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Water regimes on the development of accessions of the *Manihot* genus

Regimes hídricos no desenvolvimento de acessos do gênero *Manihot*

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ABSTRACT - The objective of this work was to select water deficit-tolerant accessions of the genus *Manihot*, through morphological characters under different water regimes. The experiment was conducted in a randomized block design, using a split-plot arrangement with plots consisting of tree water regimes (simulated rainfall and water depth of 100 and 20% crop evapotranspiration (ET_c)), and subplots consisting of eight accessions of the genus *Manihot* (Gema-de-Ovo and Engana-Ladrão from the species *M. esculenta* Crantz, and BGMS-115, BGMS-110, BGMS-102, BGMS-79, BGMS-24, and BGMS-48 from *Manihot* sp.). The accessions were evaluated considering two crop cycles: the first had 120 and 60 days from the application of the treatments. Plant height, stem diameter, number of leaves, leaf lobe length and shoot dry mass production were evaluated. For each cropping cycle, a split-plot analysis of variance was performed. The highest genotypic means were expressed by the accessions BGMS-115, BGMS-102, BGMS-79 and BGMS-24 for most of the analyzed variables, regardless of the cultivation cycle. For the characteristic shoot dry mass production, accessions BGMS-102 and BGMS-79 showed the best performances under conditions of limited water regime (20% ET_c), regardless of the cropping cycle. Accession BGMS-102 was also grouped in the group with the highest genotypic means, for this trait, in treatments with rain simulation and 100% ET_c, in the first cycle, demonstrating that, under stress conditions, this accession is an option to tolerate low water precipitation and responds well when higher precipitation occurs.

Keywords: Semiarid region. Plant morphology. Selection of accessions. Tolerance to water deficit.

RESUMO - Objetivou-se selecionar acessos do gênero *Manihot* através de caracteres morfológico-agronômicos, quando submetidos à diferentes regimes hídricos. O delineamento experimental foi em blocos casualizados, em esquema de parcelas subdivididas, sendo as parcelas três condições de regimes hídricos (simulação da chuva e reposições de 100 e 20 % da evapotranspiração da cultura (ET_c)) e nas subparcelas, oito acessos de espécies do gênero *Manihot* (gema-de-ovo e engana-ladrão da espécie *M. esculenta* e BGMS-115; BGMS-102; BGMS-79; BGMS-24; e BGMS-48 acessos de *Manihot* sp.). Os acessos foram avaliados em dois ciclos de cultivo, 120 e 60 dias após a aplicação dos tratamentos. Foram avaliadas as variáveis altura de planta, diâmetro do caule, número de folhas, comprimento, largura do lóbulo foliar e produtividade da massa seca da parte aérea. Para cada ciclo de cultivo foi realizada uma análise de variância em parcela subdividida. As maiores médias genotípicas foram expressas pelos acessos BGMS-115, BGMS-102, BGMS-79 e BGMS-24 para grande parte das variáveis analisadas, independentemente do ciclo de cultivo. Para a característica produtividade da massa seca da parte aérea, os acessos BGMS-102 e BGMS-79 apresentaram os melhores desempenhos em condições de regime hídrico limitado (20% ET_c) independente do ciclo de cultivo. O acesso BGMS-102 também estava agrupado no grupo com maiores médias genotípicas, para esta característica, nos tratamentos com simulação de chuva e com 100% da ET_c, no primeiro ciclo, demostrando que em condições de estresse este acesso é uma opção para tolerar as baixas precipitações hídricas e responde bem quando ocorre maiores precipitações.

Palavras-chave: Semiárido. Morfologia vegetal. Seleção de acessos. Tolerância ao déficit hídrico.

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INTRODUCTION

The agricultural sector is highly dependent on water for irrigation to meet crop requirements, and occurrence of severe droughts has resulted in large socioeconomic losses due to decreased food production (ZHAO et al., 2017). According to Zhang, Mu and Huang (2016), agricultural production in general increased in recent years, but droughts are the main cause of crop failure, resulting in global instability of food prices and threatening food security. The United States of America estimated losses of almost 30 billion dollars in 2012 from direct losses of agricultural production due to droughts, plus 5 billion when considering livestock and dairy products (ELLIOTT et al., 2018).

Water deficit reduces growth and yield of plants, lowering their productive capacity. However, depending on the intensity and duration of the water stress, plants can develop molecular, cellular, biochemical, and physiological adaptive processes to improve their survival in these environments (PUTPEERAWIT et al., 2017). According to Merwad, Desoky and Rady (2018), responses of plants to water deficit are complex, since they have several mechanisms to grow under low water availability conditions.

Identifying and selecting water deficit-tolerant genotypes that can maintain their productive capacity by efficiently using the available water is important for establishing crops in regions with low water availability (MANSOUR et al., 2017). Thus, researchers use different procedures to characterize and identify these genotypes, especially selection by morphological descriptors. Several plant characteristics are used to identify water deficit-tolerant genotypes for different crops, including cassava (*M. esculenta* Crantz), a commercial relative of the species discussed in this article, such as plant height, leaf lobe length and width, number of leaves (OKOGBENIN et al., 2013), leaf area (CAYÓN; EL-SHARKAWY; CADAVID, 1997) and variables related to vegetative growth (VALE et al., 2012).

According to Ferreira et al. (2009), the aerial part of Euphorbiaceae species can be an alternative to increase the economic viability and productivity of livestock in semi-arid regions, both qualitatively and quantitatively, during the most critical period of the year, that is, in the period of lower precipitation, since it has high nutritional value and good acceptability by animals. In this context, species of the genus *Manihot*, which are already widely used in agriculture, such as cassava, as well as their wild relatives known as maniçobas (*M. glaziovii*, *M. catingae*, *M. esculenta* ssp. *flabellifolia* and *M. carthaginensis*) used in animal feed, are alternatives to increase productivity levels, which are low in most areas with herds in the northeastern semi-arid region, mainly for small ruminants, mainly due to the fact that the feed is based, almost exclusively, on the Caatinga vegetation, which has its forage resources exploited in an extractive way and has low support capacity, with low animal yield (0.08 AU/ha/year) and low productivity (6–8 kg of weight gain/ha/year) (GUIMARÃES FILHO SOARES; RICHÉ, 1995).

In addition, these species differ in terms of resistance to pests and diseases, tolerance to successive cuts and leaf retention, and some of them are arboreal while others are herbaceous, which allows the selection of the most promising depending on the purpose of the breeding program. Although species of this genus are adapted to shallow, low-fertility marginal soils and irregular rainfall conditions and maintain good biomass production even under these conditions, the challenges posed by global climate change (increased temperature and drought severity) make the search for genotypes more tolerant to water deficit, as well as the understanding of its effects on plants, constant in breeding programs.

Therefore, this study aimed to evaluate the effect of different water regimes on the development of accessions of the genus *Manihot*.

MATERIAL AND METHODS

The experiment was conducted at the Caatinga Experimental Field, of the Embrapa Semiárido, in Petrolina, PE, Brazil (09°03'25"S, 40°28'95"W, and 395 m of altitude). The climate of the region is BSwh', Semi-arid, with high temperatures, according to the Köppen’s classification, climatological data during the experimental period can be seen in Figure 1. During the application of the experimental treatments there was no rainfall.

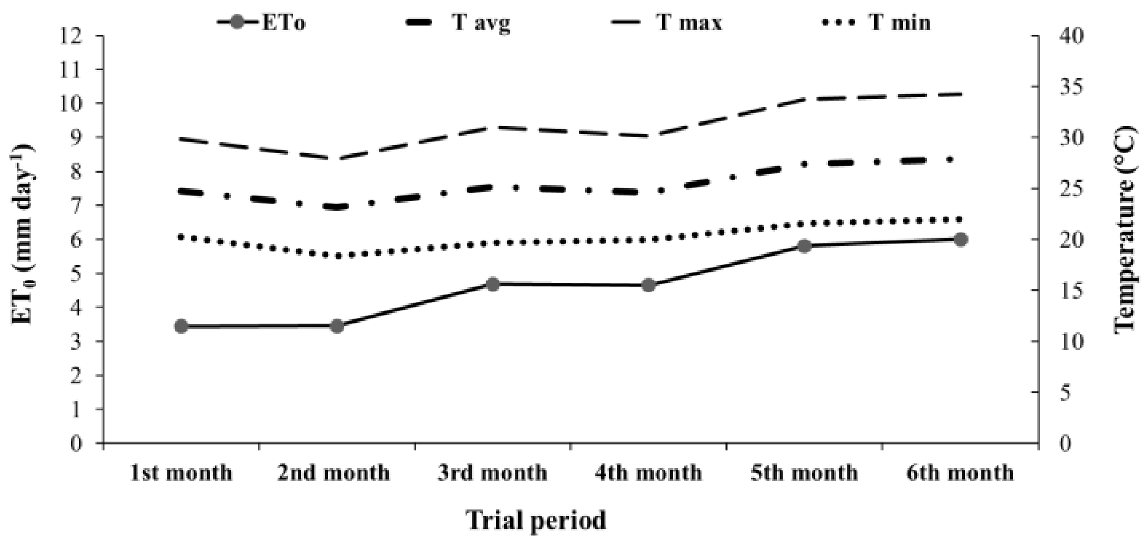

Figure 1. Climatic data of reference evapotranspiration (ETo) and minimum (T min), average (T avg) and maximum (T max) temperatures during the experimental period, Petrolina, PE, Brazil.

The soil of the experimental area is classified as *Neossolo Quartzarênico* (Entisol) (SANTOS et al., 2018). The soil of the experimental area, whose chemical and physical characteristics are described in Table 1, was prepared according to procedures commonly used by farmers in the Semi-arid region of the state of Pernambuco, Brazil. No chemical fertilization had been applied prior to the experiment. The initial preparation of the soil consisted of one plowing and two harrowing/leveling operations.

Table 1. Soil chemical characteristics and particle size of soil samples from the experimental area collected in April 2017, in Petrolina, PE, Brazil.

Depth	Density				Porosity	Particle size				
	Soil			Particles		Sand		Silt		Clay
(cm)	---------- kg dm^{-3} --------				Total (%)	----------------- g kg^{-1} ---------------				
0 – 20	1.31			2.52	47.88	755.1		155.8		89.1
20 – 40	1.28			2.58	50.28	772.3		115.3		112.5
Depth	EC	pH	C	P	K	Na	Ca	Mg	Al	H+Al
(cm)	mS cm^{-1}	-	g kg^{-1}	mg dm^{-3}	---------------------- cmol$_c$ dm^{-3} ------------------					
0-20	2.08	5.5	4.8	4.32	0.31	0.02	1.00	2.00	0.00	1.2
20-40	1.47	5.1	2.6	2.16	0.22	0.03	1.00	1.95	0.05	1.7

Eight accessions belonging to the Work Collection of Wild Species of the *Manihot* Genus of the Embrapa Semiárido were used, as follows: cultivars Gema-de-Ovo and Engana-Ladrão from the species *M. esculenta,* and BGMS-115, BGMS-110, BGMS-102, BGMS-79, BGMS-24, and BGMS-48 from *Manihot* sp. These accessions were previously selected, as they had better seedling establishment, better forage potential (such as leaf retention and higher crude protein content) and, in the case of *M. esculenta* accessions, showed greater tolerance to water stress in other works (OLIVEIRA et al., 2015).

The experiment was conducted in a randomized block design with three replications and four plants per plot (spacing of 1.5 m between rows and 1.0 m between plants), two central plants were considered for evaluation, and using a split-plot arrangement, with plots consisting of three water regimes. The subplots consisted of eight accessions of the genus *Manihot*.

The plant material was obtained from branches of the middle third of healthy plants; these branches were sectioned into 20 cm segments and planted in polyethylene bags with 1 kg of substrate to obtain uniform seedlings. The substrate was prepared using soil, washed sand, and aged goat manure at 2:1:1 ratio. The seedlings were kept in a nursery for two months and then transplanted to the field (May 3, 2017). The holes into which the seedlings were transplanted received 2 L of aged goat manure, applied around the plants, forming a circle, and 2 L at 120 days after harvest. The accessions were evaluated considering two crop cycles, with two harvests being carried out: the first harvest was performed 120 days after transplanting the seedlings, and the second harvest was performed 60 days after the first.

The three water regimes consisted of: 1 - water depths equivalent to the average of the four-month rainy period of the region, with rainfall simulated with micro-sprinklers based on a 30-year rainfall data series; 2 - 100% replacement of crop evapotranspiration (ET_C) and 3 - water depth of 20% ET_C, these last two treatments being irrigated by drip irrigation.

The drip irrigation system consisted of flexible polyethylene drip tapes with nominal diameter of 16 mm, flow rate of 2.1 L h^{-1}, with emitters spaced 0.50 m apart. The micro sprinkler system consisted of six emitters per plot, with flow rate of 45 L h^{-1}, spaced 2.5 m apart. The water application efficiency was determined according to Keller and Karmeli (1974). The distribution uniformity coefficients (DUC) found were 68.95% (micro sprinkler) and 96.52% (drip emitters); the systems were classified as good and excellent, respectively, according to Mantovani (2001).

The irrigation management was carried out in two different ways, for the two crop cycles: one with simulated rainfall based on the average rainfall depths of the region, applying the water depths as a simulation of precipitation for the region, based on the climatological normal for the months of January to May, simulating periods with rain and water stress (Table 2); and the other with irrigation, based on the crop evapotranspiration (ET_C) proposed by Allen et al. (1998), reference evapotranspiration (ET0) obtained from a weather station installed near the experiment area, and the crop coefficients (KC), which were 0.3 (initial phase of leaf production – up to 30 days in the first cycle and 20 days in the second cycle), 1.10 (beginning of the growth phase until the aerial part is harvested), and 0.50 (final phase), and corrected based on the location coefficient (KL) proposed by Keller and Bliesner (1990).

Water from the São Francisco River was used for the irrigations. It showed electrical conductivity of 0.06 dS m^{-1} and pH of 7.6. The irrigation was performed on alternate days. Soil moisture was monitored during the experimental period using TDR100 (Campbell) probes in the soil layer of 0 to 20 cm. Plots irrigated with 100% crop evapotranspiration (755.64 mm in the first cycle and 593.56 mm in the second cycle) had constant soil moisture (approximately 20%) throughout the experimental period, regardless of the crop cycle. The soil of plots under water deficit of 20% crop evapotranspiration, 151.13 mm in the first cycle and 118.71 mm in the second cycle, had moisture close to 4% in both crop cycles. The evaluated plants were cut at 20 cm from the soil surface, in all plots at the end of the first crop cycle. Altogether, the experiment was conducted in the field for 180 days. In the first 30 days, all plants of all treatments received the same amount of water, to standardize seedling growth. After 30 days the treatments were applied. The historical series used for the application of the rain simulation treatment, along 150 days, is described in Table 2.

Table 2. Monthly average rainfall of the region of the experimental field based on a 30-year rainfall data series (1984 to 2014) of the Meteorological Station of the Caatinga Experimental Field of Embrapa Semiárido, Petrolina, PE, Brazil.

Month	Week	Precipitation (mm)	Total (mm)
January	1	10.45	322.29
	2	19.61	
	3	18.33	
	4	33.03	
February	1	14.27	
	2	16.46	
	3	22.12	
	4	22.11	
March	1	22.42	
	2	28.75	
	3	24.05	
	4	33.95	
April	1	15.50	
	2	28.11	
	3	5.21	
	4	7.92	
May	1	14.00	46.22
	2	32.22	

The morphological descriptors evaluated for the first and second cycle were: plant height, from the ground level to the base of the terminal bud insertion of the plant, measured with a tape ruler (cm); stem diameter, at the base of the lateral bud insertion, measured with a digital caliper; number of leaves per plant, considering leaves with at least 60% green leaf blade; leaf lobe length, from the lobe insertion to the petiole to the upper end of the central lobe of the leaves, measured with a ruler (cm); leaf lobe width, at the basal part of the lobe, measured with a ruler (cm); and shoot dry mass production ($kg.ha^{-1}$).

For each cropping cycle, a split-plot analysis of variance was performed, considering the effects of the water regime as fixed and the accessions as random. The Scott-Knott method was applied to discriminate accession means within each studied water regime. All analyses were performed using the Exp.Des.pt package of the R Program (FERREIRA; CAVALCANTI; NOGUEIRA, 2018).

RESULTS AND DISCUSSION

Significant effects ($p<0.05$) were found in the analysis of variance for water regime, accessions and interaction between these two factors on practically all the variables evaluated in both cycles. The only exception was observed for leaf blade width, for which a significant effect was observed only for the accession factor (Table 3). The presence of the interaction between the factors, in the two cultivation cycles, indicates different behavior of the accessions as a function of the water regimes.

Studies involving genotypic characteristics of species of the Manihot genus are scarce in the literature; however, parameters such as plant height can be important for quantification of genetic diversity and selection and identification of water deficit-tolerant plants (OKOGBENIN et al., 2013), because it is essential for the evaluation of yield in several crops. Matos et al. (2016) evaluated M. esculenta under water deficit and found higher plant heights in materials subjected to water stress, especially for the BRS 399 and BRS 398 cultivars. Oliveira et al. (2017) evaluated 49 accessions of M. esculenta and observed that taller plants tend to be more susceptible to water stress. Bergantin et al. (2004) reported that some characteristics of M. esculenta, such as plant height and number of leaves, were affected by both water regime and genotype, and the water stress atrophied the plants, which had fewer leaves when compared to irrigated ones, confirming the results found in the present work (Table 4 and Table 6).

The accessions that had the highest genotypic means for plant height in the first cycle were BGMS-102, BGMS-115, BGMS-79, and BGMS-24 (simulated rainfall); BGMS-48, BGMS-102, BGMS-110, BGMS-48 and Engana-Ladrão (replacement of 100% crop evapotranspiration - 100% ETC), and Engana-Ladrão, BGMS-79, Gema-de-Ovo and BGMS-24 (replacement of 20% crop evapotranspiration - 20% ETC) (Table 4).

Table 3. Analysis of variance for growth, development and productivity variables of accessions of the *Manihot* genus subjected to different water regimes, in two crop cycles.

Character [(1)]	Source of variation			
	Block (2) [(2)]	Regime (2)	Accession (7)	R x A (14)
	First crop cycle [(3)]			
PH	1.12 ^{ns}	116.16**	26.89**	12.56**
SD	1.16 ^{ns}	25.74**	13.33**	5.56**
NL	4.63 ^{ns}	95.38**	60.95**	11.69**
LL	1.05 ^{ns}	12.12*	20.22**	4.8216**
LW	0.07 ^{ns}	1.79 ^{ns}	35.77**	1.73 ^{ns}
SDMP	0.47^{ns}	92.93**	67.56**	22.78**
	Second crop cycle [(4)]			
PH	0.03 ^{ns}	40.58**	22.22**	11.92**
SD	3.52 ^{ns}	395.26**	18.79**	10.74**
NL	0.54 ^{ns}	35.39**	25.45**	10.67**
LL	0.39 ^{ns}	76.08**	57.86**	33.93**
LW	1.16 ^{ns}	58.98**	53.09**	25.65**
SDMP	0.51 ^{ns}	141.43**	15.09**	11.15**

(1) PH = plant height (cm); SD = stem diameter (mm); NL = number of leaves (unit); LL = leaf lobe length (cm); LW = leaf lobe width (cm); SDMP = shoot dry mass production ($kg.ha^{-1}$); (2) Values within parentheses represent degrees of freedom for each source of variation; (3) 120 days after the application of the treatments; (4) 60 days from the end of the first cycle; ^{ns}= not significant by the χ^2 test; * = significant at 5.0% probability and ** = significant at 1.0% probability by the χ^2 test.

Table 4. Genotypic means for plant height (cm) of accessions of the genus *Manihot* subjected to different water regimes, in two crop cycles.

Accession [(1)]	First crop cycle		
	Water regimes		
	Simulated rainfall	100% ET_C [(3)]	20% ET_C
Gema-de-Ovo [(2)]	90.45b	91.09b	70.46a
Engana-Ladrão	82.62b	103.79a	73.51a
BGMS115	121.99a	99.99b	61.02b
BGMS110	58.67c	123.35a	57.32b
BGMS102	122.99a	123.71a	59.19b
BGMS79	115.11a	103.63b	71.98a
BGMS24	95.45a	104.91b	70.17a
BGMS48	54.89c	132.58a	57.88b
	Second crop cycle		
Accession [(1)]	Water regimes		
	Simulated rainfall	100% ET_C	20% ET_C
Gema-de-Ovo [(2)]	52.62b	110.60a	93.30a
Engana-Ladrão	67.58b	82.69b	65.20b
BGMS115	50.59b	119.11a	74.82a
BGMS110	13.52c	137.53a	68.80b
BGMS102	79.27a	110.43a	85.63a
BGMS79	75.44a	112.10a	75.23a
BGMS24	68.52b	129.41a	76.46a
BGMS48	58.22b	125.89a	64.94b

(1) Accessions from the Work Collection of Wild Species of the *Manihot* Genus of the Embrapa Semiárido. (2) Means followed by same letters in the columns belong to the same group by the Scott-Knott test ($P < 0.05$). (3) Crop evapotranspiration.

BGMS-102 and BGMS-79 had the highest genotypic means for plant height under simulated rainfall in the second period (which had lower water depths), showing significant reductions in plant height, when compared to the first crop cycle (which had higher water depths). However, BGMS-48 had relatively similar plant height in both crop cycles. Most accessions had high genotypic means, with plant heights above 80 cm for plants grown with 100% ET_C. Gema-de-Ovo, BGMS-102, BGMS-24, BGMS-79, and BGMS-115 had the highest heights when grown with 20% ET_C (Table 4). BGMS-102, BGMS-115, BGMS-79, BGMS-24, and Gema-de-Ovo showed similar plant height when grown with simulated rainfall and 100% ET_C, and their shoot yield was reduced by the limiting water supply (20% ET_C) in the first crop cycle. In the second crop cycle, in general, plants with simulated rainfall or 20% ET_C had low height, except BGMS-79 and Engana-Ladrão (Table 4).

BGMS-102, BGMS-115, BGMS-79, and BGMS-24 had the highest genotypic means for stem diameter in the first crop cycle with simulated rainfall (Table 5).

Table 5. Genotypic means for stem diameter (mm) of accessions of the genus *Manihot* subjected to different water regimes in two crop cycles.

First crop cycle			
Accession [1]	Water regime		
	Simulated rainfall	100% ET_C [3]	20% ET_C
Gema-de-Ovo [2]	17.58b	21.14a	14.27a
Engana-Ladrão	17.08b	22.77a	16.62a
BGMS115	23.26a	20.34a	12.82a
BGMS110	12.64b	21.76a	14.57a
BGMS102	25.10a	21.31a	13.26a
BGMS79	23.08a	20.03a	13.42a
BGMS24	22.68a	18.88a	14.98a
BGMS48	15.55b	21.93a	13.97a
Second crop cycle			
Accession [1]	Water regime		
	Simulated rainfall	100% ET_C	20% ET_C
Gema-de-Ovo [2]	9.28a	16.89b	12.82a
Engana-Ladrão	10.10a	14.71b	12.97a
BGMS115	9.52a	19.10a	12.49a
BGMS110	2.24b	20.53a	12.45a
BGMS102	14.48a	18.28b	12.42a
BGMS79	11.02a	17.51b	13.55a
BGMS24	10.20a	20.95a	12.30a
BGMS48	8.45a	19.79a	10.95a

[1] Accessions from the Work Collection of Wild Species of the *Manihot* Genus of the Embrapa Semiárido. [2] Means followed by same letters in the columns belong to the same group by the Scott-Knott test ($P < 0.05$). (3) Crop evapotranspiration.

Plants with 100% ET_C had similar genotypic means, with average stem diameter above 18 mm. The genotypic means ranged from 12.82 mm (BGMS-115) to 16.62 mm (Engana-Ladrão) with 20% ET_C. According to Vale et al. (2012), when the genotype is subjected to a stress condition, decreases in some characteristics are found, even in tolerant genotypes. According to Araújo Filho et al. (2013), the greater water availability to *M. pseudoglazovii* plants resulted in increased stem diameter. Several other studies confirm increases in stem diameter due to great water availability to the plants (DUTRA et al., 2012), as found in the present study. Therefore, plant growth and development depend on cell division, elongation, and differentiation, whose processes are impaired by water stress because of loss of turgescence (TAIZ et al., 2017). Stem diameter is important for the development of branches and, consequently, for the plant architecture. Thus, a low plant development regarding stem diameter and plant height resulting from water stress may reduce the number of branches for planting and hinder plant establishment (RITCHIE et al., 2010).

Stem diameter was significantly reduced in plants with simulated rainfall in the second cycle, and BGMS-110 had the lowest genotypic mean, denoting less tolerance to this condition. BGMS-24, BGMS-110, BGMS-48, and BGMS-115 had greater stem diameter in treatments with 100% ET_C. The genotypic means for stem diameter were relatively similar for all accessions evaluated with 20% ET_C.

The highest genotypic means for number of leaves in the first crop cycle were found for BGMS-102, BGMS-115, and BGMS-79 with simulated rainfall; for BGMS-24, BGMS-110, and BGMS-115 with 100% ET_C; and for Gema-de-Ovo, Engana-Ladrão, BGMS-48 and BGMS110 with 20% ET_C (Table 6).

For the second cropping cycle, only accession BGMS102 showed a higher genotypic average for this variable when the plants were subjected to the rain simulation regime in this period (Table 6). Its performance under simulated rainfall indicates a genotype with potential for growing as forage in regions with limited water supply. Plant species subjected to great water availability produce larger numbers of leaves, and reductions in growth may by a defense strategy due to drought, mainly by accelerating leaf senescence and abscission, which reduces plant transpiration (ANJUM et al., 2011).

Table 6. Genotypic means for the number of leaves of accessions of the genus *Manihot* subjected to different water regimes in two crop cycles.

First crop cycle			
Accession [(1)]	Water regime		
	Simulated rainfall	100% ET_C[(3)]	20% ET_C
Gema-de-Ovo [(2)]	58.80b	80.89b	59.98a
Engana-Ladrão	66.73b	86.76b	57.62a
BGMS115	117.04a	106.75a	7.27c
BGMS110	46.55c	108.42a	46.59a
BGMS102	165.28a	88.46b	10.09c
BGMS79	115.01a	95.73b	30.22b
BGMS24	75.77b	121.72a	35.50b
BGMS48	54.42c	88.33b	49.78a
Second crop cycle			
Accession [(1)]	Water regime		
	Simulated rainfall	100% ET_C	20% ET_C
Gema-de-Ovo [(2)]	14.38b	77.29b	28.38a
Engana-Ladrão	16.59b	64.27b	35.22a
BGMS115	12.70b	133.29a	10.63c
BGMS110	12.16b	80.86b	31.03a
BGMS102	73.62a	64.53b	22.74b
BGMS79	23.06b	120.33a	22.37b
BGMS24	29.15b	121.94a	19.98b
BGMS48	14.10b	76.30b	30.50a

[(1)] Accessions from the Work Collection of Wild Species of the *Manihot* Genus of the Embrapa Semiárido.
[(2)] Means followed by same letters in the columns belong to the same group by the Scott-Knott test ($P < 0.05$).
[(3)] Crop evapotranspiration.

With the increase of water supply, under the regime with 100% ET_C, the accessions BGMS115, BGMS-24 and BGMS-79 stood out with the highest means (Table 6). In the regime with 20% ET_C, the highest average results were observed for the accessions Engana-Ladrão, BGMS-110, BGMS-48 and Gema-de-Ovo.

Although BGMS-79 showed similar number of leaves under water regimes with limited water supply in the second crop cycle, this number decreased when the simulated rainfall stopped, indicating the presence of a mechanism of tolerance of the plants to the water stress that causes loss of leaves under limited water conditions.

In addition, differences in shoot yield between accessions and plant age must be considered, since they are factors that affect leaf production, due to increases in the number of leaves, which is important for the survival of the plant and performance of crops, since they capture sunlight for photosynthesis (MORAES et al., 2013; TAIZ et al., 2017). Thus, the number of leaves of plants is dependent on the development stages, for example, dry leaves fall when plants are older or under stress (VANDEGEER et al., 2013).

Engana-Ladrão, Gema-de-Ovo and BGMS115 had the highest genotypic means for leaf lobe length, with simulated rainfall in the first cycle (Table 7). The accessions evaluated showed similar genotypic means with 100% ET_C and 20% ET_C. BGMS-102, BGMS-115, BGMS-24, and BGMS-79 had the highest genotypic means with simulated rainfall in the second crop cycle. They maintained the leaves even with low irrigation in this period, indicating a mechanism of tolerance to water stress conditions. Gema-de-Ovo and Engana-Ladrão had the highest genotypic means with 100% ET_C. The genotypic means of the accessions were similar with 20% ET_C (Table 7).

Table 7. Genotypic means for leaf lobe length (cm) of accessions of the genus *Manihot* subjected to different water regimes in two crop cycles.

First crop cycle			
Accession [(1)]	Water regime		
	Simulated rainfall	100% ET_C [(3)]	20% ET_C
Gema-de-Ovo [(2)]	26.09a	15.68a	10.83a
Engana-Ladrão	27.29a	14.00a	12.43a
BGMS115	27.00a	14.31a	12.88a
BGMS110	13.31b	14.78a	12.82a
BGMS102	16.46b	14.78a	11.97a
BGMS79	15.35b	14.10a	12.90a
BGMS24	15.65b	13.90a	13.03a
BGMS48	14.26b	16.28a	12.19a
Second crop cycle			
Accession [(1)]	Water regime		
	Simulated rainfall	100% ET_C	20% ET_C
Gema-de-Ovo [(2)]	0.80b	17.27a	12.90a
Engana-Ladrão	1.48b	15.81a	10.65a
BGMS115	12.92a	12.65a	13.82a
BGMS110	1.50b	13.69a	12.68a
BGMS102	13.75a	13.46a	12.31a
BGMS79	12.48a	13.54a	11.80a
BGMS24	12.65a	13.42a	11.84a
BGMS48	1.38b	13.92a	13.12a

[(1)] Accessions from the Work Collection of Wild Species of the *Manihot* Genus of the Embrapa Semiárido. [(2)] Means followed by same letters in the columns belong to the same group by the Scott-Knott test ($P < 0.05$). [(3)] Crop evapotranspiration.

The accession had greater genotypic means for leaf lobe length with simulated rainfall and 100% ET_C in the first crop cycle, and reduced genotypic means with 20% ET_C, showing leaf losses as a defense mechanism for mitigating the effects of water stress, allowing its survival. The genotypic means were also reduced in the second crop cycle, mainly in the simulated rainfall.

Leaf length and width are also connected to leaf area, whose reduction is one of the most important plant defense mechanisms against water deficit. Considering the morphological characteristics, reduction of leaf area is one of the first reactions of plants to water deficit (TAIZ et al., 2017). Moreover, there is a smaller reduction in the leaf lobe length and, consequently, in leaf area, which decreases transpiration and lessens the risk of permanent wilt in plants under water deficit (ARRUDA et al., 2015). In general, considering the two crop cycles evaluated, the genotypic means of the accessions under the water regimes used were similar, especially those of accessions subjected to the greatest and lowest water availability. It may be due to the sensitivity of the studied materials to water stress regarding leaf lobe length (Table 7).

The accessions showed similar genotypic means for leaf lobe width under the water regimes evaluated in the first crop cycle (Table 8). BGMS-102, BGMS-115, BGMS-24, and BGMS-79 had the greatest genotypic means with simulated rainfall in the second crop cycle, indicating the feasibility of planting these accessions in areas with water shortage conditions. The water availability in the 100% ET_C and 20% ET_C regimes in the first crop cycle did not affected the genotypic means in the second crop cycle.

In general, the lower water supply reduced the genotypic means for leaf lobe width, and the greater water supply resulted in similar genotypic means for all accessions evaluated in the first and second crop cycles. However, BGMS-48, BGMS-110, Gema-de-Ovo, and Engana-Ladrão had reductions in genotypic means with simulated rainfall in the second crop cycle, denoting genetic materials highly sensitive to water stress.

According to PEZZOPANE et al. (2015), abiotic stresses generate a series of responses of plants through gene expression and cellular metabolism that reduce their cellular osmotic potential, and leaf expansion and overall growth are strongly affected by this reduction in cellular turgor resulting from water stresses. Leaf lobe width is also connected to leaf area and mechanisms of reduction of leaf lobe length and width, and closure of stomata, acceleration of senescence, and leaf abscission are the main responses of plants to water deficit, in the attempt to maintain the cellular water potential (TAIZ et al., 2017). This was shown mainly by the reduction of the genotypic means of leaf lobe width of accessions subjected to low water supply, regardless of the crop cycle (Table 8). Plants with greater leaf length and width subjected to water stress lose their leaves by accelerating senescence. In addition, the larger the leaf area, the greater the loss of water through transpiration.

Table 8. Genotypic means for leaf lobe width (cm) of accessions of the genus *Manihot* subjected to different water regimes in two crop cycles.

First crop cycle			
Accession [1]	Water regime		
	Simulated rainfall	100% ET_C [3]	20% ET_C
Gema-de-Ovo [2]	5.26a	5.30a	4.39a
Engana-Ladrão	4.99a	5.05a	4.80a
BGMS115	5.49a	5.05a	4.51a
BGMS110	5.09a	5.26a	4.59a
BGMS102	5.29a	5.29a	4.39a
BGMS79	5.36a	5.12a	4.45a
BGMS24	5.28a	5.08a	4.59a
BGMS48	5.24a	5.53a	4.29a
Second crop cycle			
Accession [1]	Water regime		
	Simulated rainfall	100% ET_C	20% ET_C
Gema-de-Ovo [2]	0.59b	5.30a	4.42a
Engana-Ladrão	1.22b	4.03a	3.28a
BGMS115	4.47a	3.64a	5.60a
BGMS110	0.43b	5.39a	4.95a
BGMS102	4.79a	4.22a	4.38a
BGMS79	4.05a	4.59a	4.09a
BGMS24	4.34a	4.50a	4.08a
BGMS48	0.19b	5.61a	5.67a

[1] Accessions from the Work Collection of Wild Species of the *Manihot* Genus of the Embrapa Semiárido. [2] Means followed by same letters in the columns belong to the same group by the Scott-Knott test ($P < 0.05$). [3] Crop evapotranspiration.

In the first crop cycle, BGMS-79, BGMS-115, BGMS-102 and BGMS-24 had the highest genotypic means for shoot dry mass production with simulated rainfall (Table 9). Most accessions showed similar genotypic means with 100% ET_C, especially BGMS-115, BGMS-102 and BGMS-24. BGMS-102 and BGMS-79 had the highest mean for shoot dry mass production with 20% ET_C, denoting genetic materials tolerant to water stress. In the second crop cycle, Gema-de-Ovo had the highest genotypic means for shoot dry mass with simulated rainfall, followed by BGMS-115, BGMS-102 and BGMS-24. BGMS-24 had the highest genotypic means with the 100% ET_C, whereas Gema-de-Ovo and Engana-Ladrão had the lowest means. Accessions with 20% ET_C had their genotypic means strongly reduced, denoting the importance of water for the survival and development of these plants. In the second crop cycle, BGMS-102, BGMS-79 and BGMS-24 had higher genotypic means with simulated rainfall than the other accessions in the same crop cycle with 20% ET_C.

The accessions with greater water supply had higher genotypic means for shoot dry mass production (Table 9), and lower genotypic means with water limitation, in the first and second crop cycles with simulated rainfall and 20% ET_C. This can be attributed to the water stress, which may have caused negative effects on cellular turgidity of the plant tissues, and negative alterations in the spatial relationships in membranes and organelles through the reduction of their volume, reducing the hydrostatic pressure inside the cells; this denotes the importance of water to the plant development and production (SANTOS et al., 2012). According to Teodoro et al. (2015), growth analysis through evaluation of dry weight is important to understand the performance of current cultivars, considering that several physiological processes affecting plant development are related to this parameter. Thus, production and development of plants are connected to water use efficiency and must be the basis for the genetic improvement of agricultural-interest species intended for greater productivity with a lower water demand.

Table 9. Genotypic means for shoot dry mass production (kg.ha^{-1}) of accessions of the genus *Manihot* subjected to different water regimes in two crop cycles.

First crop cycle			
Accession [(1)]	Water regime		
	Simulated rainfall	100% ET_C [(3)]	20% ET_C
Gema-de-Ovo [(2)]	485.19b	663.67b	182.63c
Engana-Ladrão	224.61c	496.89b	266.85b
BGMS115	1480.42a	1429.42a	186.75c
BGMS110	50.90d	383.11c	49.64d
BGMS102	1463.42a	1277.56a	333.67a
BGMS79	1734.14a	892.25b	342.79a
BGMS24	1317.39a	1147.44a	247.25d
BGMS48	80.67d	710.58b	54.50c
Second crop cycle			
Accession [(1)]	Water regime		
	Simulated rainfall	100% ET_C	20% ET_C
Gema-de-Ovo [(2)]	314.51a	505.57d	33.47b
Engana-Ladrão	132.50c	270.22d	48.00b
BGMS115	277.42b	1612.00b	99.00b
BGMS110	142.17c	1018.58c	13.65c
BGMS102	264.67b	833.17c	410.00a
BGMS79	202.67c	811.08c	341.83a
BGMS24	297.92b	2039.17a	260.50a
BGMS48	149.08c	1130.25c	16.37c

[(1)] Accessions from the Work Collection of Wild Species of the *Manihot* Genus of the Embrapa Semiárido. [(2)] Means followed by same letters in the columns belong to the same group by the Scott-Knott test ($P < 0.05$). [(3)] Crop evapotranspiration.

The biomass production was affected by the water regimes, so the accessions that had the highest genotypic means for shoot dry mass production showed physiological or morphological mechanisms for their development under these conditions, maintaining tissue hydration or active metabolism while dehydrated (TAIZ et al., 2017). However, a higher biomass production requires greater availability of water to the plant due to its increased transpiration (BERNIER et al., 2008). Studies have pointed out the existence of varietal differences in *Manihot* spp. and differences in their responses to stress situations. Oliveira et al. (2015) evaluated genetic parameters for drought tolerance in *Manihot* sp. and confirmed this fact, concluding that estimates of genetic variances are higher under water deficit conditions for most agronomic variables for this crop.

For 20% ET_C treatment, the accessions with the highest genotypic means for the characteristic dry matter production were BGMS79 and BGMS102, in both crop cycles. These accessions also obtained higher genotypic means for this trait for treatments with rain simulation and 100% ET_C.

Considering the genotypes separately and, regardless of the cropping cycle, the characters number of leaves, length and width of the leaf blade and dry mass of the leaves were efficient in indicating variability among the genotypes under the conditions applied in the treatments under study.

CONCLUSIONS

The highest genotypic means were expressed by the accessions BGMS115, BGMS102, BGMS79 and BGMS24, for most of the variables analyzed in this work, regardless of the cropping cycle, indicating high genetic potential to tolerate cultivation under rainfed conditions or with limited water use by irrigation.

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