Macrothink Institute™

Journal of Agricultural Studies
ISSN 2166-0379
2020, Vol. 8, No. 2

Spatial Arrangement Management of Maize Hybrids at Semiarid Microclimate

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Received: Oct. 23, 2019 Accepted: Nov. 14, 2019 Published: Nov. 17, 2019

doi:10.5296/jas.v8i2.15686 URL: https://doi.org/10.5296/jas.v8i2.15686

Abstract

Maize (*Zea mays* L.) is a plant of the Poaceae family, originating in Central America and cultivated in practically every region of the world. In Brazil, it is the most important cereal for the economy, but the productivity is lower when compared to other countries. This may be due to inadequate plant density per unit area, low soil fertility and spatial arrangement of plants. Thus, the development of better performance hybrids and changes in sowing density and spacing appear as techniques for increasing productivity without increasing production costs. Therefore, the objective of this work is to evaluate the agronomic performance of two maize hybrids as a function of plant population and row spacing in semiarid microclimate to identify those agronomic and microclimatic factors that influence it. Two simultaneous fieldwork were conducted in an experimental area, at the microregion of Paraíba swamp. A randomized complete block design was used with six treatments distributed in a 2 x 3 factorial scheme, resulting from the combination of two maize hybrids (H1 and H2) and three population densities (40,000, 60,000 and 80,000 plants.ha^{-1}) for Experiment 1; and two maize hybrids (H1 and H2) and three spacings (0.40, 0.60 and 0.80 m) for Experiment 2. In general, the results of this study suggest that larger populations of maize provide significant increases in grain yield for microclimatic conditions Paraíba semiarid, and when environmental factors are not limiting.

Keywords: *Zea mays* L., plant row spacing, plant population density, agronomic performance

1. Introduction

Maize *(Zea mays* L.) is a plant of the Poaceae family, originating from Central America and cultivated in practically every region of the world (Ferreira et al., 2015). Due to its productive potential, chemical composition and nutritional value, it assumes a relevant worldwide socioeconomic role (Fancelli and Dourado Neto, 2000).

In Brazil, maize is the most important cereal for the economy. In the 2017/2018 harvest, over 80 million tons of grain were produced on about 17 million hectares, with an average yield of 4,857 kg.ha^{-1} of grain (Anonyme, 2019). Despite its importance in Brazilian agribusiness, productivity is lower when compared to other countries, such as the United States, which average over 10,000 kg.ha^{-1} (Sangoi et al., 2010; Chioderoli et al. 2012). This may be due to inadequate plant density per unit area, low soil fertility and spatial arrangement of plants (Duarte and Kappes, 2015).

The Brazilian semiarid region covers about 60% of the Northeast area and is periodically affected by the occurrence of droughts (Fechine, 2012). The main problems in this region are rainfall irregularity and scarcity, with annual average rainfall of 800 mm or less (Cirilo, 2008), with predominance of intense but short-term rainfall. In this sense, the semiarid is characterized as a region of areas vulnerable to environmental limitations and with partial or total losses in the agricultural sector, which is practically subsistence, with maize and beans being the main crops (Brito et al., 2012; Rodrigues et al., 2019).

Given the importance of cereals to Brazil and the world, it is necessary to determine productivity increase techniques without increasing production costs. Therefore, development of better performance hybrids and changes in sowing density and spacing appear as alternatives that optimize the utilization of area units (Argenta et al., 2001; Mendes et al., 2013).

Current maize hybrids generally do not tiller, produce only one ear per plant and do not have the ability to compensate for casual emergence failures (Santos et al., 2012). According to Argenta et al. (2001), new hybrids respond better to more regular plant distribution, increasing their grain yield potential. Therefore, in order to increase crop yield, choosing the ideal plant arrangement is of paramount importance because it directly influences the interception of solar radiation, which is the main factor for grain yield, since others, such as water and nutrients, are available (Brachtvogel et al., 2012).

Therefore, changes in plant density, through crop line distribution and row spacing, have been the focus of several researchers (Pereira et al., 2018). Evaluating the effect of spatial arrangement on maize yield, Pereira et al. (2008) observed that reducing row spacing or increasing plant density alone increases grain yield for the varieties tested.

Among the spatial arrangement management techniques, the population is the one that most influences the grain yield of maize, acting directly on the ability of the crop to capture environmental resources (Almeida Júnior et al., 2017; Pereira et al., 2018). Observing the effect of plant population on growth and yield of two maize hybrids, Silva et al. (2014) concluded that the densities of 60,000 and 80,000 plants ha-1 provide grain yield increases of 12.5 and 13.6%, respectively, when compared to the population of 40,000 plants ha^{-1}.

The row spacing of the crop also has a strong relationship with the spatial arrangement of plants, enabling a reduction in intraspecific competition (Foloni et al., 2014). The reduction in spacing increases the distance of seeds in the same line, making the spatial distribution of plants more regular and contributing to greater absorption efficiency of environmental factors such as water, light and nutrients (Miotto, 2014). According to Boiago et al. (2017), equidistantly spaced plants compete minimally for environmental resources; however, the positive effect of reduced spacing on grain yield is most clearly manifested at higher densities.

Although, the behavior of maize hybrids in different densities and spacings does not always coincide, especially in different climatic conditions (Sangoi et al., 2004), in other words, the results may be controversial, since productivity is also a function of the variation of environmental conditions and genotypes (Boiago, et al., 2017).

Studies that seek a better spatial arrangement of plants for the new hybrids in the market are necessary for maize cultivation, as well as to know the behavior of the crop in relation to the environmental factors of each region. Therefore, the objective of this work is to evaluate the agronomic performance of two maize hybrids as a function of plant population and row spacing in semiarid microclimate.

2. Material and Methods

Two simultaneous fieldwork (Experiments 1 and 2) were conducted, between April and July 2018, in an experimental area of the Center for Agricultural Sciences of the Federal University of Paraíba (CCA/UFPB), in Areia-PB, located at the microregion of Paraíba swamp.

2.1 Climatic and Water Characterization

The climate of the region is characterized as AS' (hot and humid) by the Köppen classification, with annual average rainfall around 1400 mm and annual average temperature between 23 and 24 ºC. Total precipitation in the period from sowing to harvest was 593.3 mm. The temperature was relatively constant, averaging 21.82 ºC (Figures 1 and 2).

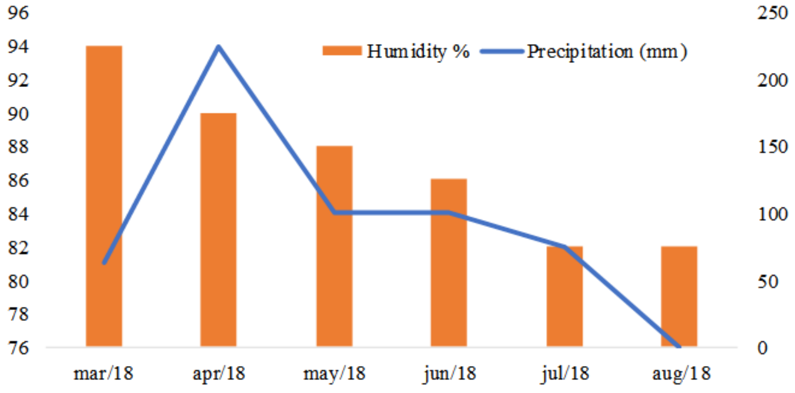

Figure 1. Water characterization of maize crop during the execution of the experiment (INMET, 2019)

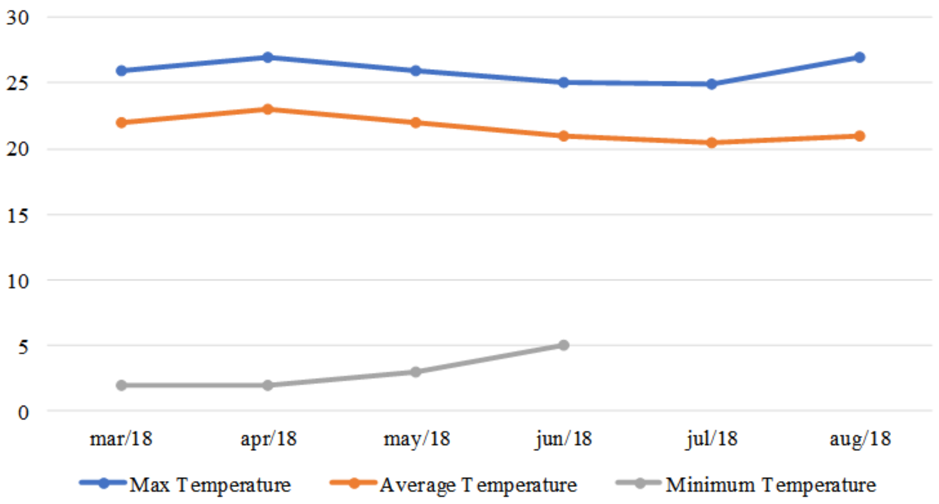

Figure 2. Climatic characterization of maize crop during the execution of the experiment (INMET, 2019)

2.2 Experimental Design and Growing Conditions

The soil was classified as Haplic Gleysol (EMBRAPA, 2013), whose results from chemical, physical and fertility analyzes are shown in table 1.

Table 1. Chemical, physical and fertility analyzes of soil sample (0-20 cm layer) from experimental area

Chemistry and fertility									
pH	P	$S\text{-}SO4^{-2}$	K^+	H^++Al^{+3}	Al^{+3}	Ca^{+2}	Mg^{+2}	SB	CTC
H_2O (1:2.5)	mg/dm^3			cmolc/dm^3					
6.2	75.35	2.89	67.03	0.04	0.00	2.00	1.32	3.53	5.71
						Physics			
M.O.	Zn	Fe	Mn	Cu	B	Sand	Silt	Clay	Textural class
g/kg	mg/dm^3					g/kg			
4.36	0.93	3.42	3.25	0.04	0.50	820	96	84	Sandy texture

P, K, Na: Mehlich Extractor 1

H + Al: 0.5 M Calcium Acetate Extractor, pH 7.0

Al, Ca, Mg: 1 M KCl Extractor

SB: Sum of exchangeable bases

CTC: Cation Exchange Capacity

M.O.: Organic Material – Walkley-Black

A randomized complete block design was used with four replications and six treatments distributed in a 2 x 3 factorial scheme, resulting from the combination of two maize hybrids (H1 and H2) and three population densities (40,000, 60,000 and 80,000 plants.ha^{-1}) for Experiment 1; and two maize hybrids (H1 and H2) and three spacings (0.40, 0.60 and 0.80 m) for Experiment 2.

The experimental plot consisted of four 5 m lines spaced according to the treatments for Experiment 2 and 0.50 m for Experiment 1; with the evaluations carried out in the two central lines, dispensing the first three plants of the borders (useful area of 5 m^2).

Sowing was done manually using 2, 3 and 4 seeds per linear meter, according to the population density of each treatment for Experiment 1, and 2 seeds per pit in Experiment 2, both at a depth of 3 to 4 cm. Thinning of seedlings was performed twenty days after sowing, leaving one plant per pit only in the second experiment.

For fertilization, 167 kg.ha^{-1} of urea (30% at planting and the remaining split at 30 and 45 days after sowing, close to row, without incorporation) and 192 kg.ha^{-1} of potassium chloride (100% at planting, incorporated to a depth of 10 cm). The source of phosphorus was the residue present in the area, dispensing with the use of phosphate fertilizers.

Weed control was carried out by the mechanical method, with the help of hoes, whenever a high level of infestation was observed.

2.3 Measurements

Growth and developmental evaluations were carried out from the 20th day after emergence (DAE) and repeated every 15 days until harvest. The following variables were observed: plant height (soil measurement until the apex of the last fully opened leaf, in meters), stem diameter (in the region of 1 cm of the plant's neck, in centimeters); leaf width and length (comprising leaf measurements in the middle third of the plant in centimeters) and number of leaves. The results correspond to the average of three random plants of the plot.

Only for Experiment 2, physiological analyzes were performed on the flag leaf at 106 DAS, and measured: photosynthetic rate, stomatal conductance, internal carbon, transpiration and leaf temperature, using an infrared gas analyzer (IRGA).

Harvesting took place at 134 DAS, with the ears of plants marked at 30 DAS being harvested. The evaluations performed were ear length and diameter (in cm), number of rows (number of rows of one ear) and grain weight (to determine yield, expressed in kg.ha^{-1}).

2.4 Statistical Analysis

The obtained data were submitted to the Shapiro-Wilk test at 5% of significance to determine their normality. In order to verify the effects of the factors, the analysis of variance was performed by the F test. If there was significant difference, the Tukey test was performed at 5% probability for comparison of hybrids and regression analysis to verify the effects of populations (Experiment 1) and spacings (Experiment 2). The data was processed by the R system (R, 2016).

3. Results and Discussion

3.1 Experiment 1

The analysis of variance from the growth and production data showed significant difference only for the isolated factors of evaluation period, hybrid and population. Thus, no interaction of any of the interactions was performed, evaluating the factors only in their average effect (table 2).

Table 2. Summary of variance analysis of growth data (plant height, stem diameter, leaf width, leaf length and number of leaves) and yield (ear length, ear diameter, number of rows, number of grains per row and yield) of two maize hybrids evaluated in three populations over three evaluation periods (except yield)

Sources of Variation		Average square									
		Growth					Yield				
	DF	ALT P	DA C	LARG F	COMP F	N F	COMP E	DA E	N FIL	N GR FIL	PROD
Evaluation Season	2	39886.32*	2.99*	73.67*	8130.23*	156.03*					
Hybrid (H)	1	141.57	0.06*	0.12	411.27	0.08					
Population (P)	2	207.07	0.01	0.40	494.41	0.26	2.20	0.09	1.21	24.47	2925050.00*
H x P	8.14	0.08	0.18	337.10	0.06	0.71	0.02	0.26	0.08	3941341.11	8.14
Residual	51										
VC (%)		24.31	11.60	25.45	40.60	9.93	12.84	10.00	10.48	12.76	25.28

Note that the growth variables showed the same trend of evolution, showing increasing values throughout the evaluations (table 3). This indicates that, during the study, the plants were still in vegetative growth, as characteristics such as cessation of phytomass accumulation, leaf fall and stem mass decrease are observed due to the onset of senescence and the transfer of carbohydrates to growing organs such as the ears (Lopes et al., 2009).

Table 3. Plant height, stem diameter, leaf width, leaf length and number of maize leaves in three evaluation periods

Evaluation Season	ALT P	DA C	LARG F	COMP F	N F
1st	33.03 a	1.59 a	2.55 a	28.96 a	4.7 a
2nd	61.85 b	1.95 b	4.66 b	46.32 b	7.0 b
3rd	113.49 c	2.3 c	6.03 c	65.75 c	9.8 c

Averages followed by different letters in column differ from each other by Tukey test at 5% probability

Based on table 2, it is observed that there was no significant difference for most growth and production characteristics. Evaluating morphological characteristics of five maize hybrids, Beleze et al. (2003) observed higher growth trends in earlier hybrids, that is, under the conditions in which the present experiment was conducted, the hybrids showed similar growth.

For stem diameter, number of grains per row and ear length, the highest values are observed in H1 (table 4). Therefore, H1 tended to produce larger and more grain ears, corroborating with Roth et al. (1970), who say that larger stem diameter values are related to higher yield characteristics of maize hybrids; Pereira et al. (2017) attributes this result to the function of the plant's supporting stem.

Table 4. Culm diameter, number of grains per row and ear length of the two maize hybrids

Hybrid	DA C	N GR FIL	COMP E
H1	2.04 a	22.56 a	12.59 a
H2	1.86 b	28.10 b	14.54 b

Averages followed by different letters in the column differ from each other by the Tukey test at 5% probability.

Regarding the population, the analysis of variance showed significant difference only for productivity, with no effect on growth characteristics (table 2). In research on the maize crop, Santos et al. (2017) also found no changes in morphological characters, but stressed the need for evaluations with more cycles, given that the study was only one.

Maize grain yield was the only production characteristic altered by the population and increased linearly with this factor, presenting values of 4,975, 7,522 and 11,060 kg.ha^{-1} for the populations of 40, 60 and 80 thousand plants, respectively (Figure 3). All yields achieved were satisfactory According to Anonyme (2019) the maize grain yield estimates are close to 4,857 kg.ha^{-1}.

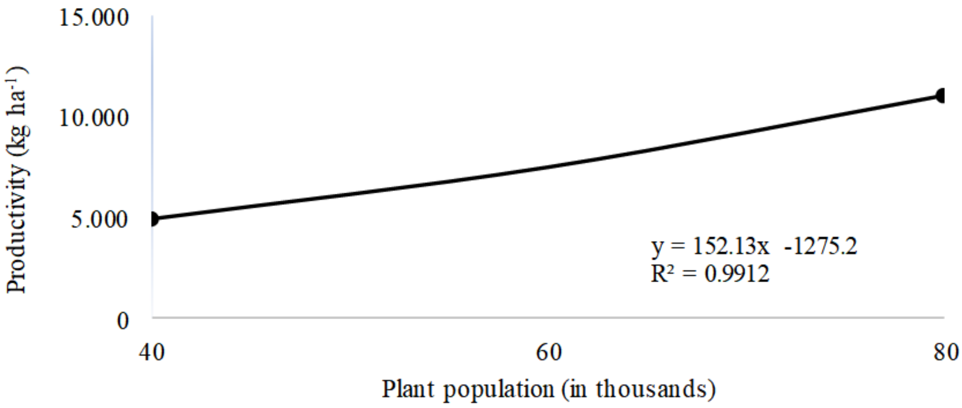

Figure 3. Maize yield as a function of plant population

This increase in productivity can be attributed to the increase in the number of plants and, consequently, to the number of ears per hectare. This fact is quite important because it shows that the increase in plant population favors increase in grain yield, Calonego et al. (2011) and Pereira et al. (2018) drew similar conclusions; Fumagalli et al. (2017) still completes saying that the positive results of the increase of plant population are more observed in reduced spacing.

Other authors, such as Dourado Neto et al. (2003) and Almeida Júnior et al. (2018) found results that go against the present study, with a reduction in productivity due to the increase in population. According to Fancelli & Dourado Neto (2004), the competition for light in dense plantings results in a reduction in sacks productivity per hectare. This indicates that, in the present research, the intraspecific competition was not enough to affect the productivity.

It is important to highlight that this study helps farmers to identify which population best fits the microclimate conditions of the Paraiban semi-arid region, called Paraíba Swamp, where maize cultivation is predominant and the climate is favorable for cultivation between March and July. Population management often allows us to identify the highest productive potential in proper crop management.

For Demetrius et al. (2008), the increase in plant density is one of the easiest and most efficient ways to increase maize grain yield, because the incident solar radiation intercepted by the plant community is greater, increasing its use and, consequently, grain yield; this response is also associated with the fact that maize, unlike other poaceae, does not have an efficient mechanism of space compensation, since it tends little and has low prolificacy and expansion capacity (Strieder et al., 2007).

3.2 Experiment 2

Analysis of variance from growth and yield data showed significant difference only for the isolated factors of evaluation period, hybrid and spacing, except for plant height (table 5).

Table 5. Summary of variance analysis of growth data (plant height, culm diameter, leaf width, leaf length and number of leaves) and yield (ear length, ear diameter, number of rows, number of grains per row and weight) of two maize hybrids evaluated in three spacings over three evaluation periods (except yield).

Sources of Variation		Average square									
		Growth					Yield				
	DF	ALT P	DA C	LARG F	COMP F	N F	COMP E	DA E	N FIL	N GR FIL	WEIGHT
Evaluation Season	2	39778.17**	17.31*	89.44*	8378.39*	25.22*	-	-	-	-	-
Hybrid (H)	1	55.20	0.21	0.97	82.18	0.64	4.17	0.01	1.70*	29.04*	0.02
Spacing (E)	2	45.87	0.54*	3.59	232.95	0.01	7.07	0.06	0.78	42.52*	0.04
H x E	2	169.93*	0.26	1.88	17.79	0.05	0.14	0.02	0.84	1.50	0.01
Residual	51										
VC (%)		8.61	16.34	15.39	12.96	7.52	9.53	3.96	3.79	6.68	15.41

As in Experiment 1, growth variables showed growth throughout the evaluations (table 6), demonstrating that these plants did not initiate the senescence period either.

Table 6. Plant height, culm diameter, leaf width, leaf length and number of maize leaves in three evaluation periods

Evaluation Season	ALT P	DA C	LARG F	COMP F	N F
1st	32.77 a	1.69 a	5.40 a	53.45 a	6.86 a
2nd	76.00 b	2.40 b	7.14 b	69.97 b	7.86 b
3rd	114.14 c	3.38 c	9.25 c	90.74 c	8.91 c

Averages followed by different letters in column differ from each other by Tukey test at 5% probability

According to table 5, there is no significant difference between hybrids for growth characteristics, indicating that both showed similar growth, as in Experiment 1.

H1 presented higher row and grain numbers per row, presenting some advantage in production characteristics over H2, as in Experiment 1 (table 7).

Table 7. Number rows and number of grains per row of the two maize hybrids

Hybrid	N FIL	N GR FIL
H1	15.36 a	30.98 a
H2	14.83 b	28.78 b

Averages followed by different letters in column differ from each other by Tukey test at 5% probability

As for spacing, the analysis of variance found significant difference only for stem diameter and number of grains per row (table 5), results that are expressed in Figure 4, showing that this characteristic did not influence expressive yield gains, such as in ear size or grain weight.

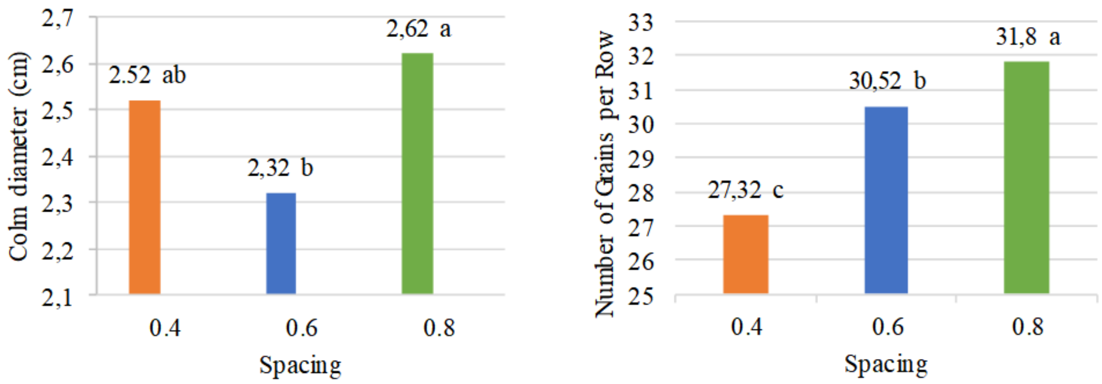

Figure 4. Culm diameter and number of grains per row of maize as a function of row spacing

Results obtained by Torres et al. (2013) corroborate this work, where the reduction of row spacing does not provide higher plant height. Authors who found this correlation attribute it to culm elongation caused by increased competition for sunlight (Argenta et al., 2001).

Assessing maize yield for silage at different spacings, Vieira & Antunes (2018) found similar results and concluded that row spacing modifications do not generate gains when the plant population is not altered.

The studies about line spacing reduction on maize grain yields present quite divergent results. While some results indicate significant increases with reduced spacing (Strieder, 2006; Boiago et al., 2017), others have not detected any benefit of thickening (Flesch and Vieira, 2004; Calonego et al., 2011). These results can be attributed to several factors, such as the tested hybrid, the plant population, the region's soil and climate characteristics, among others (Sangoi *et al*., 2002).

Denser row spacing is known to reduce weed competition due to rapid closure of spacing and lower incidence of light on the soil surface; while more spaced lines can facilitate labor and avoid tipping over possible injuries during handling. Given this, the choice of adequate spacing will also depend on the technological level of the property and the labor used (Fornasieri Filho, 2007; Kappes, 2010; Vieira and Antunes, 2018)

Analysis of variance of physiological data showed no significant difference for any of the factors (table 8).

Table 8. Summary of variance analysis of photosynthetic rate, stomatal conductance, internal carbon, transpiration and leaf temperature data of two maize hybrids evaluated in three spacings

Sources of Variation	DF	Average square				
		TX FT	CE	CI	TRNSP	T F
Hybrid (H)	1	0.35	0.01	1240.28	0.07	0.03
Spacing (E)	2	20.05	0.01	696.70	0.25	0.20
H x E	2	10.53	0.01	177.77	0.34	0.46
Residual	15					
VC (%)		11.20	18.52	28.18	13.31	2.63

Photosynthetic rate, stomatal conductance and internal carbon are physiological variables influenced by environmental factors such as water availability, light and energy (Ometto et al., 2003); showing that, in this experiment, water deficit and shading were limiting factors.

The transpiration average was 3.55 mmol H_2O m^{-2} s^{-1}, common value for C4 plants (Brito et al. 2013). This characteristic is related to the capacity of the root system to replenish water to the leaves and, consequently, to the stomatal opening. Thus, the reduction in row spacing did not cause intraspecific water competition among maize plants to the point of affecting them. The leaf temperature, in turn, is influenced by perspiration, since the loss of water in the form of vapor causes a decrease in the temperature of the leaf border, helping to regulate the leaf temperature (Nunes and Secon, 2011).

4. Conclusion

In general, larger populations of maize provide significant increases in grain yield for microclimatic conditions Paraíba semiarid, and when environmental factors are not limiting.

Under local conditions of the Paraíba Semiarid microclimate, spacings ranging from 0.4 to 0.8 m do not change grain yield.

The results of this study suggest that maize crop evaluations are required over two or more cycles for better spacing results.

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