Recibido: septiembre, 2023 Aprobado: octubre, 2023 Publicado: diciembre, 2023

17

EARLY ADVENTITIOUS ROOTING OF CUTTINGS AND VARIABILITY OF THE HARVEST INDEX OF THE VARIETY MM105 OF MANIHOT ESCULENTA CRANTZ

ENRAIZAMIENTO ADVENTICIO TEMPRANO DE ESQUEJES Y VARIABILIDAD DEL ÍNDICE DE COSECHA DE LA VARIEDAD MM105 DE MANIHOT ESCULENTA CRANTZ

Chrissy Garel Makouanzi Ekomono
E-mail: garelmak@yahoo.fr
ORCID: https://orcid.org/0000-0003-0920-5216
Marien Ngouabi University. National Forestry Research Institute

Cita sugerida (APA, séptima edición)

Makouanzi Ekomono, C. G. (2023). Early adventitious rooting of cuttings and variability of the harvest index of the variety MM105 of Manihot esculenta Crantz*. Revista Científica Agroecosistemas,* 11(3), 135-141. https://aes.ucf.edu.cu/index.php/aes

ABSTRACT

Cassava (*Manihot esculenta*) is an important crop for subsistence farmers in Sub-Saharan Africa. Cassava production is subject to a number of constraints, such as diseases and cropping systems, leading to low plant productivity. In order to improve the yield of the MM105 variety by exploring practices that encourage the root system to induce good cassava production, a fully randomisation design with two replications was installed in the nursery. Three planting positions (vertical, slant, horizontal) and two cut model (flat slice, one-sided slice) was investigated. Resultts reported that the highest number of storage roots, the highest above-ground fresh biomass and the highest harvest index was recorded with the vertical planting position. No cut models effect was found on the rooting of cuttings and harvest index. The one-sided slice induced greater variability in the harvest index than flat slice. The harvest index was negatively correlated with the number of nodes buried in the soil. However, there was a strong correlation between the number of storage roots, the fresh and dry storage roots biomass and the harvest index. The harvest index can be used as selection criterion for individuals within the MM105 variety to increase its tuber production.

Keywords:

Cassava, planting position, cut models, harvest index, adventitious rooting.

RESUMEN

La yuca (*Manihot esculenta*) es un cultivo importante para los agricultores de subsistencia del África subsahariana. La producción de yuca está sujeta a una serie de limitaciones, como las enfermedades y los sistemas de cultivo, que dan lugar a una baja productividad de la planta. Con el fin de mejorar el rendimiento de la variedad MM105 explorando prácticas que favorezcan el sistema radicular para inducir una buena producción de yuca, se instaló en el vivero un diseño de aleatorización completa con dos repeticiones. Se investigaron tres posiciones de plantación (vertical, inclinada, horizontal) y dos modelos de corte (rebanada plana, rebanada unilateral). Los resultados mostraron que el mayor número de raíces de almacenamiento, la mayor biomasa fresca por encima del suelo y el mayor índice de cosecha se registraron con la posición de plantación vertical. No se encontró ningún efecto de los modelos de corte sobre el enraizamiento de las estacas y el índice de cosecha. El corte unilateral indujo una mayor variabilidad en el índice de cosecha que el corte plano. El índice de cosecha se correlacionó negativamente con el número de nudos enterrados en el suelo. Sin embargo, hubo una fuerte correlación entre el número de raíces de almacenamiento, la biomasa fresca y seca de raíces de almacenamiento y el índice de cosecha. El índice de cosecha puede utilizarse como criterio de selección de individuos dentro de la variedad MM105 para aumentar su producción de tubérculos.

Palabras clave:

Yuca, posición de siembra, modelos de corte, índice de cosecha, enraizamiento adventicio.

INTRODUCTION

Cassava (Manihot esculenta) is a potential source of local food that is widely distributed (Adiele et al., 2020). Its wide agroecological adaptability makes cassava the third most important source of energy in the tropics (Neves et al., 2018). So, its provides household food security and income for millions of smallholder farmers in sub-Saharan Africa (Okogbenin et al., 2013). Sub-Saharan Africa is predicted to see the largest population growth of all world regions, 123% by 2050 (United Nations, 2015). So, Cassava is an important crop for subsistence farmers in this region (de Souza et al., 2017).

In the Congo, cassava is the staple food of the population. Its cultivation is the main activity for almost 98% of farmers (FAO, 2006). The rooting of cassava cuttings is important : on the one hand, the roots produced will perform the classic functions of a root system (anchoring the plant in the soil, absorbing water and feeding on minerals) ; on the other hand, some of them will accumulate carbohydrates produced by the aerial parts, in the form of starchy tubers, from the first few weeks and throughout the crop cycle (Indira and Sinha, 1970). The total number of roots is generally fixed 4 to 6 weeks after planting (Carluccio et al., 2021). The initial stage in the overall pattern of cassava yield development is the rooting established by the cutting in the first few weeks (Raffaillac, 1992).

However, cassava production is subject to a number of constraints, such as diseases and cropping systems, leading to low plant productivity (Treche and Massamba, 1990). Plant breeding is one way of improving yields. This involves having a diverse range of varieties adapted to a wide range of biotic and soil and climate conditions. Variability within a variety is also sought for genetic improvement purposes (Makouanzi et al., 2022). The Harvest index (HI), which measures the success of the distribution of assimilated photosynthates, is a criterion that contributes significantly to improving crop productivity (Gifford et al., 1984 ; Hay, 1995). Both environmental and genetic variables affect this agricultural harvest indicator (Asefa, 2019).

The quality of cassava stalks depends on stem age, thickness, number of nodes per stalk and size. Control of these factors is essential for sprouting of vigorous plants capable of producing a good number of roots. The other most important practice in cassava production is the orientation of cuttings at planting which depends on plant variety and environmental conditions, both requiring the undertaking of experiments in different ecological zones to determine the best position (Toro and Atlee, 1984 ; Legesse et al., 2011). There are three different orientations in which cassava cuttings are usually planted in the field. It may be planted upright in vertical position, upright at an angle (slant) or horizontally beneath the soil.

The orientation of the cuttings influences several growth characteristics of the plant. Moreover, cuttings from different sections of the stem have a varying influence on subsequent growth and yield of cassava (Chávez et al., 2005). It was suggested that long, moderately thick stalks, taken from the basal part of the plant result in higher root yield (Jennings & Iglesias, 2002). The results of several studies reporting that, in addition to nutrient status, different cutting surface areas cause varying number of callus formation which has implications for the growth of upper plants (Fermont et al., 2010 ; Okpara et al., 2010 ; Edet et al., 2013). In the case of cassava, the results are strongly related to tuber diameter, size and weight (Fermont et al., 2010 ; Agahiu et al., 2011).

The aim of this study is to improve the yield of the MM105 variety of Manihot esculenta by exploring practices that encourage the root system to set up in such a way as to induce good cassava production. The questions to be answered by this study are as follows. Does the cut methods at the base of the cutting influence the installation of the root system, leading to a better harvest index for the MM105 variety ? What is the planting method that induces rooting favourable to a good tuber yield from the MM105 variety ? What is the extent of phenotypic variability in harvest index as a function of cutting type and planting position ? What are the relationships between the morphological characteristics of cuttings, plant biomass, rooting characteristics of cassava cuttings and harvest index ?

METHODOLOGY

Study location and plant material

The study took place at the nursery of the Institut National de Recherche Forestière in Brazzaville (15°14' longitude East and 4°16' latitude South). The climate in Brazzaville is an equatorial climate of the low Congolese type that prevails in south-western Congo (Samba-Kimbata, 1978). The rains begin very lightly in September, become established in October and end in May. The MM105 variety is the plant material in this study, with cuttings taken at Odziba, 100km from Brazzaville. Ninety cuttings taken from an eight-month-old mature field were used.

Experiment design and traits measured

All cuttings were sectioned at the base in two ways: plat slice (figure 1a) and one-sided slice (figure 1b). The length of each cutting was 20 cm. 30 of the 90 cuttings were used to measure dry weight after being heated at 650°C for 72 hours. On the remaining 60 cuttings, the fresh weight (FWC) and mean diameter (MDC) (mean of 3 measurements taken at the extremities of the cutting and at its middle) of the individual cuttings were measured before they were installed in the trial. The dry weight of the 60 cuttings was estimated using the following simple linear regression equation : $DWC = (0{,}4609 \times FWC) - 0{,}4191$.

Other features of the cuttings was detrmined : the number of nodes in the cutting (NNC) and the number of nodes in cutting buried in the soil (NNCBS).

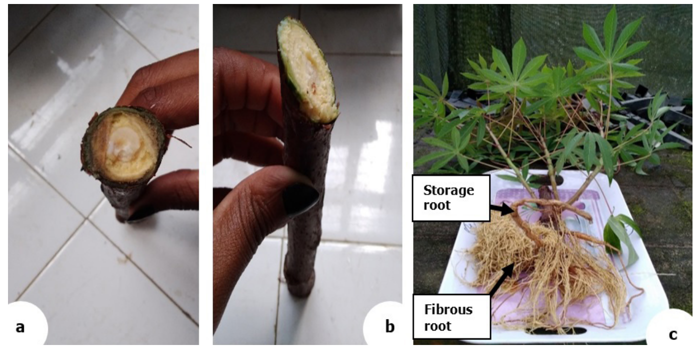
A fully randomisation design with two replications was installed in the nursery. Each block consisted of thirty culture pots, with one cutting per pot, and each treatment within a block consisted of 5 cultures pots. The cuttings were planted in three different positions : vertical and oblique positions where the cuttings were buried to a depth of 10cm, i.e. 1/2 the length of the cutting, and the horizontal position where the cuttings were buried completely to a depth of 5cm in the substrate. The substrate used is potting soil. A total of six treatments were considered (3 planting positions × 2 cut models).

A quantity of 1.5L of water was added per cutting and later per plant for irrigation. The clearance period (CP) was noted for each cutting. Eight weeks after planting, the number of nodal roots (NNR) and basal roots (NBR) was determined, including storage roots (NSR) and fibrous roots (NFR) (figure 1c). They were then weighed in order to measure fresh fibrous roots mass (FFRM) and fresh storage roots mass (FSRM). The number of stems (NS) was counted and weighed together with the leaves (AFB : above-ground fresh biomass). The length of the roots (storage LSR and fibrous LFR) and their diameter (DSR : diameter of storage roots, DFR : diameter of fibrous roots) were also measured using a graduated ruler and callipers respectively. After weighing the various parts of the plant in their fresh state, they were oven-dried at 70°C for 48 hours. After drying, each part was weighed to determine its dry mass (DMFR : dry mass of fibrous roots, DMSR : dry mass of storage roots, ADB : above-ground dry biomass).

The harvest index (HI) was calculated using the following formula :

(1) $$HI = \frac{FSRM}{AFB+FFRM+FSRM}$$

Figure 1. Flat slice (a) and one-sided slice (b) of a cutting, View of a storage and fibrous roots (c)



Statistical analysis

The data were analyzed using R software version 4.2.1. The Scheirer-Raye-Hare and Dunn tests were performed respectively to assess the influence of planting position, cut methods and their interaction on the response traits studied, and to structure the various means. The following analysis model was used:

(2) $$Y_{ijk} = \mu + Ci + Pj + Ci \times Pj + \varepsilon ijk$$

Whre Y_{ijk} is the response trait, μ is the overall mean of the observations for each trait, C_i is the cut methods, P_j is the planting position effect, $C_i \times P_j$ is the interaction effect between cut methods and planting, ε_{ij} is the residual effect.

The Pearson correlations between traits were determined according to the following formula:

(3) $$\frac{cov\,(x,y)}{\sigma_x \times \sigma_y} = \frac{\sum(x_i - \bar{x}) \times (y_i - \bar{y})}{\sigma_x \times \sigma_y}$$

Table 1. Statistics of morphological features of cuttings,of characteristicsof roorting cuttings and of plant biomass characteristics

Parameters	Mean	SD	Min value	Max value	CV (%)	P-value C effect	P-value P effect	P-value C×P effect
Morphological features of cuttings								
MDC (mm)	16.93	2.78	11.70	23.65	16.41			
FWC (g)	42.17	17.51	16.40	85.60	41.52			
DWC (g)	19.02	8.07	7.14	39.03	42.43			
NNC	8.27	2.10	2.00	12.00	25.38			
NNCBS	5.53	2.66	1.00	12.00	48.16			
CP	5.80	3.02	2.00	16.00	52.08	0.46188	0.00000	0.25887
Characteristics of rooting cuttings								
NNR	4.85	2.83	0.00	11.00	58.33	0.16446	0.01624	0.50004
NBR	0.58	0.92	0.00	3.00	159.74	0.48554	0.38241	0.46198
NSR	2.47	2.25	0.00	9.00	91.25	0.41680	0.00430	0.98006
NFR	2.95	2.63	0.00	10.00	89.02	0.23735	0.21125	0.53162
LSR (cm)	14.33	4.51	6.00	24.67	31.50	0.24954	0.08604	0.54767
LFR (cm)	11.79	3.99	6.00	21.60	33.87	0.47469	0.29614	0.42957
DSR (mm)	3.47	1.10	1.67	5.38	31.69	0.66759	0.12815	0.75493

DFR (mm)	1.68	0.34	0.43	2.56	20.56	0.14057	0.00354	0.57084
Plant biomass characteristics								
NS	3.54	2.18	0.00	9.00	61.65	0.21521	0.00536	0.57101
AFB (g)	73.43	25.05	0.70	135.70	34.11	0.00569	0.04345	0.98599
FSRM (g)	8.05	6.71	0.80	27.40	83.32	0.02269	0.01264	0.76724
FFRM (g)	53.47	20.15	0.10	97.10	37.69	0.2295	0.2875	0.9188
ADB (g)	46.49	24.66	0.20	123.10	53.04	0.01818	0.08809	0.03693
DMSR (g)	3.04	3.75	0.10	15.80	123.48	0.07799	0.01459	0.90723
DMFR (g)	35.46	19.76	0.10	74.20	55.71	0.13809	0.99086	0.75422
HI	0.05	0.03	0.01	0.14	60.00	0.08064	0.01931	0.88967

Source: Prepared by the author

Where Cov(x,y) is the covariance between two traits to be correlated, x_i and y_i are the individual measures of the two traits to be correlated, and are the means of the two traits to be correlated, denote the standard deviations of the two variables to be correlated.

RESULTS AND DISCUSSION

Description of traits

The recovery rate recorded during this study was 92%. The mean diameter of the cuttings was 17mm and their mean fresh weight was 42g. The mean time to bud break was 6 days. The cuttings had an average of 8 nodes and an average of 5.53 nodes buried in the soil. The mean number of storage roots was 2.47, with an mean length of 14.33cm and an mean diameter of 3.47. The number of nodal roots was much higher than the number of basal roots (5 vs. 0.58). With regard to biomass characteristics, the mean number of stems per plant was recorded as 3.54. The mean aerial fresh mass was 73.43g, that of fibrous roots was 53.47g and that of storage roots was 8.05g. The morphological characteristics of the cuttings, rooting and biomass are described in table 1.

MDC : mean diameter of cuttings, FWC : fresh weight of cuttings, DWC : dry weight of cuttings, NNC : number of nodes in the cutting, NNCBS : number of nodes in cutting buried in the soil, CP : Clearance period, NNR : number of nodal roots, NBR : number of basal roots, NSR : number of storage roots, NFR : number of fibrous roots, LSR : lenght of storage roots, LFR : lenght of fibrous roots, DSR : diameter of storage roots, DFR : diameter of fibrous roots, NS : number of stems, AFB : above-ground fresh biomass, FSRM : fresh storage root massk, FFRM : fresh fibrous root mass, ADB : above-ground dry biomass, DMSR : dry mass of storage roots, DMFR : dry mass of fibrous roots, HI : harvest index.

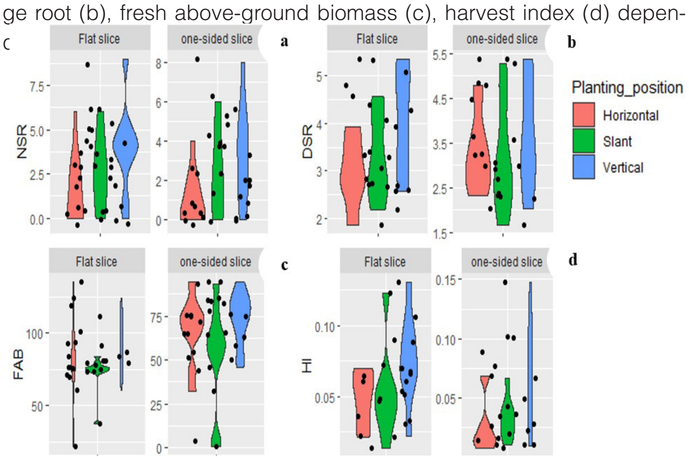
Effect of cut models and planting position on the rooting establishment and the harvest index

The vertically planted cuttings budded early. However, cuttings planted horizontally had a delayed budburst, which can be explained by the fact that all the nodes of the cutting were buried in the soil.

For both cut models, the highest number of storage roots was obtained with the vertical planting position followed by the slant position (figure 2a). The highest number of fibrous roots for the flat slice was obtained with horizontal planting position, whereas for the one-sided slice, the highest number of fibrous roots was obtained with vertical planting. The flat slice induced the emission of nodal roots in large quantities when the cuttings were planted in a vertical position. When the cuttings were planted slanty, basal roots were produced in large quantitites (table 1). The highest mean storage root length was recorded with the vertical position. The highest mean diameter of storage roots was recorded with the vertical position followed by the slant position (figure 2b). The highest number of stems, for both cutting methods, was observed in the horizontal position. This result is close to those of Legese et al. (2011) who had the highest number of stems for horizontal planting followed by slant planting and the lowest for vertical planting.

The highest above-ground fresh mass for both cutting methods was obtained with vertical planting followed by horizontal planting (figure 2c). The highest above-ground fresh mass and storage roots were obtained with the flat slice. A number of calluses form on the surface of the cuttings, contributing to the formation of numerous roots capable of absorbing the water and nutrients available in the soil, which are then distributed to all parts of the plant, promoting good development of the aerial part of the plant (Hartati et al., 2021). These formed roots also play a role in the storage of carbohydrates produced during photosynthesis (Wild and Jones, 1988), resulting in a large fresh biomass of storage roots. This explains the high above-ground and storage root fresh biomass observed with flat slice.

Figure 2. Violin plot of the number of storage root (a), diameter of storage root (b), fresh above-ground biomass (c), harvest index (d) depen-
c



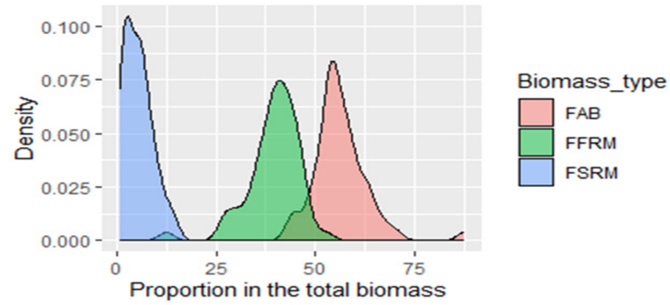
The results of the Scheirer-Raye-Hare test (Table 1) show no significant difference between the cut methods on the rooting of the cuttings. However, this factor had a significant influence on the plants biomass, particularly on the above-ground fresh biomass (AFB) and the fresh mass of the storage roots (FSRM). With regard to planting position, significant differences were noted in the rooting of cuttings and plant biomass, particularly for CP, NSR, NS, AFB and FSRM (table 1).

The method of cut did not influence the harvest index (p-value=0.08), but it was influenced by the planting method (p-value=0.01). The highest mean harvest index was obtained with the vertical position (0.07). The lowest was recorded with the horizontal position (0.03), followed by the slant position (0.04) (figure 2d). This means that vertical planting induce the yield of storage roots more than other positions (horizontal and slant), and therefore a better distribution of assimilated photosynthates. Similar results have been reported by the FAO (2014). They are also close to Legese et al. (2011) who recorded a higher harvest index for slant planting, followed by vertical planting and the lowest in horizontal planting. However the harvest index values obtained in this study are low compared to the mean value of 0.62 obtained by Setiawan et al., (2022) on three elite clones.

Phenotypic variability of harvest index

Storage roots account for 5% of the total fresh biomass, the largest proportion of which is represented by the aerial compartment (56%). Fibrous roots represent 39% of the total fresh biomass (figure 3). The low proportion of storage root biomass compared with the other two compartments is explained by the juvenile age of the plants. It is expected to increase with age, as reported by de Souza et al., (2017).

Figure 3. Proportion of different compartment in the total biomass



The one-sided slice induced greater variability in the harvest index (83.25%) than flat slice (51.17%). Environmental factors such as soil type are thought to induce greater variability for the one-sided slice (Asefa, 2019). Horizontal planting (65.28%) and slant planting (64.45%) induced greater variability in the harvest index than vertical planting (54.08%). The experiment did not show any significant difference between the three planting positions.

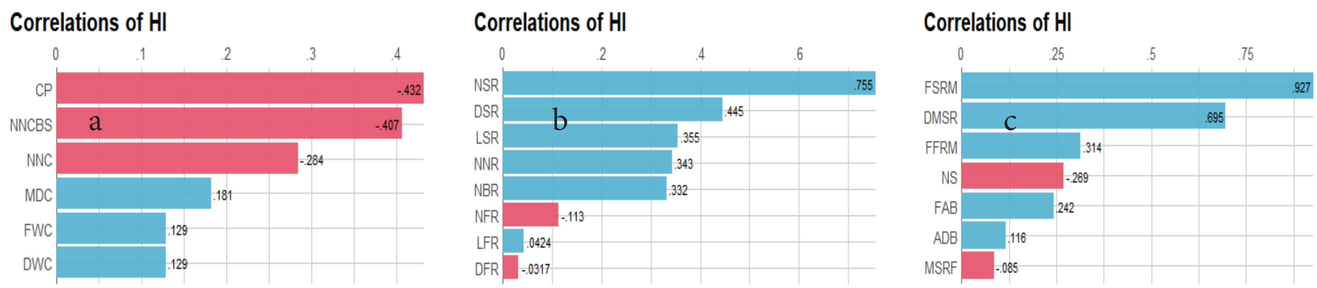
Clonal propagation does not generate variation, with the exception of somaclonal mutations (McKey et al., 2012). Moreover, at each harvest, by chance or selection, individuals will express different performances like the harvest index. Improvement of the harvest index, or the proportion of total biomass partitioned into the harvested component, was a key factor driving increased yields in the Green Revolution. Because of this improvement, cassava breeding over the past 30–40 yr has understandably focused upon increasing the harvest index (Ceballos et al., 2010 ; de Souza et al., 2017). Earlier work has suggested that genotypes in which fewer than nine tuberous roots form are sink limited (Cock et al., 1979). In this study, the maximum number of storage roots is equal to nine. Which assumes that mass selection of individuals is feasible on this plant material. This finding has driven interest in analyzing the genes, gene networks and gene products that control tuberous root initiation and bulking. Improving the sink capacity of cassava to increase yield may depend on these molecular targets.

Correlations of harvest index

The harvest index was negatively correlated with the clearance period (r = -0.43) and the number of nodes buried in the soil (r = -0.41). This is because when a cutting has several nodes, this plays very little in favour of the harvest index. Our results are close to those of Bridgemohan and Bridgemohan (2014) on the effect of initial cassava nodes on dry tuber yield at harvest. These authors found that increasing the number of nodes beyond 3 does not improve fresh tuber yield and instead decreases it, automatically acting on the harvest index. They also demonstrated that the initial dry matter content of the nodes had a significant influence on the growth and development of the crop through the production and distribution of assimilates.

The other characteristics of the cuttings (NNC, MDC, FWC and DWC) were not significantly correlated with the harvest index (figure 4a). For example, there is no significant correlation between the harvest index and the diameter and weight of the cuttings. We conclude that whatever the diameter and weight of the cutting, this has no influence on the harvest index. There was a strong correlation (r = 0.76) between the number of storage roots, FSRM (r = 0.93), DMSR (r = 0.70) and the harvest index (figures 4b, 4c). These relationships are obvious, as the number of storage roots as well as their weight determines the level of production of a cassava cutting (Cock et al., 1979).

Figure 4. Correlations between harvest index and the morphological features of cuttings (a), characteristics of rooting cuttings (b) and biomass characteristics of plants (c). *The correlation coefficients included in the bands have a p-value of less than 0.05. Those outside the bands are not statistically significant*



CONCLUSIONS

This research focused on defining the factors that promote adventitious rooting of cassava, particularly storage roots. Also, it explored the magnitude of phenotypic variability of the harvest index of the MM105 variety. The planting position has a significant effect on the rooting of cassava cuttings and the harvest index. Vertical and slant plantings performed better than horizontal planting in terms of number of storage roots and harvest index. The cut model did not have a significant effect on the number of storage roots of the cuttings, but did on the biomass of the plants where a high fresh aerial biomass and storage roots were observed. The one-sided slice induces variability in the harvest index. These results can allow breeders to use the harvest index as a selection criterion for individuals within the MM105 variety to increase its tuber production.

REFERENCES

Adiele, J.G., Schut, A.G.T., van den Beuken, R.P.M., Ezui, K.S., Pypers, P., Ano, A.O., Egesi, C.E., & Giller, K.E. (2020) Towards closing cassava yield gap in West Africa: agronomic efficiency and storage root yield responses to NPK fertilizers. *Field Crops Research*, 253 :107820. https://doi.org/10.1016/j.fcr.2020.107820

Agahiu, A.E., Baiyeri, K.P., & Ogbuji, R.O. (2011). Correlation analysis of tuber yield and yield related characters in two cassava (Manihot esculenta Crantz) morphologicaltypes grown under nine weed management systems in the Guinea savanna zone of Nigeria. *Journal of Applied Biosciences*, 48, 3316– 3321.

Asefa, G. (2019). The role of harvest index in improving crop productivity: A review. *Journal of Natural Sciences Research*, 9 (6), 2224-3186. https://doi: 10.7176/JNSR.

Bridgemohan, P., & Bridgemohan, R.S.H. (2014). Effect of initial stem nodal cutting strength on dry matter production and accumulation in cassava (*Manihot esculenta* Crantz). *Journal of Plant Breeding and Crop Science*, 6(6), 64-72.

Carluccio, A.V., David, L.C., Claußen, J., Sulley, M., Adeoti, S.R., Abdulsalam, T., Gerth S., Zeeman S.C., Gisel A., & Stavolone L. (2022). Set up from the beginning: The origin and early development of cassava storage roots. *Plant, Cell & Environment,* 45, 1779–1795. https://doi.org/10.1111/pce.14300

Ceballos, H., Okogbenin, E., Perez, J., Lopez-Valle, L., & Debouck, D. (2010). Cassava. In : Bradshaw J, ed. Root and tuber crops. New York, NY, USA : Springer-Verlag, pp. 53–96.

Chávez, A.L., Sánchez, T., Jaramillo, G., Bedoya, J.M., Echeverry, J., Bolaños, E.A., Ceballos, H., Iglesias, C.A. (2005). Variation of quality traits in cassava roots evaluated in landraces and improved clones. Euphytica 143, 125–133. https://doi.org/10.1007/s10681-005-3057-2

Cock, J.H., Franklin, D., Sandoval, G., & Juri, P. (1979). The ideal cassava plant for maximum yield. *Crop Science*, 19, 271–279.

De Souza, A.P., Massenburg, L.N., Jaiswal, D., Cheng, S., Shekar, R., & Long, S.P. (2017). Rooting for cassava: insights into photosynthesis and associated physiology as a route to improve yield potential. *New Phytologist*, 213(1), 50–65. https://doi.org/ 10.1111/nph.14255

Edet, M.A., Tijani-Eniola, H., & Okechukwu, R.U. (2013). Comparative evaluation of organomineral fertilizer and NPK151515 on growth and yield of cassava varieties in Ibadan, southwestern Nigeria. *African Journal of Root and Tuber Crops*, 10(1), 9–14.

F.A.O. (2006). Situation du manioc en République du Congo état des lieux et perspectives. Rapport présenté par l'équipe nationale de coordination des activités sur le manioc au Congo, 26p.

F.A.O. (2014). Variétés et matériel végétal in Le manioc : Produire plus avec moins, Lavoisier, pp. 36-57.

Fermont, A.M., Titonell, P.A., Baguma, Y., Ntawuruhunga, P., & Giller, K.E. (2010). Towards understanding factors that govern fertilizer response in cassava: lessons from East Africa. *Nutrient Cycling Agroecosystem*, 86(1), 133–151. https://doi.org/10.1007/s107 05-009-9278-3

Gifford, R.M., Thorne, J.H., Hitz, W.D., & Giaquinta, R.T. (1984). Crop productivity and photoassimilte partitioning. *Science*, 225, 801-808.

Hartati, T.M., Roini, C., & Rodianawati, I. (2021). Growth Reponse of Local Cassava to Cutting Models and the Number of Buds*. Caraka Tani: Journal of Substainable Agriculture*, 36(2), 379-391.

Hay R.K.M. (1995). Harvest index : a review of its use in plant breeding and crop physiology. Annals of Applied, 126 (1), 197-216. https://doi.org/10.1111/j.1744-7348.1995.tb05015.x

Indira, P. & Sinha, S.K. (1970). Studies on the initiation and development of tubers in *Manihot esculenta* Crantz. *Indian Plant Physiol*., 13: 24-39.

Jennings, D.L., Iglesias, C. (2002). Breeding for crop improvement. In: Hillocks RJ, Thresh JM, Bellotti AC. (Eds): Cassava: Biology, Production and Utilization. CABI Publications pp. 149-166.

Legese, H., Gobeze, L., Shegro, A., & Geleta, N. (2011). Impact of Planting Position and Planting Material on Root Yield of Cassava (*Manihot esculenta* Crantz). *Journal of Agricultural Science and Technology*, 5 (4), 449-454.

Makouanzi Ekomono, C.G., Nzila, J.D., Kampe, J.P., Nguelet, Moukaha, I., Yallo Mouhamed, S., Dipakama C.M., & Kimpouni, V. (2022). Genotype-by-environment interaction and yield performance of two *Manihot esculenta* Crantz varieties cultivated with legumes in two agro-climatic zones in Congo. *Trop. Agric. (Trinidad)*, 99 (4), 322-332.

McKey, D., Elias, M., Pujol, B., Duputié, A., Delêtre, M., & Renard, D. (2012). Maintien du potentiel adaptatif chez les plantes domestiquées à propagation clonale. *Revue d'ethnoécologie*, 1 : DOI : 10.4000/ethnoecologie.741

Neves, R.J., Diniz, R.P., & Oliveira, E.J. (2018). Productive potential of cassava plants (Manihot esculenta Crantz) propagated by leaf buds. *Anais Da Academia Brasileira de Ciências*, 90(2), 1733–1747. http://dx.doi.org/10.1590/0001-3765201820170867

Okogbenin, E., Setter, T.L., Ferguson, M., Mutegi, R., Ceballos, H., Olasanmi, B., Fregene, M. (2013). Phenotypic approaches to drought in cassava: Review. *Frontiers in Physiology* 4, 93. https://doi.org/10.3389/fphys.2013.00093

Okpara, D.A., Agoha, U.S., & Iroegbu, M. (2010). Response of cassava variety TMS 98/0505 to potassium fertilization and time of harvest in South Eastern Nigeria. *Nigeria Agricultural Journal*, 41(1), 91–100.

Raffaillac, J.P. (1992). Enracinement de la bouture de manioc (*Manihot esculenta* Crantz) au cours des premières semaines de croissance. *L'Agronomie Tropicale*, 46 (4), 273-281.

Samba-Kimbata, M. (1978). Le climat bas-Congolais. Thèse de Doctorat 3ème cycle, Université de Bourgogne, Dijon, 280p.

Setiawan, K., Paresta, R., Hadi, M.S., Utomo, S.D., Karyanto, A., & Najib, M.F. (2022). Genetic Variation and Genetic Advance of Three Elite Cassava (*Manihot Esculenta* Crantz) Clones Under Wet Dry Climate of Lampung. *IOP Conf. Series: Earth and Environmental Science*, 1012 (012067) : https://doi:10.1088/1755-1315/1012/1/012067

Toro, J.C., & Atlee, C.B. (1984) Agronomic Practices for Cassava Production, in: Seminar on Cultural Practices of Cassava. Embrapa, Salvador, Anais Brasilia.

Treche, S. & Massamba, J.P. (1990). Importance du Manioc dans le Régime Alimentaire Congolais. Conférence de l'ORSTOM, Quarante ans de Recherche Scientifique au Congo, Brazzaville, 23 novembre 1989, République du Congo.

United Nations. 2015. World population prospects : the 2015 revision, key findings and advance tables. Working Paper No. ESA/P/WP. 241. New York, NY, USA : United Nations.

Wild, A. & Jones, L.H.P. (1988). Mineral nutrition of crop plants. In A. Wild (Ed), *Russell's soil conditions and plant growth* (11th ed.). Harlow, UK: Longman Scientific and Technical, pp. 69-112.