Experimental Agriculture, available online 27 March 2017
DOI:10.1017/S0014479717000023

CUTTING LENGTH AND BUD REMOVAL ON CASSAVA YIELD

EFFECTS OF CUTTING LENGTH AND BUD REMOVAL ON ROOT YIELD AND STARCH CONTENT OF CASSAVA UNDER RAINFED CONDITIONS

By MAPITA PRASITSARN†, ANAN POLTHANEE‡†, VIDHAYA TRELO-GES† *and* ROBERT W. SIMMONS¶

†Department of Plant Science and Agricultural Resources, Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand 40002
and ¶School of Water Energy and Environment, Cranfield University, Cranfield, Bedfordshire, United Kingdom MK43 0AL
‡Corresponding author. Email: panan@kku.ac.th

SUMMARY

Bud removal of the cuttings at underground level has been claimed by cassava growers in Thailand as a method to increase cassava yield. This practice should be tested experimentally to explain the reason for yield increase. The objective of this study was to investigate the effects of bud removal and cutting length on storage root yield and starch content of three cassava varieties. Field experiment was conducted in a split-split plot design with four replications in 2010 and 2011, under rainfed conditions. Three cassava varieties (KU50, RY9 and HB60) were assigned as main plot. Two cutting lengths (15 cm and 30 cm) were assigned as sub plots, and two treatments of buds (buds cut and not cut) were assigned as sub-sub plots. The buds on the cuttings that were inserted into the soil were removed. In 2010, the plants from 15 cm long cuttings subjected to bud removal had higher fresh storage root yield (88.4 Mg ha^{-1}) than did plants from 30 cm long cuttings subjected to bud removal (75.8 Mg ha^{-1}). Cutting of buds also had higher fresh storage root yield (89.1 Mg ha^{-1}) than did non bud-cutting (75.0 Mg ha^{-1}). KU50 had the highest fresh storage root yield (91.4 Mg ha^{-1}), dry root yield (48.4 Mg ha^{-1}) and starch yield (20.1 Mg ha^{-1}). Cutting length of 15 cm had higher starch concentration in storage roots (25.6%) than did cutting length of 30 cm (24.2%). HB60 had the highest starch concentration (27.0%) among cassava varieties tested. The data in 2011 were similar to the data in 2010. The responses of varieties to bud removal and cutting length are discussed.

Keywords: bud removal, cutting length, farmers' practice, root yield

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) originated in the tropical areas of South America and it is grown widely in tropical areas of the world due to its starch containing roots (Alves, 2001; Scott *et al.,* 2000). Globally, the area planted with cassava was recently estimated at 20.4 million hectares with a total production of 262.5 million tonnes (MT) (FAO, 2014). Thailand ranks third for world cassava production with an average total production of 22.5 MT year^{-1}, with the areas in the northeastern region accounting for approximately 51.3% of the country's entire cassava production (OAE, 2014). The national average yield in 2006 was about 20 MT ha^{-1}, which is higher than the world average but lower than the potential of the crop (FAO, 2014). The main causal factors driving low yields in Thailand are infertile soils and drought (FAO, 2014), as well as inappropriate agronomic practices (Jones, 2013).

It has been reported previously that cassava yield depends on plant population density, number of roots and tuber root weight per plant (Hahn and Hozyo, 1984). In cassava cultivation, the cuttings from the stems are used as planting materials for the succeeding crop (Nassar and Teixeira, 1983; Leihner, 2002). The number of cassava roots can be increased by adopting a vertical planting position and using longer cuttings (Osiru *et al.,* 1997). However, no significant difference in root yield between cuttings with 10 cm and 50 cm length has been reported (Velasco, 1982). Short cuttings produced better yields than long cuttings (Villamayor *et al.,* 1992) and cuttings with 20 cm length have higher root yield than longer cuttings with 25 cm length (Tongglum *et al.,* 1992).

One local agronomic practice that the farmers in northeastern Thailand claim to considerably increase root yield of cassava is to cut the buds off the section of the cuttings to be inserted into the soil. However, the yield components that contribute to root yield have not been clearly investigated. The hypothesis underlying this research is that bud removal increases storage root yield and modifies yield components of cassava. The reason for yield increase of this local practice has not been verified experimentally. Therefore, the objective of this research was to evaluate the effects of cutting length and bud removal on plant growth, root yield and starch content of three cassava varieties grown under rain-fed conditions in northeastern Thailand.

MATERIALS AND METHODS

Crop management and experimental design

Field experiments were conducted at the Agronomy Experimental Fields of Khon Kaen University, Khon Kaen, Thailand (16º28'N, 102º48'E, 200 m above sea level) under rainfed conditions in two consecutive years (2010 and 2011). The crops were planted in June and harvested after 12 months for both years. Soil type is loamy sand in texture. Soil samples were collected from 0-30 cm depth before planting and analyzed for selected chemical and physical properties (Supplementary Material Table S1).

Rainfall, maximum and minimum air temperature were recorded daily and summarized on a monthly basis for entire growing period (Figure 1). Total rainfall in 2010 and 2011 during the growing period was recorded as 1,099 mm and 1,620 mm, respectively. The highest monthly rainfalls observed were 404 mm in August 2010 and 356 mm in September 2011.

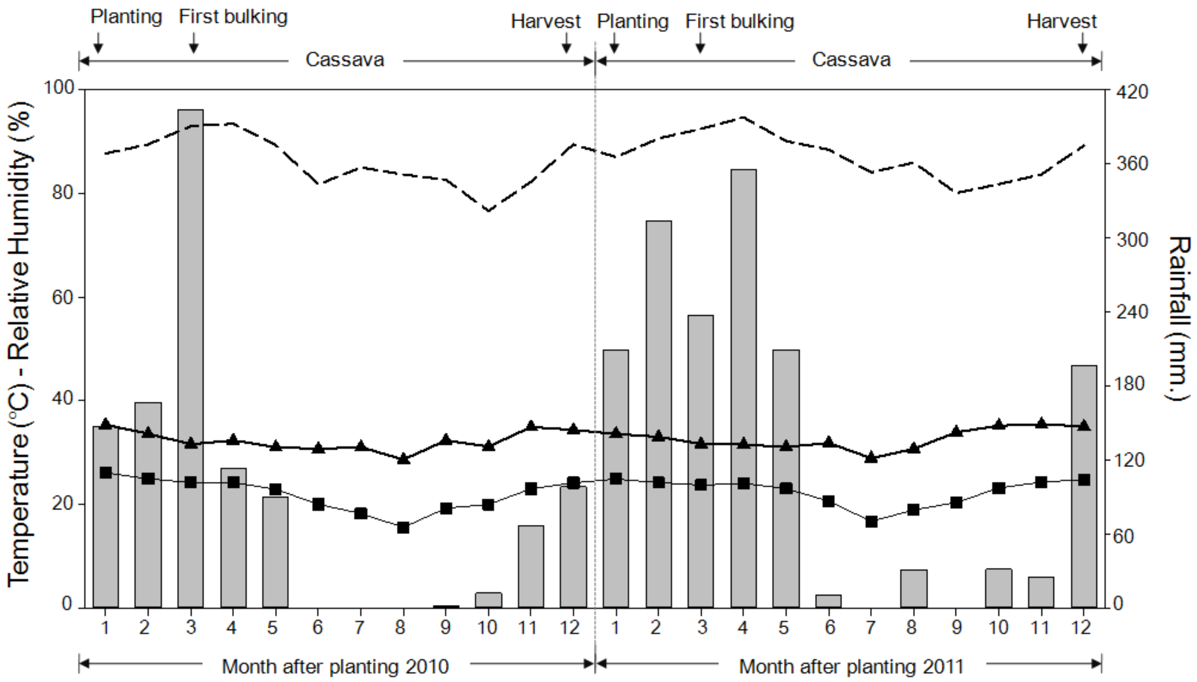

Figure 1. Rainfall (▭), relative humidity (---), minimum temperature (—■—) and maximum temperature (—▲—) entire the growing period in 2010 and 2011. Khon Kaen, Thailand.

The experiment was subjected to water stress during the growing period for 4 months in 2010 (starting at 6 months after planting, MAP) and 3 months in 2011 (Figure 1). The experiment also encountered intermittent water-logging events for 5 months in 2011, starting at 1 MAP.

The experimental fields were ploughed twice with a 3-disk tractor and a 7-disk tractor. Ridging was undertaken with a 7-disk tractor forming a ridge height of 30 cm. The distance between planting rows and cassava plants was 1 m. Pre-emergence herbicide (metholachor) was sprayed immediately after planting at the rate of 1.5 kg a.i. ha^{-1}. A split-split plot design with four replications and plot size of 11 × 12 m was adopted in this study.

Three cassava varieties (Kasetsart 50 [KU50], Rayong 9 [RY9] and Huay Bong 60 [HB60]), two cutting lengths of 15 cm and 30 cm and two bud removal treatments (bud cut and not cut) were assigned in main plots, sub-plots and sub-sub-plots, respectively. Three buds on the cutting of 15 cm length (from six normal buds) and five buds on the cutting of 30 cm length (from ten normal buds) were removed using a sharp knife. The buds, bark and cambium layer were removed (Supplementary Material Figure S1). The cuttings were inserted vertically into the soil with two-third of the length exposed on top of ridges. Chemical fertilizer of grade 15-15-15 (N, P_2O_5, K_2O) at the rate of 312.5 kg ha^{-1} (31.3 g $plant^{-1}$) was applied 1 month after planting. The granule fertilizer was dropped into the hole made using a hand hoe 15 cm from the cassava plant and covered with soil.

Hand weeding was undertaken only one time at 1 month after planting and no weeding was done for the rest of cropping period in both years. No insecticide or fungicide was used in these experiments for the entire growing period over both years.

Data collection

Four plants from each plot were selected randomly outside the harvesting area of the experimental plots at 120, 240, 300 and 360 days after planting (DAP) and shoot dry weight per plant, storage root dry weight per plant and storage root number per plant were evaluated. The harvested plants were separated into leaves, stems and roots. Twenty leaves of each plant from each plot were randomly chosen and leaf area was determined by an automatic leaf area meter (model AAC-400, Hayashi Denkoh Co., Ltd., Bunkyo-ku, Tokyo, Japan). The leaf samples were subsequently oven-dried at 80 ^{o}C to a constant weight and leaf dry weight was measured. Leaf dry weight and leaf area of 20 leaves were converted to leaf dry weight and leaf area of total sample using the relationship; total leaf area equals leaf area of 20 leaves × total leaf dry weight/leaf dry weight of 20 leaves. Leaf area index (LAI) was calculated by leaf area per plant divided by ground area covered (Ekanayake, 1994).

Fresh storage root yield and dry storage root yield were measured at 360 DAP in the harvesting area of 6 × 4 m (twenty-four plants). Subsequently, fresh and dry storage root yield were calculated in Mg ha^{-1}. Harvest index (HI) was calculated by storage root dry weight divided by total plant dry weight (Ekanayake, 1994). Starch content was measured using a Riemann scale balance (Bainbridge *et al.,* 1996) and starch yield was calculated by multiplying the actual starch content with the fresh root weight per hectare and divided by 100 (Knutsson, 2012).

Data analysis

The data for each year were analyzed statistically according to a split-split plot design using Statistica Ver. 11 (Statsoft Inc., Tulsa, USA) and the error variances were tested for variance homogeneity. As some error variances were three-fold different, means were separated by post-hoc Fisher's least significant difference (LSD) at 0.05 probability level.

RESULTS

Fresh storage root yield, dry storage root yield and harvest index

Cutting lengths affected ($P \leq 0.05$) fresh storage root yield, dry storage root yield and harvest index across years (Table 1). Cutting of 15 cm length caused higher values than that of 30 cm for these traits. Significant differences ($P \leq 0.05$) between bud removal treatments were also observed and cutting with bud removal induced the highest fresh storage root yield, dry storage root yield and harvest index across years (Table 1). Cassava varieties were also significantly different ($P \leq 0.05$) for these traits across years, with KU50 presenting the highest fresh storage root yield (91.4 Mg ha^{-1} in 2010 and 87.4 Mg ha^{-1} in 2011), dry storage root yield (48.4 Mg ha^{-1} in 2010 and 44.7 Mg ha^{-1} in 2011) and harvest index (0.53 in 2010 and 0.52 in 2011).

Starch yield and starch content

Significant differences ($P \leq 0.05$) between cutting lengths were observed for starch yield and starch concentration (Table 1). Cutting of 15 cm length determined the highest starch yields (22.6 Mg ha^{-1} in 2010 and 18.5 Mg ha^{-1} in 2011) and starch concentrations (25.6% in 2010 and 25.1% in 2011). Cutting with bud removal induced the highest ($P \leq 0.05$) starch yields (22.5 Mg ha^{-1} in 2010 and 18.6 Mg ha^{-1} in 2011) and starch concentration (25.3% in 2010 and 24.8% in 2011).

Cassava varieties were also significantly different (P≤0.05) for starch yield and starch concentration across years. KU50 had the highest starch yields of 20.1 and 18.7 Mg ha^{-1} in 2010 and 2011, respectively, whereas HB60 and RY9 had the highest starch concentration of 27.0% and 25.7% in 2010 and 26.5% and 25.2% in 2011, respectively.

Table 1. Fresh storage root yield (FRY), dry storage root yield (DRY), starch yield (SY), starch content (SC) and harvest index (HI) of cassava with differences in cutting lengths, bud removal treatments and varieties at 360 days after planting (DAP) in 2010 and 2011.

	2010					2011				
	FRY (Mg/ha)	DRY (Mg/ha)	SY (Mg/ha)	SC (%)	HI	FRY (Mg/ha)	DRY (Mg/ha)	SY (Mg/ha)	SC (%)	HI
Cutting length										
15 cm	88.4^{a}	43.3^{a}	22.6^{a}	25.6^{a}	0.54^{a}	74.0^{a}	38.2^{a}	18.5^{a}	25.1^{a}	0.52^{a}
30 cm	75.8^{b}	32.4^{b}	18.3^{b}	24.2^{b}	0.51^{b}	61.0^{b}	32.4^{b}	14.4^{b}	23.7^{b}	0.50^{b}
Bud removal										
Cut	89.1^{a}	44.1^{a}	22.5^{a}	25.3^{a}	0.53^{a}	75.2^{a}	38.1^{a}	18.6^{a}	24.8^{a}	0.52^{a}
Not cut	75.0^{b}	37.6^{b}	18.3^{b}	24.5^{b}	0.52^{b}	59.9^{b}	31.5^{b}	14.3^{b}	24.0^{b}	0.50^{b}
Variety										
KU50	91.4^{a}	48.4^{a}	20.1^{a}	22.0^{b}	0.53^{a}	87.4^{a}	44.7^{a}	18.7^{a}	21.5^{b}	0.52^{a}
HB60	70.8^{c}	38.1^{b}	19.1^{b}	27.0^{a}	0.51^{b}	57.1^{b}	31.0^{b}	15.1^{b}	26.5^{a}	0.50^{b}
RY9	82.6^{b}	39.0^{b}	21.2^{a}	25.7^{a}	0.53^{a}	62.0^{b}	32.6^{b}	15.6^{ab}	25.2^{a}	0.51^{ab}

Means of the same category in the same column followed by different letters are significantly different at 0.05 probability level by LSD.

Table 2. Leaf area index (LAI) of cassava with differences in cutting lengths, bud removal treatments and varieties evaluated at 120, 240, 300 and 360 days after planting (DAP) in 2010 and 2011.

	2010				2011			
	120 DAP	240 DAP	300 DAP	360 DAP	120 DAP	240 DAP	300 DAP	360 DAP
Cutting length								
15 cm	4.03	1.40	1.64	4.51^{a}	3.95	1.32	1.56	4.43^{a}
30 cm	3.93	1.21	1.57	3.76^{b}	3.85	1.13	1.49	3.68^{b}
Bud removal								
Cut	4.10	1.34	1.62	4.24	4.03	1.27	1.54	4.16
Not cut	3.86	1.27	1.59	4.03	3.78	1.19	1.51	3.96
Variety								
KU50	4.25	1.39	2.37^{a}	4.94^{a}	3.64	1.32	2.29^{a}	4.86^{a}
HB60	3.71	1.29	0.81^{c}	3.56^{c}	4.17	1.22	0.74^{c}	3.48^{c}
RY9	3.99	1.23	1.63^{b}	3.91^{b}	3.91	1.16	1.55^{b}	3.84^{b}

Means of the same category in the same column followed by different letters are significantly different at 0.05 probability level by LSD.

Leaf area index (LAI)

Cutting lengths were only significantly different ($P \leq 0.05$) for LAI at 360 DAP in 2010 and 2011 (Table 2). The cuttings of 15 cm length had the highest LAI across varieties and bud removal treatments. Bud removal treatments did not affect LAI across growth stages. Significant differences ($P \leq 0.05$) among cassava varieties were observed for LAI at 300 and 360 DAP in 2010 and 2011, with. KU50 showing the highest LAI at 360 DAP regardless cutting lengths, bud removal treatments and years.

Shoot dry weight

Shoot dry weight increased with time for all treatments, with cutting of 30 cm length causing ($P \leq 0.05$) higher shoot dry weight than cutting of 15 cm length at 360 DAP (Table 3). At 360 DAP, the highest shoot dry weight for the cutting 30 cm length was 2,370 and 2,321 g plant^{-1} in 2010 and 2011, respectively, whereas the highest shoot dry weight for the cutting of 15 cm length were 2,196 and 2,149 g plant^{-1}.Cutting without bud removal caused higher shoot dry weight ($P \leq 0.05$) than cutting with bud removal at 120, 240 and 300 (DAP). Significant differences ($P \leq 0.05$) among cassava varieties were also observed for shoot dry weight at 120, 240, 300 and 360 DAP across years. HB60 had consistently and significantly the highest shoot dry weight across sampling times followed by KU50 and RY9. The highest values of shoot dry weight (2,291 g plant^{-1} in 2010 and 2,247 g plant^{-1} in 2011) were obtained from HB60 at 360 DAP.

Table 3. Shoot dry weight per plant (g) of cassava with differences in cutting lengths, bud removal treatments and varieties evaluated at 120, 240, 300 and 360 days after planting (DAP) in 2010 and 2011.

	2010				2011			
	120 DAP	240 DAP	300 DAP	360 DAP	120 DAP	240 DAP	300 DAP	360 DAP
Cutting length								
15 cm	772^{b}	1,670^{b}	1,819^{b}	2,196^{b}	639^{b}	1,652^{b}	1,811^{b}	2,149^{b}
30 cm	876^{a}	1,876^{a}	2,027^{a}	2,370^{a}	734^{a}	1,858^{a}	2,017^{a}	2,321^{a}
Bud removal								
Cut	789^{b}	1,730^{b}	1,881^{b}	2,259	652^{b}	1,708^{b}	1,871^{b}	2,231
Not cut	859^{a}	1,815^{a}	1,965^{a}	2,307	721^{a}	1,799^{a}	1,957^{a}	2,239
Variety								
KU50	815^{b}	1,791^{b}	1,939^{b}	2,285^{b}	697^{b}	1,783^{b}	1,924^{b}	2,234^{ab}
HB60	848^{a}	1,812^{a}	1,966^{a}	2,291^{a}	715^{a}	1,796^{a}	1,960^{a}	2,247^{a}
RY9	808^{c}	1,716^{c}	1,864^{c}	2,272^{c}	648^{c}	1,697^{c}	1,857^{c}	2,224^{b}

Means of the same category in the same column followed by different letters are significantly different at 0.05 probability level by LSD.

Table 4. Storage root dry weight (g) per plant of cassava with differences in cutting lengths, bud removal treatments and varieties evaluated at 120, 240, 300 and 360 days after planting (DAP) in 2010 and 2011.

	2010				2011			
	120 DAP	240 DAP	300 DAP	360 DAP	120 DAP	240 DAP	300 DAP	360 DAP
Cutting length								
15 cm	867	1,996[a]	2,840[a]	3,333[a]	446	1,442[a]	2,139[a]	2,723[a]
30 cm	922	1,633[b]	2,353[b]	2,838[b]	475	1,206[b]	1,855[b]	2,238[b]
Bud removal								
Cut	948	1,928[a]	2,912[a]	3,407[a]	468	1,494[a]	2,440[a]	2,807[a]
Not cut	840	1,701[b]	2,280[b]	2,764[b]	454	1,155[b]	1,555[b]	2,154[b]
Variety								
KU50	990	2,485[a]	3,680[a]	4,337[a]	543	1,928[a]	3,057[a]	3,574[a]
HB60	824	1,395[c]	1,846[c]	2,097[c]	423	985[c]	1,326[c]	1,703[c]
RY9	870	1,564[b]	2,263[b]	2,822[b]	416	1,060[b]	1,611[b]	2,165[b]

Means of the same category in the same column followed by different letters are significantly different at 0.05 probability level by LSD.

Storage root dry weight

Significant differences (P≤0.05) between cutting lengths were observed for storage root dry weight at 240, 300 and 360 DAP across years (Table 4), with the highest values being found in cuttings of 15 cm length. Cutting with bud removal had higher (P≤0.05) storage root dry weight than cutting without bud removal at 240, 300 and 360 DAP across years. At final harvest (360 DAP), cutting with bud removal had the highest storage root dry weight of 3,407 and 2,807 g plant^{-1} in 2010 and 2011, respectively. Cassava varieties were significant different (P≤0.05) for storage root dry weight at 240, 300 and 360 DAP across years. KU50 had the highest storage root dry weight at 240, 300 and 360 DAP in both years. At 360 DAP, KU50 had the highest storage root dry weight of 4,337 and 3,574 g plant^{-1} in 2010 and 2011, respectively.

Storage root number per plant

Significant differences (P≤0.05) between cutting lengths were observed for storage root number per plant at 120, 240, 300 and 360 DAP in both years (Table 5). Cutting of 15 cm length caused higher storage root number per plant than that of 30 cm length. Bud removal treatments were significantly different (P≤0.05) for storage root number per plant across sampling times, and cutting with bud removal had higher storage root number per plant than cutting without bud removal. Cutting with bud removal also had the highest numbers of storage roots at 360 DAP (14.9 and 13.5 roots in 2010 and 2011, respectively). Cassava varieties were significantly different (P≤0.05) for storage root number per plant for most sampling times and across years. At 360 DAP, KU50 had the highest storage root number per plant (14.7 roots in 2010 and 13.7 roots in 2011).

Table 5. Storage root number per plant of cassava with differences in cutting lengths, bud removal treatments and varieties evaluated at 120, 240, 300 and 360 days after planting (DAP) in 2010 and 2011.

	2010				2011			
	120 DAP	240 DAP	300 DAP	360 DAP	120 DAP	240 DAP	300 DAP	360 DAP
Cutting length								
15 cm	8.6^{a}	11.7^{a}	13.7^{a}	14.6^{a}	6.3^{a}	10.2^{a}	12.3^{a}	13.2^{a}
30 cm	8.3^{b}	10.9^{b}	12.8^{b}	13.8^{b}	5.4^{b}	9.4^{b}	11.3^{b}	12.4^{b}
Bud removal								
Cut	9.2^{a}	11.9^{a}	13.9^{a}	14.9^{a}	6.5^{a}	10.5^{a}	12.4^{a}	13.5^{a}
Not cut	7.7^{b}	10.7^{b}	12.6^{b}	13.6^{b}	5.2^{b}	9.1^{b}	11.2^{b}	12.1^{b}
Variety								
KU50	9.4^{a}	12.0	13.8^{a}	14.7^{a}	6.7^{a}	10.6^{a}	12.7^{a}	13.7^{a}
HB60	7.6^{c}	10.7	12.7^{c}	13.7^{c}	5.0^{c}	9.0^{c}	11.0^{c}	11.9^{c}
RY9	8.5^{b}	11.2	13.2^{ab}	14.2^{b}	5.8^{b}	9.8^{b}	11.8^{b}	12.8^{b}

Means of the same category in the same column followed by different letters are significantly different at 0.05 probability level by LSD.

DISCUSSION

Sustainable improvements in crop yield and quality are always the main purpose of crop production. This can be achieved by modifying the genetics of crop plants as well as altering agronomic practices favoring optimum crop productivity. This research focused on altering agronomic practice by removing buds of cassava cuttings and adjusting cutting length to increase storage roots number and ultimately increasing economic root yields. The assumptions of this study are that the increase in root yield is proportional to the increase in root number and this yield component can be modified by bud removal. In addition, long cuttings should have higher root number than short cuttings and cassava genotypes may respond differently to bud removal. As the practice of bud removal is not common for cassava production, this research should be beneficial to cassava growers especially the small cassava growers.

Bud removal

Cutting with bud removal significantly increased fresh storage root yield and dry storage root yield (Table 1) and these results confirmed the claim of cassava growers in Thailand. These gains were associated with storage root dry weight per plant and storage root number per plant (Tables 4 and 5). As other studies on bud removal experiment are not available, the direct comparison of the results with others is not possible. Hypothetically, fibrous roots arise from the basal cut surface of the cuttings and occasionally from the buds. Some of these fibrous roots start to bulk and became storage roots (Knoth, 1993). Cutting with bud removal may produce a higher number of fibrous roots than those of non-cutting bud treatment. This is probably due to the accumulation of assimilates transported from other parts of the cuttings at the wounds created by bud removal. The wounds may develop more fibrous roots and increase the possibility of these roots to become storage roots.

In a classical experiment conducted in 1686, phloem tissue was cut by removing the bark. The assimilates produced in leaves were transported along the phloem tissue and stopped at the wound, resulting in high accumulation of assimilates at the wound and the development of roots (Malpighi, 1686). Wound-induced roots have been reported in geranium (Davies *et al.,* 1982; Cline and Neely, 1983) and woody plant (Jackson, 1986). This knowledge is commonly used for plant propagation such as cutting and layering. Stem cuttings with removal of buds, bark (phloem tissue) and cambium layer at underground level increased root number and also increased the possibility of these roots (fibrous roots) to become storage roots. As consequences, bud-removal treatment caused higher fresh storage root yield, dry storage root yield, starch yield, starch content, harvest index, storage root dry weight and storage root number per plant (Tables 1, 4 and 5). However, the experiment focused on storage roots and aerial growth and the formation of fibrous roots at early growth stages was not investigated. Further deliberate experiments are required to verify the hypothesis for yield increase as affected by bud removal.

Cutting length

The question underlying this research is what length is suitable for bud removal practice and then cuttings of 15 and 30 cm length were compared as these lengths are commonly used for cassava production. In this study, cutting of 15 cm caused higher storage root yield than that of 30 cm and this is partially explained by higher LAI, storage root dry weight per plant and storage root number (Tables 2, 4 and 5). The results were in agreement with those of Tongglum *et al.* (1992), who found that cutting of 20 cm had higher storage root yield than that of 25 cm. Another work also reported the advantage of short cuttings over long cuttings (Villamayor *et al.,* 1992). Ganado (1956) found that short cuttings were better than long cuttings when the cuttings were planted vertically, and long cuttings were better than short cuttings when the cuttings were planted horizontally. However, cuttings of 10 and 50 cm were not significantly different for root yield (Velasco, 1982). Long cuttings with more than 10 nodes had a better chance of conserving their viability, and stem cuttings of 5 to 7 nodes and minimum length of 20 cm were recommended to obtain optimum yield (Carvalho *et al.*, 1993). Cuttings with 4 to 7 nodes were not different with respect to mean storage root length, radius of storage root tip and the number of major stem per plant (Onwueme, 1978). However, longer cuttings produced a faster growing canopy (Lahai *et al.*, 1999). The differences among above studies would be due to differences in planting methods (vertical insert and horizontal insert) and environments (tillage and soil moisture).

In this study, cutting of 30 cm had higher shoot dry weight per plant than that of 15 cm, which was associated with higher stem dry weight (data not shown). However, higher shoot dry weight of cutting of 30 cm length did not cause root yield advantage and this would be due to lower starch content, harvest index and root number (Tables 1, 3 and 5). The assumption is that a longer cutting has higher sprouting and development due to the presence of more buds. Storage root number and root yield were shown to be affected by cutting length and root yield was associated with the number of storage roots (Didier and El-Sharkawy, 1994). The higher LAI associated with cutting of 15 cm indicates that plants can produce higher levels of photosynthate, which has been correlated positively with root yield (Lenis *et al.,* 2005; Lebot, 2009; Lahai *et al.,* 2013). During the period of 120 to 180 DAP, plants maintained LAI above 4.0 (2010) and 3.9 (2011), with LAI subsequently declining to 1.4 in 2010 and 1.3 in 2011 for the remainder of their growth cycle. This pattern is due to leaf senescence and abscision during rainless period (Figure 1). Following the onset of rainy season, new leaves were produced and LAI values above 4.5 (2010) and 4.4 (2011) were recorded (Table 2; Figure 1).

In the present study, the long cutting (30 cm) had higher shoot dry weight (Table 3) due to the presence of higher reserved carbohydrate. However, lower LAI in long cutting might be attributed to the limitation of nutrients applied to the soil. The application of chemical fertilizer formula 15-15-15 (N_2, P_2O_5, K_2O) at the rate of 312.5 kg ha^{-1} is generally recommended for cuttings of 15 to 20 cm. Long cutting produced higher branch number, but it had lower LAI possibly due to poor partitioning of assimilates to the branches. Although long cutting produced higher number of fibrous roots, the formation of storage roots was low due to low LAI (Table 2). Shoots depend on roots for nutrient and water uptake, while the continued root growth is reliant on photosynthates produced by leaves (Kramer and Boyer, 1995). Crop performance in 2011 was generally lower than in 2010 for most parameters investigated. The reduction in crop performance was in large part due to rainfall amount and distribution during the growing season. The crop received a total rainfall of 1,621 mm in 2011 and 1,099 mm in 2010. Then, water logging occurred during high rainfall intensity in September 2011, and resulted in the reduction in crop growth and yield as compared to 2010 (Figure 1).

Cassava variety

KU50 had the highest fresh storage root yield and dry storage root yield in 2010 and 2011, which was associated with the highest LAI, storage root dry weight per plant and storage root number (Tables 1, 2, 4 and 5). In previous investigations, high LAI is an important factor leading to high yield in cassava varieties (Enyi, 1973; Lahai, 1999). On the other hand, HB60 had the highest starch content in storage root. Accordingly, Vichukit *et al.* (2004) reported that HB60 had higher starch content than RY5, RY72 and KU50. Herein, KU50 produced the highest starch yield due to the highest fresh storage root yield. KU50 also had higher HI than did HB60, indicating that KU50 was highly efficient in transporting photoassimilates for storage in tuber roots. KU50 is popular among cassava growers in the Northeast, Thailand, being widely adapted to unfavorable growing conditions (Rojanaridpiched *et al.,* 1995). In this study, only three cassava varieties were investigated to understand the responses to bud removal and cutting lengths. The results indicated that the varieties responded similarly in terms of rooting and formation of storage roots. However, more cassava varieties should be investigated to reach a recommendation of management practice to cassava growers. In addition, the experiment was conducted in the early rainy season planting date and results do not cover the planting date in the late rainy season. This is the main planting date for cassava growing in Thailand and such seasonal influence on cassava management should be further investigated.

CONCLUSIONS

Bud removal practice did increase cassava yield in all evaluated varieties and the combination for the best yield was bud removal with cutting of 15 cm. The interaction between cutting length and environment should be considered. KU50 had the highest fresh storage root yields.

ACKNOWLEDGMENTS

This work was supported by the Royal Golden Jubilee Ph.D. Program under the Thailand Research Fund. The authors would like to thank the Department of Plant Science and Agricultural Resources, Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand and School of Water Energy and Environment, Cranfield University, United Kingdom for their cooperation during the experimentation.

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Supplementary material

Table S1. Baseline soil physical and chemical properties prior to planting in 2010 and 2011

Soil properties	2010	2011
Chemical		
pH[1]	6.1	6.2
Total nitrogen (%)[2]	0.034	0.015
Available phosphorus (Mg kg^{-1})[3]	21.7	9.3
Exchangeable potassium (Mg kg^{-1})[4]	32.6	16.7
Organic matter (%)[5]	0.58	0.34
Soil texture[6]		
Sand (%)	78.0	84.9
Silt (%)	13.0	8.9
Clay (%)	9.0	6.1
Texture	loamy sand	loamy sand

[1] = pH method
[2] = Micro-Kjedahl method (Bremner, 1965)
[3] = Bray II method (Bray and Kurtz, 1945)
[4] = 1 N ammo-nium acetate pH =7.0 (McKeague, 1978)
[5] = Walkley and Black (Walkley and Black, 1934)
[6] = Hydrometer method (Bouyoucos, 1962)

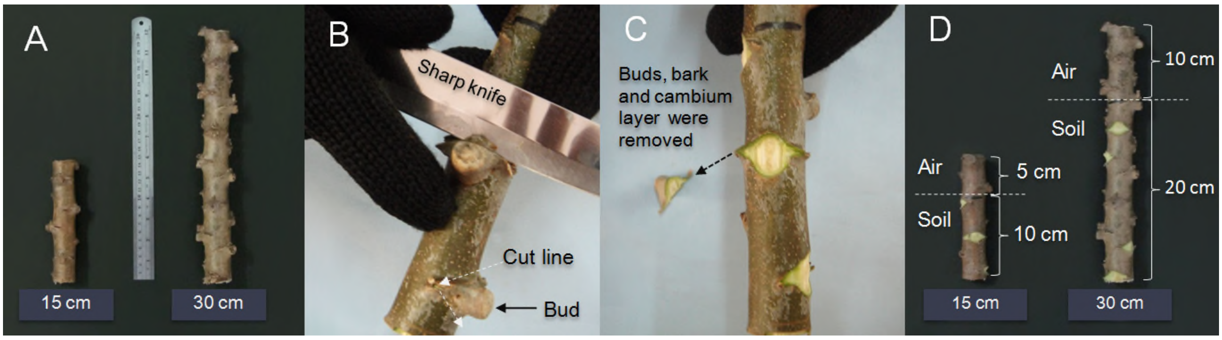

Figure S1. The process of removing buds from stem cuttings: A, cuttings of 15 and 30 cm lengths, B, buds at underground level being cut; C, buds at underground level after cut; and D, cuttings of 15 and 30 cm length showing underground part and aerial part.