nitrogen rates, but there was no significant difference based on different rates of potassium. Nitrogen and potassium uptake in leaf blade, OSC, tuber and total uptake increased with higher nitrogen and potassium rates. The total N and K uptakes were positively correlated with the fresh and dry weights, and a high positive correlation between the total N uptake and the total K uptake was found. It might be suggested that nitrogen and potassium had a synergistic effect on the nutrient uptake of cassava, and their synergistic effect on cassava growth was found only leaf blade.

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