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Revista Facultad Nacional de Agronomía

UNIVERSIDAD NACIONAL DE COLOMBIA

# Agronomic and physiological evaluation of eight cassava clones under water deficit conditions

## Evaluación agronómica y fisiológica de ocho clones de yuca sometidos a condiciones de déficit hídrico

doi: 10.15446/rfnam.v73n1.75402

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## ABSTRACT

Cassava (*Manihot esculenta* Crantz) is an important crop in Africa, Asia, Latin America, and the Caribbean. This species grows adequately in drought conditions and is ideal to ensure food safety in marginal environments, such as soils with low fertility and low rainfall conditions. Complementary irrigation practices can be used, or genotypes with good yield potential can be identified against these conditions to enhance productivity in those environments. For this reason, this research aimed to study several physiological mechanisms and agronomical characteristics in eight cassava clones under prolonged water deficit. The experimental design was a split-plot where the principal plot was composed of three irrigation treatments (7, 15, and 21 days without irrigation, DWI) and the secondary plot by the eight clones. The results showed that cassava plants against drought conditions (21 DWI) decreased their growth, foliar expansion, and partially closed the stomata, avoiding water losses through transpiration. The variables of the net assimilation rate of $CO_2$, yield, and biomass accumulation were not affected by the maximum drought period. The best clones under drought were Guajira, Guajira 3, Guajira 4, Concha Rosada, and MeVen 77-1. The frequency of irrigation 15 DWI increased the variables of gas exchange and vegetative growth. This behavior is due to the ability to tolerate complex conditions through morphological and physiological mechanisms, among them, long life leaf, stomatal control, and high photosynthetic potential.

**Keywords:**
Drought
Gas exchange
Growth
*Manihot esculenta*
Productivity

## RESUMEN

La yuca (*Manihot esculenta* Crantz) es un cultivo importante en África, Asia, América Latina y el Caribe. Esta especie crece adecuadamente en condiciones de sequía y es ideal para garantizar la seguridad agroalimentaria en ambientes marginales, tales como suelos con baja fertilidad y bajas precipitaciones. Para ampliar la productividad en tales ambientes, se pueden utilizar prácticas de riego complementario o identificar genotipos con buen potencial de rendimiento frente a estas condiciones. Por ello, se planteó este experimento con el objetivo de estudiar algunos mecanismos fisiológicos y características agronómicas en ocho clones de yuca en condiciones de déficit hídrico prolongado. Se realizó un diseño experimental en parcelas divididas, donde la parcela principal estuvo conformada por tres niveles de riego (7, 15 y 21 días sin riego, DSR) y la parcela secundaria por ocho clones de yuca. Los resultados muestran que las plantas de yuca frente a condiciones de sequía (21 DSR) disminuyeron su crecimiento, expansión foliar y cerraron parcialmente los estomas, evitando las pérdidas de agua por transpiración, sin afectar las variables de tasa de asimilación neta de $CO_2$, rendimiento y acumulación de biomasa. Los clones que sobresalieron en este tratamiento fueron Guajira, Guajira 3, Guajira 4, Concha Rosada y MeVen 77-1. La frecuencia de riego 15 DSR afectó positivamente las variables de intercambio gaseoso y crecimiento vegetativo. Este comportamiento se debe a la capacidad de tolerar condiciones complejas mediante mecanismos morfológicos y fisiológicos, entre ellos, vida útil de la hoja, control estomático y alto potencial fotosintético.

**Palabras clave:**
Sequía
Intercambio gaseoso
Crecimiento
*Manihot esculenta*
Productividad

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Received: October 8, 2018; Accepted: August 23, 2019
Rev. Fac. Nac. Agron. Medellín 73(1): 9109-9119. 2020

ISSN 0304-2847 / e-ISSN 2248-7026

Cassava is a tropical root crop and represents, due to its high content of starch, a basic daily source of dietary energy for more than 500 million people in Africa, Asia and Latin America (FAO, 2012). It has the ability to develop under complicated conditions on marginal lands. It is mostly grown on small-scale farms, usually intercropped with other vegetables and plantation crops. The roots (1-8 kg) mostly used for human consumption are processed into a wide variety of traditional foods. The cultivated cassava varieties contain cyanogenic glycosides (linamarin and lotaustralin) in concentrations that range 6-370 mg $kg^{-1}$. It releases the toxic HCN upon the rupturing of the cells (e.g., during cutting, peeling, and processing) owing to the action of indigenous enzymes also present in the cassava root (Rawell and Kroll, 2003). The demand in the cultivation of cassava (*Manihot esculenta* Crantz) is increasing on the production of processed foods, animal feed, bioethanol, starch, and its derivatives (FAO, 2012).

However, loss in the yield of crops such as cereals, legumes, tubers and root crops due to the drought incidents borne out of global climate change are evidently demonstrated in several regions of the world (Daryanto *et al.*, 2017). In tuber crops (potato and cassava), the storage root initiation is more sensitive to drought stress than vegetative developmental stages (Daryanto *et al.*, 2017).

In Latin America, approximately 45% of the total area of cassava cultivation comes from areas with low water availability or where rains are sporadic (Tofiño *et al.*, 2008). Despite this, the cassava plant is susceptible to drought at the beginning of the phenological stages because the water deficit causes a decrease in the vegetative growth, production, and quality of the roots. The drought is an important factor that directly influences various physiological processes of plants since water stress increases the overall resistance water vapor diffusion, by closing the stomata and reducing respiration and $CO_2$ supply for photosynthesis (Nogueira, 1997).

In Venezuela, it is one of the crops within the sector of roots and tubers with the highest consumption *per capita* a year (8 kg) (Fedeagro, 2013).

At present, the information in Venezuela on the water requirements of cassava cultivation is limited. Current experience suggests that the plant requires moisture for sprouting and establishment of the crop, increasing its demand between the fourth and fifth months after planting (León *et al.*, 2016, 2018). It has also been estimated that very frequent irrigation can cause excessive growth of the aerial part, reducing the production of radical biomass.

Therefore, the objective of this work was to evaluate eight cassava clones physiologically and agronomically against water deficit conditions in order to identify the cultivars with the best response and the appropriate irrigation frequencies in Maracay, Venezuela.

## MATERIALS AND METHODS

### Study location

The study was conducted in the Experimental Field of the National Center for Agricultural Research (CENIAP), Maracay, Aragua State, Venezuela, located in a Tropical Premontane Dry Forest zone, at 10°17'14" N and 67°36'02" W, and 480 m.a.s.l. The precipitation during the whole crop cycle was 1,208 mm.

The experiment was developed in a plot with loam-silty texture soil; the chemical analysis of the plot for phosphorus was 57 mg $kg^{-1}$, potassium 111 mg $kg^{-1}$, calcium 600 mg $kg^{-1}$, magnesium 21 mg $kg^{-1}$, organic matter 2.76%, pH 6.1 and hydraulic conductivity 0.13 mg $kg^{-1}$ (Ceniap soil-water-plant analysis service unit).

### Vegetal material

Eight clones of cassava were studied (Guajira, Guajira 1, Guajira 3, Guajira 4, MeVen 77-3, MeVen 77-1, Concha Rosada, and Bolívar 32), previously selected according to their favorable potential behavior against drought.

### Description and design of the experiment

Under field conditions, an experimental trial was established with eight cassava clones, planted at 1 m between plants and 1 m between rows, three rows per genotype, three repetitions and six plants per row, guaranteeing irrigation and also the establishment and budding of the crop until the first 15 days. Irrigation was carried out by gravity, and water stress was applied by irrigation frequencies, which were made up of treatments 7, 15, and 21 days without irrigation (DWI).

Fertilization was applied at the time of sowing with a complete fertilizer (10-20-20 NPK) using a dose of 50 g per plant and was re-fertilized with urea three months after sowing with 50 g per plant. Weed control was manual and uniform throughout the plantation. During the investigation, there were no pests and diseases.

A design was made in split-plots, whose main plot consisted of three irrigation management (7, 15, and 21 days without irrigation, DWI) and the secondary plot with eight clones, with four replications. The clones were subjected to water stress from 21 to 111 days after sowing, at which time the dry period ended (precipitation greater than half of the potential evapotranspiration). The experimental unit (EU) consisted of irrigation treatments and clones, represented by 18 $m^2$ per EU (18 plants per EU). The data were analyzed using an analysis of variance and Tukey's mean test, with a level of significance of 5%, using the Infostat program.

### Physiological and agronomic evaluation

The evaluated variables were measured in weeks 7 and 17, at which time the three irrigation levels coincided.

**Degree of greenness (spad).** It was evaluated with the chlorophyll meter Spad 502 plus Minolta, taking the fifth fully expanded leaf, apex-base sense, in two plants and two leaves per plant for each experimental unit.

**Photosynthesis (µmol $CO_2$ $m^{-2}$ $s^{-1}$), stomatal conductance (mmol $CO_2$ $m^{-2}$ $s^{-1}$), and transpiration (mmol $H_2O$ $m^{-2}$ $s^{-1}$).** These variables were measured from 11:00 to 13: 00 h. An infrared gas analyzer equipment CI-340 Photosynthesis Systems (CID Inc, Washington, USA) was used, taking the fifth fully expanded leaf, apex-base sense, in two plants and two leaves per plant for each experimental unit.

**Xylematic hydric potential (MPa).** This variable was measured from 11:00 to 13:00 h. The last fully expanded sheet was taken, previously covered for approximately half an hour in the plant with aluminum foil bags, to be then taken to the pressure chamber according to the methodology described by Scholander *et al.* (1965). Two leaves were evaluated per clone and experimental unit.

**Foliar area ($cm^2$).** The fifth leaf, fully expanded, in the apex-base direction, was cut into three plants and taken to the laboratory, where they were then scanned and processed with the ImageJ program (Rincón Guerrero *et al.*, 2012).

**Number of leaves.** The number of leaves of two plants of the central thread per experimental unit was counted, from the basal part of the plant to the apical stem.

**Plant height (cm).** This variable was measured in two plants of the central thread per experimental unit from the base to the apex of the stem.

**Fresh aerial biomass (g).** The aerial part was weighed in two plants of the central thread in the ninth month after the crop was established.

**Dry biomass (g).** The amount of dry matter per stem and root was measured during the ninth month. One plant of each clone was cut in each EU and taken to the laboratory. The stem and root samples were weighed once they were dried in an oven at 60 °C for 72 h.

**Yield (g).** Three plants of the central thread were evaluated in the ninth month, determining the following variables: number and mass of commercial roots (roots greater than 20 cm long and greater than 4 cm wide) and non-commercial roots.

## RESULTS AND DISCUSSION

### Physiological characterization of cassava clones

**Degree of greenery (Spad).** This variable did not show significant effects for the interactions and neither for the effects of the irrigation. However, there were significant differences between clones at the seventh week of evaluation in which the clone Guajira 3 stood out, while in week 17, the clone Guajira 4 showed the greatest value. This genotype was one of the worst in the behavior of this clone. Variable on the first evaluation date shows an unfavorable response and then adapts to the conditions of the experiment and manages to maintain higher values in this parameter (Table 1).

On the other hand, it is possible that the clones against different water supplies maintained similar chlorophyll content, due to the strong association between the degree of greenness and the chlorophyll content (Barbosa, 2013).

**Table 1.** Degree of greenness (spad) in eight clones of cassava in weeks 7 and 17 of evaluation.

| Clone | Spad 7[1] | Spad 17 |
|---|---|---|
| Guajira 3 | 42.44 a | 47.55 ab |
| Guajira 4 | 35.35 c | 48.94 a |
| Guajira | 36.36 bc | 46.30 abc |
| MeVen 77-1 | 37.62 abc | 43.40 cd |
| MeVen 77-3 | 40.42 ab | 44.75 bc |
| Guajira 1 | 34.24 c | 44.33 bc |
| Concha Rosada | 32.96 c | 39.56 e |
| Bolívar 32 | 36.05 bc | 39.74 de |

[1]Spad 7 and Spad17: degree of greenery to week 7 and 17 of evaluation.
Different letters in the column indicate statistical differences among genotypes (*P*≤0.05).

**Rates of photosynthesis, transpiration, and stomatal conductance.** For the photosynthesis variable, the irrigations did not show significant differences in week 17 of evaluation, but week 7 showed significant changes among the clones evaluated, highlighting the treatment 7 DWI Concha Rosada with 17.02 µmol $CO_2$ m$^{-2}$ s$^{-1}$, 15 DWI Guajira with 16.76 µmol $CO_2$ m$^{-2}$ s$^{-1}$, and Guajira 4 with 13.98 µmol $CO_2$ m$^{-2}$ s$^{-1}$, respectively. Values that exceeded more than 14 µmol $CO_2$ m$^{-2}$ s$^{-1}$ to the treatment present the worst behavior for this variable (21 DWI and 15 DWI Concha Rosada) (Table 2).

**Table 2.** Photosynthesis rate (µmol $CO_2$ m$^{-2}$ s$^{-1}$) in week 7 of evaluation in three irrigation levels and eight cassava clones.

| Clone | Days without irrigation | | |
|---|---|---|---|
| | 7 | 15 | 21 |
| Guajira 3 | 11.93 Ba | 12.25 BCa | 5.67 Ab |
| Guajira 4 | 7.66 Cb | 13.98 ABa | 5.62 Ab |
| Guajira | 14.69 ABa | 16.76 Aa | 3.07 Ab |
| MeVen 77-1 | 14.03 ABa | 10.28 BCa | 5.73 Ab |
| MeVen 77-3 | 12.02 Ba | 9.82 Ca | 5.35 Ab |
| Guajira 1 | 12.86 Ba | 13.42 ABCa | 2.39 Ab |
| Concha Rosada | 17.02 Aa | 9.60 Cb | 2.10 Ac |
| Bolívar 32 | 12.52 Ba | 11.72 BCa | 3.76 Ab |

Different capital letters within the column indicate statistical differences (*P*≤0.05) among genotypes. Different lowercase letters within the rows indicate statistical differences (*P*≤0.05) regarding the days without irrigation.

Same as the photosynthesis variable, the irrigations did not show significant differences for the stomatal conductance variable in weeks 7 and 17, with average values of 261 and 141 mmol $CO_2$ m$^{-2}$ s$^{-1}$, respectively. This suggests that watering with a frequency of 21 days is sufficient to maintain adequate levels for these parameters (stomata partially open) since these were equally favored with 7 DWI, so that farmers can save water and make efficient use of this resource. This is explained because the response of cassava plants under conditions of abiotic stress is modulated by stomatal functions that allow reducing the loss of water by transpiration and by factors such as the canopy architecture and leaves orientation (León *et al.*, 2016, San José and Mayobre, 1982).

In this regard, De Tafur (2002) found significant differences between cultivars and environments for the variable rate of assimilation of $CO_2$, as well as a significant correlation between the same variable and dry root yield. This suggests that the rate of assimilation of $CO_2$ is an important parameter to identify superior genotypes in the face of water stress due to drought. The rate of photosynthesis was 27 and 12 µmol $CO_2$ $m^{-2}$ $s^{-1}$ for the dry and semi-arid environment, respectively. El-Sharkawy and De Tafur (2007) reported a similar trend, they refered to transpiration, values of 1 to 3 mol $H_2O$ $m^{-2}$ $s^{-1}$ in environments without stress due to drought, while in semiarid environments they reached values from 0 to 2 mmol $H_2O$ $m^{-2}$ $s^{-1}$.

The treatments that exceeded in the variable photosynthesis (7 DWI Concha Rosada and 15 DWI Guajira). They also exceeded in the transpiration rates in 1.83 and 1.75 mmol $H_2O$ $m^{-2}$ $s^{-1}$ to the treatment with 21 DWI, this treatment causes partially close of the stomata to avoid water losses (Table 3). On 17 DWI, Guajira 1 had similar behavior for all irrigation treatments, an outstanding characteristic of this clone against drought conditions. Even so, the high $CO_2$ concentration reduced the negative effect of drought on transpiration, water use efficiency, all growth measures and harvest index, which gives indications that in the future, the crop could have different behavior with low rainfall and high concentrations of $CO_2$ (Cruz *et al.*, 2018).

**Table 3.** Transpiration (mmol $H_2O$ $m^{-2}$ $s^{-1}$) measured in weeks 7 and 17 of the evaluation in three irrigation levels and eight cassava clones.

| Clone | Week 7 Days without irrigation | | | Week 17 Days without irrigation | | |
|---|---|---|---|---|---|---|
| | 7 | 15 | 21 | 7 | 15 | 21 |
| Guajira 3 | 1.87 Aa | 1.59 BCa | 0.80 ABb | 1.25 Ab | 1.80 Aa | 1.34 ABCa |
| Guajira 4 | 1.49 Ba | 1.55 BCa | 0.77 ABCb | 1.55 Aa | 1.46 Aa | 0.70 Db |
| Guajira | 1.99 Aa | 2.06 Aa | 0.48 ABCb | 1.66 A | 1.74 A | 1.72 A |
| MeVen 77-1 | 2.01 Aa | 1.23 Cb | 0.75 ABCc | 1.48 A | 1.36 A | 1.24 BC |
| MeVen 77-3 | 1.84 Aa | 1.45 Ca | 0.91 Ab | 1.39 Aa | 1.48 Aa | 0.98 Cb |
| Guajira 1 | 1.96 Aa | 1.91 ABa | 0.35 BCb | 1.63 A | 1.42 A | 1.29 ABC |
| Concha Rosada | 2.14 Aa | 1.44 Cb | 0.31 Dc | 1.63 Aa | 1.67 Aa | 1.12 Cb |
| Bolívar 32 | 1.80 Aa | 1.53 BCa | 0.59 ABCb | 1.69 Aa | 1.15 Bb | 1.61 ABa |

Different capital letters within the column indicate statistical differences ($P \leq 0.05$) among genotypes. Different lowercase letters within the rows indicate statistical differences ($P \leq 0.05$) regarding the days without irrigation.

On the other hand, León *et al.* (2014) found a different behavior for the variables of transpiration, stomatal conductance, and photosynthesis, in which no differences were observed between clones during the crop cycle, with values ranging between 1.27-1.61 mmol $H_2O$ $m^{-2}$ $s^{-1}$; 94.63-138.4 mmol $CO_2$ $m^{-2}$ $s^{-1}$ and 16.63 µmol $CO_2$ $m^{-2}$ $s^{-1}$, respectively.

**Xylematic water potential.** This variable had no significant interactions between factors and no statistically significant differences between the clones and irrigation factors for both evaluation dates. However, the values oscillated between -0.75 and -1.34 MPa, which indicates that the plants showed slight stress in the environmental conditions in which they were sown. Taiz and Zeiger (2006) indicate that the highest stresses are reached when the plants have water potentials less than -2 MPa.

In this aspect, El-Sharkawy (2007) showed that the leaf water potential in cassava suffers little variation with water stress with values ranging between -1.3 to -0.4 MPa. The capacity of cassava to maintain its water potential is due to the stomata closure and, therefore, to a considerable reduction of the stomatal conductance, which prevents the loss of water. Cassava plants conserve water under conditions of prolonged drought stress through a restriction in the formation of new leaves, production of smaller leaves, and leaf fall (Alves and Setter, 2004).

Similarly, in a study evaluating the leaf water potential in treatments without and with soil water stress in eight clones, they found values of -0.98 to -1.2 MPa and -0.97 to -1.19 MPa, respectively, without significant differences among clones evaluated, attributing these results to stomatal control to avoid water losses (El-Sharkawy, 2007; León *et al.*, 2016).

Contrary to the above, San Jose and Mayobre (1982) observed differential changes in stomatal conductance and, therefore, in transpiratory rates, as well as a notable change in water potentials of leaves maintained by adequate turgor pressure.

**Agronomic characterization of cassava clones**

**Leaf area.** In none of the two evaluation dates, this variable showed significant effects of the clone interaction. In the same way it happened in week 7 for the irrigation factor, but it was significant in week 17, reaching the highest values (159.9 $cm^2$) with the irrigation level of 7 DWI, then 15 DWI with 135.13 and 21 DWI with 118.9 $cm^2$, respectively, since the greater frequency of water supply caused the plants to produce larger leaves. The lower frequency irrigation (21 DWI) caused a decrease for this variable of approximately 41.01 $cm^2$ compared to 7 DWI, with the tendency to have the same behavior in the net assimilation rate variable of $CO_2$.

In this aspect, San José and Mayobre (1982) indicated that the increase in the assimilation apparatus and in the assimilation rate might be due to leaf expansion, but in terms of specific leaf area. Likewise, the clone factor varied significantly in both evaluation dates, reaching the highest leaf area in week 7, the genotype Guajira 3 with 73.39 $cm^2$, while in week 17, they were Guajira and Concha Rosada with 216.99 and 191.25 $cm^2$, respectively. The tendency in time was to increase the leaf area; this last evaluation date (week 17) is approximately the time when this species reaches its maximum vegetative growth potential. This is possible because foliar expansion depends above all on cell expansion; the principles that govern those processes are similar.

Similar behavior is observed by Alves and Setter (2004), in which at 15 days after causing stress, the leaf area decreased from 200 $cm^2$ in control to approximately 80 $cm^2$ in the clones to which the volume of water was reduced. On the other hand, León *et al.* (2014) observed significant differences for the clone and evaluated months and interactions of the clones, highlighting the La Reina and Concha Rosada varieties, with values of 261 $cm^2$ at the fourth month and 61 $cm^2$ at the eighth month of evaluation. In this sense, the leaf area and the number of leaves decreased in the treatment to which the lower water demand of the cassava crop was supplied (25% of the field capacity of the soil). This reduction is attributed to the decrease and completion of production of new leaves, as well as foliar abscission under drought conditions (Helal *et al.*, 2013).

**Plant height.** This variable was strongly influenced by the interaction irrigation of clones in week 17, whose highest rates were observed in all treatments of irrigation in the clones Guajira, Guajira 3, and Concha Rosada (Table 4), genotypes that can be recommended for seed production in dry environments. In this same sense, it is important to point out that clone MeVen77-3 had the lowest growth in the three irrigation treatments, which could be attributed to a low size characteristic of the genotype (Table 4).

**Table 4.** Plant height (cm) in week 17 of evaluation in three irrigation levels and eight cassava clones

| Clone | Days without irrigation | | |
|---|---|---|---|
| | 7 | 15 | 21 |
| Guajira 3 | 131.00 Aa | 117.37 BCa | 124.37 a |
| Guajira 4 | 102.62 CDEa | 96.50 DEa | 93.12 CDEa |
| Guajira | 123.00 Aba | 120.00 Aba | 110.00 ABCa |
| MeVen 77-1 | 85.75 Ea | 100.87 CDEa | 102.00 BCDa |
| MeVen 77-3 | 71.25 Fa | 74.50 Fa | 75.87 Ea |
| Guajira 1 | 83.75 Ea | 108.50 BCDa | 81.75 Eb |
| Concha Rosada | 111.62 BCDb | 136.50 Aa | 113.33 ABb |
| Bolívar 32 | 111.75 BCa | 84.87 Eb | 91.00 CDEb |

Different capital letters within the column indicate statistical differences ($P \leq 0.05$) among genotypes. Different lowercase letters within the rows indicate statistical differences ($P \leq 0.05$) regarding the days without irrigation.

Irrigation levels showed that the heights on 7 and 15 DWI were significantly higher (65.6 and 58.8 cm, respectively) in week 7 because they caused adequate moisture in the soil, allowing the plants to show an increase in the vegetative development.

On the other hand, the clones varied only for weeks 7 and 17 of evaluation, with the tendency to have the highest rates in clones Guajira 3, Guajira, and Concha Rosada (Table 5). In this regard, Montaldo (1996) show that plant height is one of the biggest indicators for agronomic management. In this sense, plants with intermediate and high heights are preferred, with values for plant height and first branching above 150 and 100 cm, respectively. Different investigations point out differences for this variable between different genotypes and evaluation dates, which indicates that it is a character strongly influenced by the genotype and environment (León *et al.*, 2013, 2014; Barbosa, 2013; Rós *et al.*, 2011; Marín *et al.*, 2008). Otherwise, refer Albuquerque *et al.* (2009), who, in their research, did not obtain important differences between the clones and between the dates of measurement for the plant height variable with averages of 143 cm at seven months of culture and 208 cm in 13 months.

**Number of leaves.** This variable showed significant effects neither for the clone interactions nor for the irrigation factor. On the other hand, the clones did not vary significantly in the seventh week of evaluation. In the opposite case, it occurred in week 17, significantly varying with the highest value being the Guajira 3 clone and with the worst behavior MeVen 77-1 (Table 5), which could translate into Guajira 3 being faster growing and, therefore, of more precocious behavior than the rest. In this aspect, San José and Mayobre (1982) reported in the Cuban clone, under savanna conditions, that partition mechanisms in the plant promoted the growth of the canopy and the development of new leaves with a distribution over time of the assimilated between leaves and other organs. Similarly, Ledent (2002) reports that, during a period of prolonged drought, the crop produces fewer leaves, and these are smaller and increases the retention of the already expanded leaves. When the drought ends, the plant begins to recover quickly and produces new leaves at the expense of the starch of the roots and stems. In the same order, Suárez and Mederos (2011) indicate that the total number of leaves produced by the plant and its longevity are varietal characteristics, deeply influenced by environmental conditions. In this regard, León *et al.* (2014) and Vandegeer *et al.* (2013) indicated that the loss of leaves in the cassava crop is a strategy of the plant to economize water. In spite of this, in their investigation, there were no significant differences between clones nor between interactions with the months, showing values of the number of leaves per plant that ranged from 181 to 305. Likewise, the number of leaves in cassava was significantly dropped in plants grown under water deficit conditions. At 150 DAP (120 days water withholding), number of leaves in water-deficit stressed plants was 15.34% lower than that in under well-watered plants (WW). It was evidently demonstrated that the number of fallen leaves was promoted by an adaptive period of water deficit, leading to decrease LAI parameter. LAI in both WW and water-stressed (WS) conditions increased in relation to the growing period. In addition, the reduction percentage of LAI in WS cassava at 150 DAP was 34.32% lesser than WW plants (Pipatsitee *et al.*, 2019).

**Fresh and dry biomass aerial and root.** These variables did not present significant effects on the interactions. The same happened with the irrigation factor; however, the trend observed during the experiment was the decrease in the variables associated with vegetative growth on 21 DWI and, therefore, a decrease in fresh and dry aerial biomass.

On the other hand, the clones had a differential behavior (Table 5), in which Guajira 3 reached the highest value for aerial biomass, as well as the highest transport rates. Otherwise, it occurred with clones MeVen 77-1, Guajira 1, Guajira 4, Bolívar 32 and MeVen 77-3, which presented the lowest values for these variables, product of which during the cycle they reached the lowest vegetative growth rates, and therefore the least possibility of transferring the assimilated to the aerial part.

With regard to dry stem biomass, the genotypes that stood out were Guajira 3, Guajira, Concha Rosada, and Bolívar 32 (Table 5), which possibly was due to the fact that it was the clone that stood out in most of the physiological variables and agronomic, favoring a positive stem-root relationship towards all the elements that make up the plant. San José and Mayobre (1982) explain this behavior in a cassava cultivar in the humid savanna season, where they observed that a large part of the assimilated production was not due to the demand of the storage roots, but was due to the morphological development, production of new leaves and the canopy. Similarly, Barbosa (2013), El-Sharkawy *et al*. (2012) and León *et al*. (2018) observed a positive and significant correlation between the height of the cassava plant with the diameter of the canopy, diameter of the root and stem, aerial weight of the plants and root dry weight, which indicates that increases in vegetative parts, have a significant effect on cassava dry matter production. In this regard, Olasanmi (2010) observed that the genotypes that stood out against drought conditions were those that maintained a robust development in the roots, while the clones with the worst behavior showed a better development of other organs in favor of the roots.

**Table 5.** Agronomic variables Leaf area (LA), number of leaves (NL), plant height (PH), fresh stem weight (FSW), and dry stem weight (DSW) on the aerial part of the plant in eight cassava clones.

| Clone | LA1* ($cm^2$) | LA2* ($cm^2$) | NL2 | PH1 (cm) | FSW (g) | DSW (g) |
|---|---|---|---|---|---|---|
| Guajira 3 | 73.39 a | 129.64 b | 66.41 a | 72.08 a | 4689 a | 1740 a |
| Guajira 4 | 46.08 bc | 92.65 b | 58.00 ab | 59.77 bc | 2214 cd | 930 bc |
| Guajira | 45.08 bc | 216.99 a | 32.04 cde | 67.54 ab | 3650 ab | 1610 ab |
| MeVen 77-1 | 29.35 c | 128.03 b | 27.87 de | 51.04 cd | 1447 cd | 600 c |
| MeVen 77-3 | 47.99 b | 106.39 b | 47.58 bc | 45.87 d | 1025 d | 470 c |
| Guajira 1 | 42.74 bc | 117.41 b | 35.25 cd | 53.54 bcd | 2109 cd | 830 bc |
| Concha Rosada | 49.90 b | 191.25 a | 37.40 cd | 62.18 abc | 2703 bc | 1170 abc |
| Bolívar 32 | 38.83 bc | 131.30 b | 33.91 cd | 54.16 bcd | 2039 cd | 960 abc |

*1 and 2 refer to week 7 and 17, respectively.
Different letters within the column indicate statistical differences ($P \leq 0.05$) among genotypes.

Similar to this study, Helal *et al*. (2013) and El-Sharkawy (2007) observed that water stress reduced weight plant compared with the control with irrigation and with significant differences between stress irrigation treatments. The reduction in the weight plant was associated with a decrease in cell growth and foliar senescence under stress conditions (Bhatt and Srinivasa, 2005). This is attributed to thef reduction of the foliar area as a strategy of the plant to avoid water losses in the leaves due to a reduction in the photosynthetically active area (León *et al*., 2016).

**Yield (Number of total roots, number of commercial roots, and weight of total and commercial roots).** The variables associated with performance did not show statistically significant effects for the interactions between the evaluated factors nor for the irrigation factor. This could be attributed to the fact that these clones were adapted to drought conditions so that the plants were adjusted physiologically to avoid damages caused by water stress without detriment to the production variables.

In the same aspect, it can be pointed out that the clones varied in this investigation; the best cultivar clone evaluated is Guajira 3 (Table 6). The clone Guajira, despite having eight roots in total, they did not manage to form with a commercial size, decreasing the weight of commercial roots. This genotype was the fourth with the highest number of roots, so it could be a genotype with the ability to exploit its maximum yield potential in other environmental conditions, transferring its assimilated to the roots in the filling stage. It is important to point out that in general, all the evaluated clones presented the potential of yield, since they surpass the national yield (1 to 3 kg per plant) (Fedeagro, 2013), except the clone Guajira.

Otherwise reported Caraballo and Velásquez (1997), in this case, the roots reached on average 2.9 kg per plant when the crop received at least 324 mm of water between the fourth and seventh month after sowing; when the availability of water was 156 mm, the weight of the roots reached 1.8 kg per plant. Also, several researchers observed on irrigation, clones and their interactions, that plants against drought decreased their yields, but some genotypes excelled against stressful conditions in different phenological phases, indicating that some genotypes adapted to dry environments can be selected, as well as materials with early development to avoid stress (Albuquerque *et al*., 2009; Barbosa, 2013; León *et al*., 2016; Rós *et al*., 2011;Vandegeer *et al*., 2013). Drought significantly decreased shoot dry weight, total root number, and root length by 84%, 30%, and 25%, respectively. A high adventitious root number was associated with increased shoot dry weight (r=0.44) under drought (Kengkanna *et al*., 2019).

**Table 6.** Behavior of agronomic variables root dry weight (RDW), root fresh weight (RFW), weight of commercial root (WCR), weight of non-commercial root (WnCR), total number of roots (TNR), total number of commercial roots (TNCR) and total number of non-commercial roots in eight cassava clones.

| Clone | RDW (g) | RFW (g) | WCR (g) | WnCR (g) | TNR - | TNCR - | TnNCR - |
|---|---|---|---|---|---|---|---|
| Guajira 3 | 1260 a | 2613 a | 1744 a | 869 abc | 10.33 a | 3.50 a | 6.83 abcd |
| Guajira 4 | 750 ab | 1466 b | 1022 ab | 444 c | 5.77 c | 2.33 abc | 3.44 e |
| Guajira | 380 b | 653 c | 0 c | 607 abc | 8.00 abc | 0 d | 7.42 ab |
| MeVen 77-1 | 730 ab | 1430 bc | 697 bc | 733 abc | 7.05 bc | 1.94 bc | 5.11 bcde |
| MeVen 77-3 | 870 ab | 1718 b | 1131 ab | 587 bc | 7.00 bc | 2.75 ab | 4.25 de |
| Guajira 1 | 850 ab | 1585 b | 502 bc | 1022 ab | 9.23 ab | 1.35 cd | 7.44 abc |
| Concha Rosada | 800 ab | 1912 b | 825 b | 1087 a | 10.37 a | 2.00 bc | 8.37 a |
| Bolívar 32 | 590 b | 1505 b | 855 b | 613 abc | 6.29 c | 1.41 bcd | 4.61 cde |

Different letters within the column indicate statistical differences ($P \leq 0.05$) among genotypes.

Finally, it can be said that clone Guajira 3, in all irrigation treatments maintained high spad values, which could be associated with a high chlorophyll content, very important behavior, since, throughout the treatments with and without stress, it was possible to observe a superior behavior in the variables of photosynthesis and transpiration, which mean that their photoassimilates could be used efficiently for their vegetative growth (higher plant height and leaf area) and greater root yield, behavior that was contrary for the Bolívar 32 clone in the physiological and agronomic variables. Whereas, Concha rosada, despite not excelling in stress treatment (21 DWI), it was possible to observe higher rates of transpiration and photosynthesis at 7 DWI, which makes it a relevant clone in irrigation conditions or without stress by water deficit. About this aspect, leaf relative water content in cassava declined significantly upon a long period of water withholding, and regulated non-photochemical quenching, leading to chlorophyll degradation, reduced number of leaves and limited leaf area index and loss of storage root yield when compared with well-irrigated plants (Pipatsitee *et al*., 2019).

## CONCLUSIONS

The clones interacted significantly with the irrigation in the variables of gas exchange and vegetative growth; so that the Guajira, Guajira 3, Guajira 4, Concha Rosada and MeVen 77-1 genotypes can be identified in seed production systems in dry environments.

The vegetative growth variables affected positively the fresh and dry stem-root biomass and yield, obtaining outstanding behavior the clones Guajira 3 and Guajira 1.

The treatment of 21 DWI negatively affected the vegetative growth of the cassava plants. However, the variables associated with gas exchange and yield did not vary in the irrigation treatments; therefore, it can be recommended for these experimental conditions to irrigate with a frequency of 21 days.

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