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Plant density optimisation to improve sustainable cassava (*Manihot esculenta* Crantz) stem and tuberous root yield in Cambodia

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Abstract

Cassava (*Manihot esculenta* Crantz) is an important crop in Cambodia. The estimation of the yield of cassava stem and tuberous root from plants cultivated at different plant densities in the Battambang province remains elusive, although it is possible to obtain a higher yield these tissues. In this study, we investigated the optimal density of cultivation for Rayong 7 (R 7) and Kasetsart 50 (KU 50), which are the most commonly used cultivars of cassava in Cambodia. The 0.5 × 0.65 m spacing resulted in high yields of stem and tuberous root for R 7 whereas a row width of 0.6 × 0.8 m was appropriate for producing the highest yields for KU 50. Regression analysis showed that the density of R 7 had a positive linear correlation with tuberous root yield when all factors were considered. In contrast, the density of KU 50 did not significantly correlate with the yield of tuberous roots. Each 25% increase in density increased, on an average, the tuberous root weight by 5.5% and 10% for the R 7 cultivar. Our results suggest that a high planting density of cassava is positively correlated with its tuberous root yield, and for R 7, tuberous root yield improves as the density increases.

Keywords: Cambodia, cassava, planting density.

Introduction

Cassava (*Manihot esculenta* Crantz) is an important crop in Cambodia. When declaring cassava as one of the potential crops for agro-industrial development in Cambodia, the Royal Government of Cambodia (RGC) announced the 'National Policy on Cassava 2020-2025' in 2020 (RGC, 2020). While the policy clearly states that the Ministry of Agriculture, Forestry, and Fisheries (MAFF) and collaborating universities need to 'promote and encourage propagation farms and private cassava stem suppliers to sell and distribute healthy and disease-free cassava stems', detailed discussions on it have commenced. In addition to various constraints, such as pests and diseases, the Sri Lankan Cassava mosaic virus has been spreading in Southeast Asia and causing damage to cassava cultivation (Wang et al., 2016; Uke et al., 2018; Minato et al., 2019; Wang et al., 2019; Leiva et al., 2020; Siriwan et al., 2020; Uke et al., 2021). Prior to the spread of the mosaic virus, our project 'Development and Dissemination of a Sustainable Cultivation System Based on Invasive Pest Management of Cassava in Vietnam, Cambodia and Thailand' has been underway to establish a sustainable market-based healthy cassava stem cultivation and distribution system in Cambodia (Tokunaga et al., 2018). Because the cultivation of infected cassava stems leads to yield loss and aids the spread of Sri Lankan Cassava mosaic disease (SLCMD), we aim to provide healthy cassava stem to reduce the problem of the SLCMD outbreak in recent years.

To produce uninfected healthy cassava stem on a limited area of land, we first examined the planting density and stem production. For sustainable cultivation of healthy cassava stem and tuber, the different constraints should necessarily be considered to maximise the profit. Previous studies have clarified the various constraints that affect cassava yield in Cambodia, such as soil nutrient deficits, short crop duration, high weed density, net nutrient removal, and the gradual decline in soil fertility by continuous cropping (Sopheap et al., 2012; Peuo et al., 2021). However, the effect of planting density on cassava cultivation has not been fully investigated in Cambodia. Silva et al. (2013) and Streck et al. (2014) explored the effect of different planting densities on growth, development, and stem and tuberous root yields of Vermelhinha and Fepagro-RS 13, respectively, in Brazil, and suggested the optimal densities to maximise each trait. Tabngoen et al. (2004) conducted five spacing experiments on Huay Bong 60, Kasetsart 50 (KU 50), and Rayong 5 in Thailand. They found that the optimum spacing depends on cassava varieties and for KU 50, used in this research, 0.8 × 0.8 m and 1.0 × 1.0 m spacing was expected to provide a high yield of fresh tuberous root. Changing planting density does not require additional cost; however, it can positively change cassava yield and is beneficial for healthy cassava stem cultivation as well as for all cassava producers in Cambodia. Therefore, in this study, we aimed to evaluate the planting density for achieving optimal tuberous root and stem yields and other traits in the cultivation of Rayong 7 (R 7) and KU 50, which are the most commonly used cultivars of cassava in Cambodia.

Methods

Location of the experimental site and weather conditions during the trial

The experiment was conducted at the Cassava Propagation and Distribution Center of the National University of Battambang (NUBB), located in Srah Keo village (latitude 12.99557″ N latitude and longitude 103.3167′ E longitude), Kompong Preah commune, Sangkae district, Battambang province, Cambodia, during the 2017/2018 season cycle. According to the Köppen–Geigner climate classification, the climate is tropical and is classified as AW (Peel et al., 2007). The average annual temperature is 29.17 °C and about 682.17 mm of precipitation falls annually. The driest months are January and February, with approximately 20 mm of rainfall and most precipitation falls in September, with an average of 367.40 mm. The warmest months of the year are March and April, with an average temperature of 32–33 °C (World Weather Online, 2021).

Experimental materials, treatments, and design

The field area was 0.25 ha, which was divided into eight blocks, as shown in Figure 1. Cultivars R 7 and KU 50 were selected, as they were the most commonly used cultivars among farmers in Battambang province at the time of the experiment. R 7 was developed in 1992 by conventional breeding between CMR35-17-25, a high-starch content cultivar, and OMR29-20-118, a high-yield cultivar (Boonseng et al., 2005). KU 50 is cultivated in Thailand, Vietnam, Indonesia, Cambodia, Myanmar, and the Philippines. In Thailand and Vietnam, this cultivar is cultivated on more than one million hectares of land (Malik et al., 2020). As indicated in Figure 1, R 7 was planted in blocks D and H, and KU 50 was planted in blocks B and E for this experiment. The textural class of the field corresponded to clay. The soil was tilled two times using a tractor with six-to-seven-disc harrows. The furrow, with a height of 0.35 m, was prepared using a tractor with a disc attachment and was arranged by hand to cultivate the plants at the desired planting density.

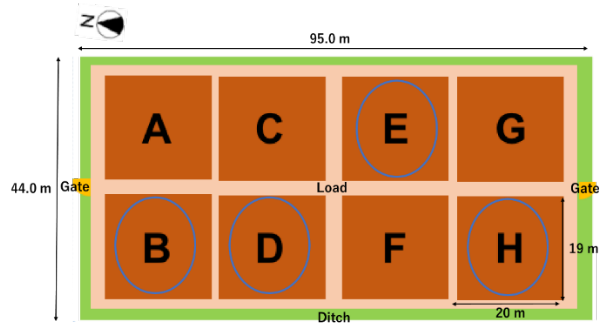

Fig.1: Map of the study site in Battambang province, Cambodia. Note: A) KU 50, B) KU 50, C) R 7, D) R 7, E) KU 50, F) R 7, G) KU 50, H) R 7. Blocks B, D, E, and H were used for this experiment. Other blocks were used for cultivation of healthy seeds (Tokunaga et al., 2018; Uke et al., 2021).

The distribution of cassava planted with various ridge distance × hill distance (m) spacing is shown in Table 1. This is reflected in the density, which was 10,000, 12,500, 15,625, 20,833, 25,641, and 30,769 ha^{-1} in different plots. It has the same allocation of various ridge distances and hill distances (m). Each plot was randomly arranged for each block.

Planting materials without any disease were produced in the NUBB field in the last cycle. Stem cuttings, at least 15 cm in length, were arranged vertically at the top of the soil bed at a depth of 0.10 m. The cassava plants received approximately 8 mm of water per day, which was applied by drip irrigation in the early morning and late afternoon when it did not rain. Chemical fertiliser (50 kg N, 12.5 kg P_2O_5, and 50 kg K_2O per hectare) was applied four times during cultivation. Urea (46%N w/w), single super phosphate (20%P), and KCl (water soluble potassium, K_2O content: 60% w/w) were used as sources of nitrogen, phosphate, and potassium, respectively. One of the four fertilisations was applied immediately after planting.

The remaining three fertilisations were applied every two months. To produce one stem per plant, lateral branches were pruned when they appeared. Furrow-weeds were sprayed with a mixture with 4 L of glyphosate (480 g/L soluble concentrate) and 1 kg of 2,4-D (95% wettable powder) per hectare between furrows. The weeding near the plants was performed manually.

Table 1: Distribution of cassava planted at various densities

Cultivar	Block	Plot	Plants/hectare	Ridge distance × Hill distance (m)	Number of samples
R 7	D	b	10,000	1.0 × 1.0	24
	D	e	12,500	0.8 × 1.0	24
	D	a	15,625	0.8 × 0.8	24
	D	d	20,833	0.6 × 0.8	24
	D	f	25,641	0.6 × 0.65	24
	D	c	30,769	0.5 × 0.65	24
	H	b	10,000	1.0 × 1.0	24
	H	e	12,500	0.8 × 1.0	24
	H	a	15,625	0.8 × 0.8	24
	H	d	20,833	0.6 × 0.8	24
	H	f	25,641	0.6 × 0.65	24
	H	c	30,769	0.5 × 0.65	24
KU 50	B	b	10,000	1.0 × 1.0	24
	B	e	12,500	0.8 × 1.0	24
	B	a	15,625	0.8 × 0.8	24
	B	d	20,833	0.6 × 0.8	24
	B	f	25,641	0.6 × 0.65	24
	B	c	30,769	0.5 × 0.65	24
	E	b	10,000	1.0 × 1.0	24
	E	e	12,500	0.8 × 1.0	24
	E	c	15,625	0.8 × 0.8	24
	E	f	20,833	0.6 × 0.8	24
	E	d	25,641	0.6 × 0.65	24
	E	a	30,769	0.5 × 0.65	24

Data collection

The plants were planted between 3rd and 4th August, 2017 and harvested between 3rd and 8th May, 2018, 9 months after planting. Twenty-four plants per plot were randomly collected as samples, and the plants adjacent to the load and other plots were excluded (Table 1). As mentioned earlier, the density (the number of plants per hectare) of cassava plants varied from 10,000 to and 30,769 plants ha^{-1}, with various ridge distance × hill distance (m) spacing. Stem height from the bottom to the top of the stem (m), the average size of the north–south and east–west widths of the canopy (m), number of nodes on the stem from the bottom to the first leaves from the top, fresh weight of leaves (kg), fresh weight of stem (kg), diameter of stem (m), number of tuberous roots, and fresh weight of tuberous roots (kg) were measured. The harvest index (HI) on fresh weight basis is defined as the fresh weight of the tuberous root divided by the total weight of the fresh tuberous root, leaves, and stem (Chaengsee et al., 2020). The yield of tuberous root per hectare (tonne), the weight of top biomass (leaf+stem) per hectare (tonne), and the yield of stem per hectare (tonne) were calculated by multiplying the respective value for each sample by planting density (plant number per m^2).

Model

We applied a multiple log-log regression model to determine the association of other cassava elements with the yield of tubers per hectare of the healthy cassava. Multiple regression is a statistical technique that can be used to analyse the relationship between a single dependent variable and several independent variables. In this study, both dependent and independent variables took the logarithmic form. The objective of a multiple regression analysis is to use independent variables whose values are known to predict the value of a single dependent variable (Greene, 2012).

$$\log y_i = \beta_0 + \log x_{i1}\beta_1 + \log x_{i2}\beta_2 + \cdots + \log x_{ik}\beta_k + \varepsilon_i, i = 1, \ldots, n$$

The observed value of y_i is the sum of two parts, a deterministic part and a random part, ε_i. Our objective was to estimate the unknown parameters of the model and cassava elements, which are correlated with the yield of tubers per hectare. In calculating the weights β_0, β_1, …, β_k, regression analysis ensures maximal prediction of the dependent variable from the set of independent variables, which is usually done by least-squares estimation. The logarithmic form of the stem leaf weight was highly correlated with the height of the stem (correlation: 0.66) of R 7 and (correlation: 0.58) of KU 50. Thus, Model 1 includes '*ln*weightsemleaf' whereas Model 2 includes the variable '*ln*heightstem' of R 7 and KU 50, respectively.

Results

Descriptive summary of R 7 and KU 50

A descriptive summary of R 7 and KU 50 is presented in Table 2. First, we compared the characteristics of these cultivars. The variable '*tuberyield*' is the yield of fresh tuberous root per hectare; its mean for R 7 was 57.35 tonne/ha, whereas that for KU 50 was 45.71 tonne/ha. The mean of the weight of tuberous root per plant, '*tuberweight*', was 3.38 and 2.75 kg for R 7 and KU 50, respectively. The variable '*stemheight*' is the height of the stem; KU 50 was taller (2.44 m) than R 7 (2.06 m). The variable '*canopysize*' is the average size of the north–south and east–west widths of the canopy. The canopy size was also larger for KU 50 than for R 7, being 0.91 and 0.83 cm, respectively. Similarly, the variable '*leafweight*', the weight of leaves, and the variable '*stemleafweight*', the weight of stem and leaves, were higher for KU 50 than for R 7. The variable '*numnodeswithoutpetiole*', the number of nodes without petiole, was, however, much higher for R 7 (119.74) than for KU 50 (92.53). The variable '*bottomstemsize*', the outer circumference of the bottom stem, '*middlestemsize*', the outer circumference of the middle stem, and '*neartopstemsize*', the outer circumference of stem near the top were not very different, being 0.10 and 0.09 m, 0.08 and 0.08 m, and 0.07 and 0.07 m for R 7 and KU 50, respectively. The number of tuberous roots was much higher for R 7 than for KU 50, with a mean of 9.25 and 6.42, respectively. The number of nodes was also much higher for R 7 than for KU 50, being 178.96 and 148.13, respectively. The variable '*stemweight*' was higher for KU 50 than for R 7, being 1.14 and 0.93, respectively. The weight of the top biomass (leaf+stem) per hectare was higher for KU 50 than for R 7, being 27.45 and 22.67 tonnes, respectively. The variable '*yieldofstemperha*' was also higher for KU 50 than for R 7, being 19.55 and 16.26 tonnes, respectively. Finally, '*HI*' was larger for R 7 than for KU 50, being 0.72 and 0.62, respectively.

Stem yield, tuberous root yield, and HI for different planting densities

There was a wide variation in row width of cassava planting, which is decided based on differences in soil fertility, the branching habit of cassava cultivar, and climatic conditions (Figure 2). The row width is usually 0.6–1.0 m between rows, with a plant-to-plant distance of 0.6–1.0 m. In this study, planting density had an effect on yields of stem, tuberous root, and above-ground biomass, and on HI. Increased planting density, as high as 0.5 × 0.65 m, resulted in increased yields of stem, tuberous root, and above-ground biomass for the R 7 cultivar whereas there was a decrease in the HI for R 7. Conversely, at planting densities of 0.6 × 0.65 m and 0.6 × 0.8 m, the yields of stem and tuberous root for KU 50, respectively, were the highest.

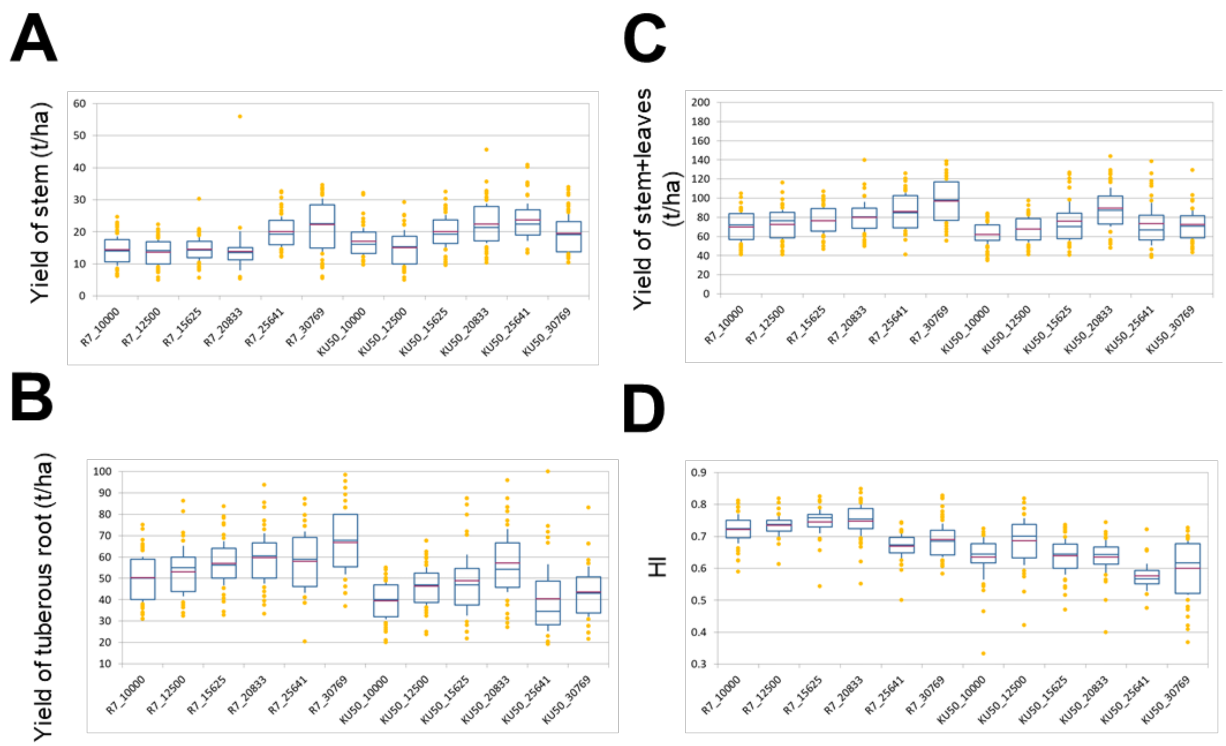

Fig. 2: Characteristics for cassava cv. R 7 and KU 50 as a response to planting density at 9 months after planting. Note: A) yield of stem per hectare; B) yield of tuberous root per hectare; C) yield of stems and leaves (biomass) per hectare; D) harvest index (HI).

Table 2: Descriptive summary.

R 7 (N=286)

Variables	Definition	Unit	Mean	St. Dev.	Min.	Max.
tuberyield	*yield of tuberous root per hectare*	tonne	57.35	13.55	31.00	94.00
tuberweight	*weight of tuberous root per plant*	kg	3.38	1.32	1.20	7.50
stemheight	*height of stem*	m	2.06	0.31	1.13	2.88
density	*planting density*	plant number per m^2	1.91	0.73	1.00	3.08
canopysize	*average size of North–South width and East–West width of canopy*	cm	0.83	0.09	0.55	1.04
leafweight	*weight of leaves*	kg	0.36	0.14	0.12	0.87
stemleafweight	*weight of stem and leaves*	kg	1.29	0.53	0.40	3.20
numnodeswithoutpetiole	*number of nodes without petiole*	number	119.74	19.26	68.00	234.00
bottomstemsize	*outer circumference of bottom stem*	m	0.10	0.01	0.07	0.13
middlestemsize	*outer circumference of middle stem*	m	0.08	0.01	0.06	0.12
neartopstemsize	*outer circumference of near top stem*	m	0.07	0.01	0.05	0.11
numtuber	*number of tuberous roots*	number	9.25	2.73	3.00	19.00
numnodes	*number of nodes*	number	178.96	23.36	125.00	308.00
stemweight	*weight of stem*	kg	0.93	0.42	0.18	2.68
yieldoftopperha	*yield of top (leaf+stem) per hectare*	tonne	22.67	8.05	8.00	62.00
yieldofstemperha	*yield of stem per hectare*	tonne	16.26	6.59	5.00	56.00
HI	*harvest index (weight of tuber/(weight of stem+leaf+tuber))*		0.72	0.05	0.55	0.85

KU 50 (N=284)

Variables	Definition	Unit	Mean	St. Dev.	Min.	Max.
tuberyield	*yield of tuberous root per hectare*	tonne	45.71	14.31	19.00	88.00
tuberweight	*weight of tuberous root per plant*	kg	2.75	1.24	0.70	5.60
stemheight	*height of stem*	m	2.44	0.33	1.45	3.16
density	*planting density*	plant number per m^2	1.91	0.73	1.00	3.08
canopysize	*average size of North–South width and East–West width of canopy*	cm	0.91	0.10	0.64	1.18
leafweight	*weight of leaves*	kg	0.44	0.18	0.09	0.89
stemleafweight	*weight of stem and leaves*	kg	1.58	0.60	0.50	4.00
numnodeswithoutpetiole	*number of nodes without petiole*	number	92.53	13.33	60.00	126.00
bottomstemsize	*outer circumference of bottom stem*	m	0.09	0.01	0.06	0.13
middlestemsize	*outer circumference of middle stem*	m	0.08	0.01	0.05	0.11
neartopstemsize	*outer circumference of near top stem*	m	0.07	0.01	0.04	0.10
numtuber	*number of tuberous roots*	number	6.42	2.03	2.00	13.00
numnodes	*number of nodes*	number	148.13	20.45	101.00	195.00
stemweight	*weight of stem*	kg	1.14	0.49	0.34	3.21
yieldoftopperha	*yield of top (leaf+stem) per hectare*	tonne	27.45	8.55	8.00	54.00
yieldofstemperha	*yield of stem per hectare*	tonne	19.55	6.69	5.00	46.00
HI	*harvest index (weight of tuber/(weight of stem+leaf+tuber))*		0.62	0.08	0.33	0.82

The results of the regression analysis are presented in Table 3. In Models 1 and 2 of R 7, the density was positively correlated with the dependent variable '*ln*tuberyield'. In Model 1 of R 7, other factors that contributed to higher yield of tuberous root were '*ln*weightstemleaf' and 'blockddummy'. Regarding 'blockdummy', block D had a lower yield than block H.

Model 1 of KU 50 showed that density was negatively correlated with the dependent variable '*ln*tuberyield', although it was not statistically significant. In Model 1 of KU 50, other factors that contributed to higher yield of tuberous root were '*ln*stemheight' and '*ln*canopysize'. Finally, regarding 'blockdummy', tuberous root yield of block B was not statistically different from that of block E.

Table 3: Results of regression analysis.

	R 7								KU 50							
	Model 1				Model 2				Model 1				Model 2			
Variable	Coeff.		Std. Error		Coeff.		Std. Error		Coeff.		Std. Error		Coeff.		Std. Error	
lndensity	0.43	***	(0.038)		0.24	***	(0.032)		0.26	***	(0.066)		-0.03		(0.050)	
lnstemleafweight	0.39	***	(0.040)						0.43	***	(0.061)					
lnstemheight					0.64	***	(0.099)						0.48	***	(0.138)	
lncanopysize	0.06		(0.112)		0.11		(0.124)		0.24		(0.186)		0.51	***	(0.194)	
blockdummy	-0.07	***	(0.024)		-0.06	**	(0.028)		0.05		(0.035)		0.05		(0.039)	
Constant	3.47	***	(0.490)		2.95	***	(0.524)		2.35	***	(0.816)		1.05		(0.836)	
Adjusted	0.434				0.340				0.191				0.087			
R-squared	0.442				0.349				0.203				0.100			

Discussion

In this study, we investigated the optimal density for R 7 and KU 50 and the contributing characteristics of cassava for obtaining higher yield of tuberous root. The effect of planting density on the weight of cassava root has not been reported from Cambodia. Our data show that the 0.50 × 0.65 m spacing produced a high yield of stem and tuberous roots for R 7 whereas the appropriate row width, 0.6 × 0.8 m, resulted in the highest yield of stem and tuberous root for KU 50. In low-fertility soils and on sloping land, a spacing of 0.8 × 0.8 m is recommended to obtain a higher yield in the east Asian areas (Ratanawaraha et al., 2000). Compared to the study by Tabngoen et al. (2004), wherein 0.8 × 0.8 m and 1.0 × 1.0 m spacing showed the highest yield of fresh root, in the present study, we found that with a denser (0.6 × 0.8 m) spacing, satisfactory KU 50 cultivation can be practiced. R 7 can be cultivated at a greater density than KU 50. Furthermore, our findings confirm that the optimal density can result in a significantly higher yield of stem and tuberous roots.

The lowest HI for KU 50 was observed for the plant density 0.6 × 0.65 m. The narrow spacing resulted in the lowest yield of tuberous roots in KU 50. KU 50 provided the highest fresh root yield for a plant-to-plant distance of 0.8 × 0.8 m and 1.0 × 1.0 m under a sandy loam soil texture at the Kao Hin Son Research Station in Thailand (Tabngoen et al., 2004). Another study at Rayong in Thailand reported that the highest fresh root yield of KU 50 was obtained with the widest plant spacing of 0.6 × 0.6 m whereas the lowest fresh root yield was observed with a small spacing of 0.3 × 0.3 m (Martwanna et al., 2005). Our data show that the effect of increasing plant density on the yields of stem and tuberous roots depends on the plant cultivars. Specifically, a narrow spacing resulted in high yields of stem and tuberous root for R 7, whereas a row width of 0.6 × 0.8 m was appropriate for the highest yields of stem and tuber in KU 50.

From the regression analyses, we interpreted the coefficient in terms of the effects of changes in density on the weight of tuberous root per hectare. The natural logarithm of a number is its logarithm to the base of the mathematical constant e, which is an irrational and transcendental number of approximately 2.72. The natural logarithm of x is generally written as $\ln x$, $\log_e x$, or sometimes, if base e is implicit, simply as $\log x$. To obtain the proportional change in y associated with a p percent increase in x, we calculated $a = \log_e\left(\frac{[100+p]}{100}\right)$ and take $e^{a\hat{\beta}}$ (Benoit, 2011). The density increased by 25%, on an average, for each experiment, and the coefficient of density was 0.43 in Model 1 and 0.24 in Model 2 of R 7; thus, we calculated $e^{\log_e 125/100*0.43} \approx 1.100$ and $e^{\log_e 125/100*0.24} \approx 1.055$, respectively. Therefore, each 25% increase in density, on an average, increased the weight of tuberous root by 10% in Model 1 and by 5.5% in Model 2. Based on this analysis, we suggest that a high planting density is positively correlated with the yield of tuberous root for R 7, that is, as the density increases, the yield of the tuberous root improves within the range of 10,000 to 30,769 plants ha^{-1}. In the case of KU 50, only Model 1 of density is significant; we calculated based on the estimation of Model 1 only. As density increased by 25%, on an average, for each experiment, and the coefficient was 0.26 in Model 1 of KU 50, we calculated $e^{\log_e\frac{125}{100}*0.26} \approx 1.060$ As a result, each 25% increase in density on an average increased the root weight by 6.0% in Model 1 for KU 50. Also, based on Model 1 of KU 50, the yield of the tuberous root improved by 6.0%; however, within the range 10,000 to 20,833 plants ha^{-1}, the yield of stem per hectare and yield of tuberous root per hectare decreased after 20,833 plants ha^{-1} as shown in Figure 2. In this study, we have determined the optimal planting density for R 7 and KU 50. The use of the optimal planting density can be beneficial in the production of uninfected healthy cassava stem on a limited area and should be profitable for all cassava producers in Cambodia.

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