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Research Article

Root Yield and Nutrient Removal of Four Cassava Cultivars Planted in Early Rainy Season of Northeastern Thailand: Crop Experienced to Drought at Mid-Growth Stage

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Abstract

The objectives of this study were to evaluate growth yield and nutrients removal of cassava cultivars planted in early rainy season under rainfed condition of Northeastern Thailand. Four cassava cultivars including Rayong-7, Rayong-11, Rayong-72 and Huaybong-80 were tested in randomized complete block design with four replications. The crops were planted in May and harvested after 345 days. Cassava plantation experienced to drought in December to March for four months. The results showed that the vigorous cultivar Rayong-7 gave highest of leaf dry weight, number of leaf retained per plant, number of new leaf produced per plant, number of storage root, storage root fresh weight per plant and storage root yield. Irrespective of nutrient removal; N, P and K removed ranges from 3.5-5.2, 0.62-0.85 and 3.5-5.3 kg t^{-1} fresh root weight, respectively depending on cassava cultivar. The cultivar Rayong-7 removed maximum quantities of N, the cultivar Rayong-11 and Huaybong-80 removed the highest quantities of P and K, respectively. Regardless of nutrient removal at different plant parts; N, P and K removed maximum quantities in leaf, stem and storage root, respectively.

Key words: Cassava root yield, drought, adaptation, nutrients removal, relative water content

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Northeastern region of Thailand has been considered among the various regions of the country to be the largest producer of cassava (*Manihot esculenta* Crant). This crop has been recognized as an important subsidiary cash crop beside sugarcane. Cassava planting usually takes place at the early of the rainy season starting from May-June and root yield could be harvested after being grown for 8-12 months. The climate of the Northeastern is tropical monsoon with a dry season from November to April and a wet season from May to October. In recent climate, temperature increased in November-January due-global warming in northeastern region (Polthanee and Promkhambut, 2014). This will in turn affect the performance of cassava crop. The worsening trend in climatic change with consequent high temperature resulted to high soil evaporation rate, thereby limiting soil moisture for plant growth. In general, cassava planted in early rainy season will be exposed to prolong drought at terminal (7-12 months) after planting growth stage. In Africa, the cassava growth cycle is typically interrupted by 3-6 months of drought, influencing various plant physiological processes resulting in depressed growth, development and economic yield (Pardales *et al*., 2001; Bakayoko *et al*., 2009). In general, cassava can withstand significant periods of drought stress. Mechanisms of drought tolerance in cassava have been identified such as avoidance, to partial stomatal closure to reduce transpiration (Connor and Palta, 1981; El-Sharkawy *et al*., 1984; Tardieu and Simonneau, 1998; Alves and Setter, 2000), development of extensive root systems and proportionally strategies reduction in leaf canopy (El-Sharkawy, 2007; Connor and Cock, 1981; Ike and Thurtell, 1981). In some study it has been reported that greater leaf retention has been correlated with drought tolerance (Lenis *et al*., 2006). Cassava cultivars differed in their vigor to water stress (El-Sharkawy and Cock, 1987; El-Sharkawy *et al*., 1992; CIAT., 1993; El-Sharkawy and Cadavid, 2002; El-Sharkawy, 2006). In general, cassava storage roots contain relatively large amounts of potassium (Amarasiri and Perera, 1975). Cassava removed N, P and K ranges 193-222, 23-27, 181-218 kg ha^{-1} in tuber yield respectively, depending on type of organic manure application (Amanullah *et al*., 2007). Lack of information available on nutrient removal at different plant parts and performance of cassava cultivars planted in early rainy season. Therefore, the objectives of this research was to evaluate growth and yield as well as nutrients removed by four cassava cultivars planted in the early rainy season of northeastern, Thailand.

MATERIALS AND METHOD

Experimental site: The field experiment was carried out at Faculty of Agriculture Farm, Khon Kaen University, Thailand in 2013-2014 (latitude 16°28'N, longitude 102°48'E, 200 ma.sl.). The planting date was May 20 and the crops were harvested at 345 Days After Planting (DAP). The soil texture of the experimental area is loamy sand with 6.4 pH, 0.017% total N, 28.11 mg kg^{-1} available P and 39.27 mg kg^{-1} exchangeable K. The field capacity and permanent wilting point of the soil were obtained as 12.68 and 2.85%, respectively.

Experimental design and plant culture: The randomized complete block design with four replications was used in this study. The treatments consisted of four cassava cultivars; Rayong-7 (RY-7), Rayong-11 (RY-11), Rayong-72 (RY-72) and Huaybong-80 (HB-80). A four-wheel tractor was used to prepare the land by plowing twice and creating ridges. The distance between rows and plant of cassava was about 1×1 m and the ridge height was about 0.4 m. The mature stems of 15 cm length were inserted vertically into the soil on the ridges. Chemical fertilizer formula 15-15-15 (N, P_2O_5, K_2O) at the rate of 938 kg ha^{-1} was applied after one month of planting. Hand weeding was done once before fertilizer application. Pesticides were not used throughout the growing period.

Crop measurements: Data on tuber yield, yield components and growth parameters were recorded at 345 DAP from harvesting area (3×6 m). The harvest index was calculated from storage roots dry matter dividing by total dry matter. Leaf samples were taken during the drought phase at 240, 280 and 320 DAP outside the harvesting area to determine relative water content. Tree leaves of the fourth fully-expanded leaf from the top of each plant within plot were sampled and twenty leaf disks (1.5×2.0 cm, wide×long) excised from the middle of the center lobe (avoiding the midrib) were weighted and placed in a petri dish of distilled water for 4 h, re-weighted to determine hydrated weight and then dried at 60° C for 48 h for dry weight determination. Relative water content was then calculated using equation (Blomstedt *et al*., 1998) as following:

$$\frac{\text{Fresh weight} - \text{Dry weight}}{\text{Hydrated weight} - \text{Dry weight}} \times 100$$

Climatic measurements: The weather data was recorded in an open field at a distance of 300 m from the experiment field.

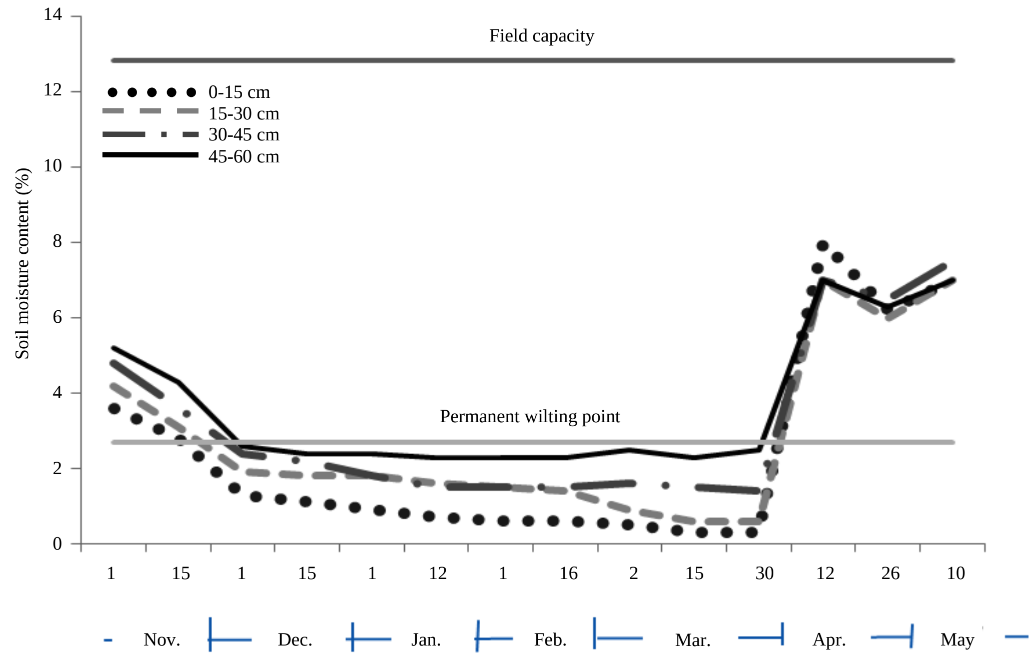

Fig. 1: Soil moisture content (% by weight) depth during dry phase of cropping season

Table 1: Weather data of experimental site during cropping season

	Temperature (°C)					
Months	Max	Min	Rainfall (mm)	ET (mm day^{-1})	RH (%)	Sunshine (h day^{-1})
Year 2013						
May	36.3	25.0	81.3	5.91	86	6.97
June	33.9	25.1	49.8	5.16	86	5.64
July	32.6	24.5	204.9	4.12	91	4.48
August	32.1	24.3	105.2	4.99	89	4.72
September	31.7	23.9	219.7	3.62	93	3.38
October	31.1	22.3	35.4	4.29	87	6.74
November	31.6	21.2	0.0	4.95	86	7.60
December	27.5	14.5	26.2	4.63	86	8.27
Year 2014						
January	29.7	13.7	0.0	4.91	84	9.04
February	33.4	19.2	0.0	5.37	81	7.78
March	36.6	23.4	2.7	6.25	82	8.02
April	35.6	24.6	164.2	5.49	87	7.55
May	35.9	24.9	75.7	5.49	87	8.04

Max: Maximum mean temperature, Min: minimum mean temperature, ET: Pan evaporation, RH: Relative humidity

The values of air temperature, relative humidity, incoming sunshine, evaporation and rainfall are shown in Table 1.

Soil moisture measurements: The soil moisture content was determined by gravimetric measurement at 0-15, 15-30, 30-45 and 45-60 cm depth at 7 day interval during dry season (Fig. 1). The average field capacity and permanent willing point were measured with pressure plate equipment for the top soil.

Nutrient removal and returning dry matter harvests and samples for plant nutrient analysis such as leaf, stem and storage root were collected at 345 DAP. Samples of stems were collected from the middle one-third of three plants and root samples were obtained from four randomly selected medium-sized storage root. Leaves were collected from entire plant samples were dried at 60°C, ground and was analyzed for total N, P and K concentration. Nitrogen concentration was measured by micro Kjeldahl method, P concentration by emission spectrophotometer and K concentration by emission flame photometer. Nitrogen, P and K uptake was calculated by multiplying the quantity of dry matter for plant parts with nutrient concentration. Regardless of nutrient returning, falling leaves were collected three times during the cropping season with sampled areas 2×6 m from each plot. The nutrient concentration and uptake were measured by following the same procedure followed for the nutrient removal.

Statistical analysis: All obtained data was statistically analyzed according to the technique of analysis of variance (ANOVA) for the randomized block design as published by Gomez and Gomez (1984), using MSTAT statistical package (MSTAT-C) with MGRAPH version 2.10, Crop and Soil Sciences Department, Michigan State University, USA). Least Significant Difference (LSD) method was used to test the differences between treatment means.

RESULTS

Shoot growth: The leaves dry weight retained on plant at harvest was significantly difference among cassava cultivars. The cultivar RY-7 produced the maximum leaves dry weight (Table 2), whereas, stem dry weight had no significant effect among cassava cultivars. Cassava cultivars had significant effect on the leaves number per plant which retained on plant toward the end of the drought period and produced new leaves in the recovery phase with the commencement of rainfall toward the end of growth cycle (Table 2). The cultivar RY-7 retained highest number of leaves on plant during drought period and produced maximum number of new leaves in recovery phase. Irrespective of leaves falling, cassava cultivars had significant effect on leaves dropped dry weight and shedding percentage. The maximum leaves dropped dry weight was obtained with the cultivar RY-7. While, the cultivar RY-11 exhibited the highest percentage of dropping leaves (Table 2). In the present study, cassava cultivars had significant effect on total leaf dry weight (leaves retained on plant including leaf falling). The cultivar RY-7 produced the maximum total leaf dry weight.

Root growth: Cassava cultivars had significant effect on storage root fresh yield, but not significant difference on the number of storage root and storage root fresh weight per plant at harvest (Table 2). The highest storage root yield was obtained with the cultivar RY-7 in the present experiment.

Relative water content and harvest index: The Relative Water Content (RWC) of leaves at 320 DAP was significantly difference among cultivars, but had no effect on RWC at 240 and 280 DAP during commencement of the drought period (Table 2). The greatest RWC value was performed in the cultivar RY-72 in this experiment. Regardless of Harvest Index (HI), cassava cultivars had no significant effect on HI (Table 2). However, the cultivar RY-72 tends to give the higher HI than those of RY-7, HB-80 and RY-11, respectively.

Table 2: Growth characteristics, harvest index and relative water content of four cassava cultivars grown in early rainy season in northeastern Thailand

	Cultivar					
Characteristics	RY-7	RY-11	RY-72	HB-80	F-test	CV (%)
Plant growth						
Total leaf dry weight (t ha^{-1})[a]	4.94^{a}	3.68^{ab}	2.83^{b}	3.69^{ab}	*	21.2
Leaf dropped dry weight (t ha^{-1})[b]	2.59^{a}	2.30^{ab}	1.55^{b}	1.94^{ab}	*	22.2
Leaf dropped percentage[c]	52.30^{b}	62.60^{a}	54.90^{b}	52.80^{b}	*	5.5
Leaf retained dry weight(t ha^{-1})[d]	2.34^{a}	1.38^{b}	1.28^{b}	1.75^{ab}	*	22.2
Stem dry weight (t ha^{-1})[e]	3.65	4.86	2.69	4.29	NS	33.3
Number of leaf retained per plant[f]	141.70^{a}	86.70^{bc}	80.70^{c}	129.00^{ab}	*	19.7
Number of new leaf per plant[g]	186.70^{a}	110.00^{c}	123.30^{bc}	152.70^{ab}	*	13.8
Number of storage root per plant	12.90	11.20	11.30	12.50	NS	14.3
Storage root fresh weight (kg plant^{-1})	1.62	1.09	1.55	1.31	NS	20.3
Storage root fresh yield (t ha^{-1})	33.70^{a}	20.30^{b}	29.40^{ab}	27.60^{ab}	*	20.1
Harvest index	0.65	0.57	0.71	0.62	NS	11.5
Relative water content (%)						
240 days after planting	84.20	89.20	90.30	87.90	NS	4.6
280 days after planting	89.70	91.40	89.10	88.50	NS	3.0
320 days after planting	78.60^{c}	82.50^{ab}	83.30^{a}	79.70^{bc}	*	1.9

*Means followed by different letter within rows are significantly different at $p \leq 0.05$ by LSD, NS: Not significantly, [a]Leaf retained on plant at harvest including leaf dropped to the soil surface during cropping season, [b]Total leaf dropped during cropping season, [c]Percentage of total leaf dry weight (leaf dropped dry weight/total leaf dry weight×100), [d]Leaf retained on plant at harvest, [e]Stem dry weight at harvest, [f]No. of leaf retained towards the end of the drought period, [g]No. of new leaf produced in the recovery phase with the commencement of rainfall toward the end of growth cycle

Nutrient uptake: The leaf, stem and storage root were significantly difference on nitrogen uptake among cassava cultivars (Table 3). The cultivar RY-7 produced the highest N uptake quantities for all plant parts. In the present experiment, leaf seems to remove more N than those of storage root and stem. Regardless of P, cassava cultivars had significant effect on P uptake of leaf and storage root, but no significant effect on stem uptake (Table 3). The maximum P uptake was obtained with cultivar RY-7 in this experiment. Among plant parts, the stem removed more P than those of storage root and leaf. Irrespective of K, cassava cultivars had significant effect on K uptake of leaf, stem and storage root (Table 3). Among plant parts, storage roots removed more K than those of stem and leaf.

Nutrient removal and supplying: Cassava cultivars had significant effect on total N removal, N returning and net N removal quantities, but not significant difference on N removal per tonne fresh storage root weight (Table 4). The cultivar RY-7 removed the greatest quantities of N, although, it returned the maximum quantities of N in this experiment. The cultivar RY-7 also exhibited greatest net N (removal-supplying) quantities. However, cassava cultivars had no significant effect on N removed per ton fresh storage root weight in this study (Table 4).

Irrespective of P, cassava cultivars had significant effect on P returning quantities, but not significant difference on total P removal, net P (removal-supplying) quantities and P removal per tonne fresh storage root weight (Table 4). The cultivar RY-7 returned highest P quantities in this experiment. Regardless of K, cassava cultivars were significantly difference on total K removal, K returning, net K removal quantities and K removal per tonne fresh storage root weight (Table 4). The cultivar HB-80 removed maximum of total K, net K (removal-returning) quantities and per tonne of fresh storage root weight at harvest. Whereas, cultivar RY-7 returned the highest K by dropping leaves into the soil.

Table 3: Nitrogen, phosphorus and potassium uptake (t ha^{-1}) by leaf, stem and storage root of four cassava cultivars at harvest

	Cultivars					
Nutrient/plant part	Ry-7	RY-11	RY-72	HB-80	F-Test	CV (%)
Nitrogen						
Leaf	73.9^{a}	40.1^{c}	45.6^{bc}	65.4^{ab}	*	19.5
Stem	36.9^{a}	34.1^{a}	14.9^{b}	28.3^{ab}	*	39.3
Storage root	62.8^{a}	27.8^{b}	40.9^{b}	42.3^{b}	*	18.5
Phosphorus						
Leaf	6.5^{a}	4.2^{b}	3.4^{b}	4.8^{ab}	*	18.9
Stem	8.9	7.5	8.5	9.3	NS	35.5
Storage root	8.5^{a}	5.2^{bc}	7.4^{ab}	3.5^{c}	**	18.9
Potassium						
Leaf	30.2^{a}	13.8^{b}	16.0^{b}	27.1^{ab}	**	20.1
Stem	29.8^{a}	29.8^{a}	20.2^{b}	31.3^{a}	*	37.1
Storage root	55.9^{b}	58.2^{b}	68.5^{ab}	89.5^{a}	*	18.1

NS: Not significant, *,**Significant at $p\leq 0.05$, 0.01, respectively. Means in the same row with different letters are significantly different at $p\leq 0.05$ and $p\leq 0.01$ by LSD

Table 4: Nitrogen, phosphorus and potassium removed in the harvest products and returned by dropping leaves into the soil of four cassava cultivars

	Cultivars					
Nutrient	RY-7	RY-11	RY-72	HB-80	F-Test	CV (%)
Nitrogen						
N-removed (kg ha^{-1})[a]	173.70^{a}	101.90^{b}	101.50^{b}	136.70^{ab}	*	19.8
N-returned (kg ha^{-1})[b]	21.70^{a}	15.90^{ab}	12.90^{b}	18.40^{ab}	*	21.9
Net N-removed (kg ha^{-1})[c]	152.00^{a}	86.00^{b}	88.60^{b}	118.30^{ab}	*	21.0
N-remove per ton fresh root	5.21	5.17	3.46	4.89	NS	22.1
Phosphorus						
P-removed (kg ha^{-1})	23.90	16.90	19.30	17.60	NS	2.4
P-returned (kg ha^{-1})	4.20^{a}	2.40^{b}	2.40^{b}	4.10^{ab}	*	23.1
Net P-removed (kg ha^{-1})	19.80	14.20	16.90	13.50	NS	23.9
P-remove per ton fresh root	0.72	0.85	0.65	0.62	NS	24.8
Potassium						
K-removed (kg ha^{-1})	115.90^{b}	101.70^{b}	104.80^{ab}	147.90^{a}	*	19.1
K-returned (kg ha^{-1})	16.90^{a}	16.70^{ab}	6.80^{b}	7.90^{b}	*	25.7
Net K-removed (kg ha^{-1})	99.00^{ab}	85.00^{b}	98.00^{ab}	140.00^{a}	*	20.6
K-remove per ton fresh root	3.50^{b}	5.10^{b}	3.60^{b}	5.30^{a}	*	15.9

NS: Not significant, *Significant at $p\leq 0.05$. Means in same row with different letters are significantly different at $p\leq 0.05$ LSD, [a]N-removed in storage root, stem and leaf (uptake) at harvest, [b]N-returned by dropping leaf (uptake) during cropping season, [c]Net N-removed which calculated by N-removed subtract with N-returned

DISCUSSION

Growth and yield: Cassava planted in early rainy season and harvest 345 days in the present experiment. The crop experienced to water stress about 120 days at 195 DAPS. Cassava adapted to long drought period by dropping leaves in order to reduce water use. The leaves shedding were about 52-63% of total leaf biomass dry weight, depending on cassava cultivar. In the present experiment, cultivar RY-7 produced storage root yield higher than those of cultivars RY-72, HB-80 and RY-11. The lowest percentage of dropping leaf was observed with cultivar RY-7. Moreover, the cultivar RY-7 retained higher number of leaf per plant towards the end of the drought period in comparison to other cultivars. It can also produce a higher number of new leaves in the recovery phase with the commencement of rainfall toward the end of growth cycle than those of the rest cultivars.

In the present experiment, leaf Relative Water Content (RWC) at 240 and 280 days after the commencement of the drought period was not found significantly different among cassava cultivars. It was observed that the RWC values range 88.5-91.4% at 280 DAP during the severe drought period. This indicates that water content in leaves that were retained exhibited little change due to water stress. Cassava can decrease water loss through closing its stomata (Setter and Fregene, 2007) and decreasing leaf area through leaf shedding (Alves and Setter, 2000; Burns *et al*., 2010). In this study, cassava would be able to quickly resume growth when conditions become more favorable. Such rapid recovery in leaf growth has been reported by many researchers (Connor *et al*., 1981; Baker *et al*., 1989; El-Sharkawy, 1993). In this experiment, leaf RWC was found significantly different among cassava cultivars at the beginning of the rainy period (after the drought period) 320 DAP. The cultivar RY-72 produced higher root yield than cultivar HB-80 and RY-11. It performed greater leaf RWC than those of both cultivars. However, cultivar RY-7 which produced higher root yield than that of cultivar RY-72, exhibited lower leaf RWC than that of cultivar RY-72. This indicates that cassava adaptation mechanism to drought may depend the specific cassava cultivar such as root system development (Subere *et al*., 2009) beside leaf dropping and stomata closer.

The cultivar RY-7 gave the maximum storage root yield. This was due to higher number of leaf retained on plant towards the end of the drought period, number of new leaf produced in the recovery phase, resulting to higher number of storage root per plant and storage root fresh weight per plant than those of the other cultivars. However, the highest HI was obtaining with cultivar RY-72, indicating that it was highly efficient in translocation of assimilates for storage in tuber roots. Similar result was observed by Polthanee *et al*. (2014).

Nutrient removal: At harvest, cassava had removed the greatest quantities of N in the leaf, P in the stem and K in the storage root. Similar results occurred for N, P and K removal quantities was report by Mason *et al*. (1986). In the present study, cassava removed from the greatest quantities in root was observed by 3.5-5.2 kg N, 0.62-0.72 kg P and 3.5-5.3 kg K t^{-1} fresh roots depending on the cassava cultivars. Potassium removed from 3.5 kg t^{-1} fresh roots was reported by Howeler (1981).

CONCLUSION

Cassava planted in May in early rainy season, the crop experienced to drought in December-March for four months. The storage root yield ranges from 20-34 t ha^{-1}, depending on the ability of adapting cassava cultivar to drought. This indicates that cassava gave a satisfactory yield; even crop is grown under unfavorable condition. The vigorous cultivar RY-7 could retain higher number of leaves per plant during the drought period as well as produced higher number of new leaves per plant during the recovery phase than those of other cultivars. Irrespective of nutrient removal, N removed per ton fresh root weight at harvest ranges from 3.5-5.2 and 0.62-0.85 kg for P and 3.5-5.3 kg for K depending on cassava cultivar. Regardless of nutrient removal in plant part, N removed maximum quantities in leaf, P in the stem and K in the storage root in the present experiment.

REFERENCES

Alves, A.A.C. and T.L. Setter, 2000. Response of cassava to water deficit: Leaf area growth and abscisic acid. Crop Sci., 40: 131-137.

Amanullah, M.M., K. Vaiyapuri, K. Sathyamoorthi, S. Pazhanivelan and A. Alagesan, 2007. Nutrient uptake, tuber yield of cassava (*Manihot esculenta* Crantz.) and soil fertility as influenced by organic manures. J. Agron., 6: 183-187.

Amarasiri, S.L. and W.R. Perera, 1975. Nutrient removal by crops growing in the dry zone of Sri Lanka. Trop. Agric., 131: 61-70.

Bakayoko, S., A. Tschannen, C. Nindjin, D. Dao, O. Girardin and A. Assa, 2009. Impact of water stress on fresh tuber yield and dry matter content of cassava (*Manihot esculenta* Crantz) in Cote d'Ivoire. Afr. J. Agric. Res., 4: 21-27.

Baker, G.R., S. Fukai and G.L. Wilson, 1989. The response of cassava to water deficits at various stages of growth in the subtropics. Aust. J. Agric. Res., 40: 517-528.

Blomstedt, C.K., R.D. Gianello, D.F. Gaff, J.D. Hamill and A.D. Neale, 1998. Differential gene expression in desiccation-tolerant and desiccation-sensitive tissue of the resurrection grass, *Sporobolus stapfianus*. Aust. J. Plant Physiol., 25: 937-946.

Burns, A., R. Gleadow, J. Cliff, A. Zacarias and T. Cavagnaro, 2010. Cassava: The drought, war and famine crop in a changing world. Sustainability, 2: 3572-3607.

CIAT., 1993. Cassava program annual report for 1993. Centro International de Agricultural Tropical, Cali, Colombia.

Connor, D.J. and J. Palta, 1981. Response of cassava to water shortage III. Stomatal control of plant water status. Field Crops Res., 4: 297-311.

Connor, D.J. and J.H. Cock, 1981. Response of cassava to water shortage II. Canopy dynamics. Field Crops Res., 4: 285-296.

Connor, D.J., J.H. Cock and G.E. Parra, 1981. Response of cassava to water shortage I. Growth and yield. Field Crops Res., 4: 181-200.

El-Sharkawy, M.A. and J.H. Cock, 1987. Response of cassava to water stress. Plant Soil, 100: 345-360.

El-Sharkawy, M.A. and L.F. Cadavid, 2002. Response of cassava to prolonged water stress imposed at different stages of growth. Exp. Agric., 38: 333-350.

El-Sharkawy, M.A., 1993. Drought-tolerant cassava for Africa, Asia and Latin America: Breeding projects work to stabilize productivity without increasing pressures on limited natural resources. BioScience, 43: 441-451.

El-Sharkawy, M.A., 2006. International research on cassava photosynthesis, productivity, eco-physiology and responses to environmental stresses in the tropics. Photosynthetica, 44: 481-512.

El-Sharkawy, M.A., 2007. Physiological characteristics of cassava tolerance to prolonged drought in the tropics: Implications for breeding cultivars adapted to seasonally dry and semiarid environments. Braz. J. Plant Physiol., 19: 257-286.

El-Sharkawy, M.A., A.D.P. Hernandez and C. Hershey, 1992. Yield stability of cassava during prolonged mid-season water stress. Exp. Agric., 28: 165-174.

El-Sharkawy, M.A., J.H. Cock, K. Held and A. Alexander, 1984. Water efficiency of cassava. II. Differing sensitivity of stomata to air humidity in cassava and other warm-climate species. Crop Sci., 24: 503-507.

Gomez, K.A. and A.A. Gomez, 1984. Statistical Procedures for Agricultural Research. 2nd Edn., John Wiley Sons, New York, Pages: 381.

Howeler, R.H., 1981. Mineral nutrition and fertilization of cassava (*Manihot esculenta* Crantz). CIAT Series 09 EC-4, Centro Internacional de Agricultura Tropical, Cali, Colombia, pp: 52.

Ike, I.F. and G.W. Thurtell, 1981. Response of indoor-grown cassava to water deficits and recovery of leaf water potential and stomatal activity after water stress. J. Exp. Bot., 32: 1029-1034.

Lenis, J.I., F. Calle, G. Jaramillo, J.C. Perez, H. Ceballos and J.H. Cock, 2006. Leaf retention and cassava productivity. Field Crop Res., 95: 126-134.

Mason, S.C., D.E. Leihner and J.J. Vorst, 1986. Cassava-cowpea and cassava-peanut intercropping. III. Nutrient concentrations and removal. Agron. J., 78: 441-444.

Pardales, J.R. Jr., A. Yamauchi, D.V. Jr. Belmonte and C.B. Esquibel, 2001. Dynamics of root development in root crops in relation to the prevailing moisture stress in the soil. Proceedings of the 6th Symposium of the International Society of Root Research, November 2001, Nagoya, Japan, pp: 72-73.

Polthanee, A. and A. Promkhambut, 2014. Impact of climate change on rice-based cropping systems and farmers' adaptation strategies in Northeast Thailand. Asian J. Crop Sci., 6: 262-272.

Polthanee, A., C. Janthajam and A. Promkhambut, 2014. Growth, yield and starch content of cassava following rainfed lowland rice in Northeast Thailand. Int. J. Agric. Res., 9: 319-324.

Setter, T.L. and M.A. Fregene, 2007. Recent Advances in Molecular Breeding of Cassava for Improved Drought Stress Tolerance. In: Advances in Molecular Breeding Toward Drought and Salt Tolerant Crops, Jenks, M.A., P.M. Hasegawa and S.M. Jain (Eds.). Chapter 28, Springer, Netherlands, ISBN-13: 978-1-4020-5578-2, pp: 701-711.

Subere, J.O.Q., D. Bolatete, R. Bergantin, A. Pardales and J.J. Belmonte *et al*., 2009. Genotypic variation in responses of cassava (*Manihot esculenta* Crantz) To drought and rewatering: Root system development. Plant Prod. Sci., 12: 462-474.

Tardieu, F. and T. Simonneau, 1998. Variability among species of stomatal control under fluctuating soil water status and evaporative demand: Modelling isohydric and anisohydric behaviours. J. Exp. Bot., 49: 419-432.