

# WATER AND AGRONOMIC EVALUATION OF MAIZE HYBRIDS IN RESPONSE TO DIFFERENT ENVIRONMENTS AND NITROGEN DOSES

Homero Alonso-Sánchez<sup>1</sup>, Margarita Tadeo-Robledo<sup>1\*</sup>, Alejandro Espinosa-Calderón<sup>2</sup>,  
Benjamín Zamudio-González<sup>2</sup>, Job Zaragoza-Esparza<sup>1</sup>, Consuelo López-López<sup>1</sup>

<sup>1</sup> Universidad Nacional Autónoma de México. Facultad de Estudios Superiores Cuautitlán. Carretera Cuautitlán-Teoloyucan km 2.5, Col. San Sebastián Xhala, Cuautitlán Izcalli, Estado México, México. C. P. 54700.

<sup>2</sup> Campo Experimental Valle de México-INIFAP. Carretera Los Reyes-Texcoco km 13.5, Coatlinchán, Texcoco, Estado de México, México. C. P. 56250.

\* Corresponding author: tadeorobledo@yahoo.com

## ABSTRACT

To achieve water and food safety, it is necessary to identify crops outstanding in regard to efficient water use. In Mexico, the Valles Altos region has frequent water scarcity, so it is necessary to characterize maize genotypes that show outstanding traits under conditions of low water availability. The objective of this study was to identify water productivity, yield and hectolitre weight of white maize hybrids grown in Valles Altos. Ten white maize hybrids were used in the experiment; five from UNAM and five from INIFAP. These hybrids were established under two levels of nitrogen fertilization (low: 80 kg ha<sup>-1</sup> and high 160 kg ha<sup>-1</sup>) in two environments: FESC-UNAM (Cuautitlán Izcalli) and CEVAMEX (Texcoco) in the State of Mexico. The experiment was established as randomized complete blocks, variables were recorded to calculate grain yield at 14 % commercial moisture and related to the volume of water entering each environment, the total water productivity was identified. Statistical analysis was performed with SAS and means were compared with Tukey's test. With a combined analysis, a significant interaction of environment with hybrids and nitrogen fertilization was found in grain yield. Total water productivity, estimated at an overall mean of 0.78 kg m<sup>-3</sup>, was significant for environments, hybrids and nitrogen dosage. Grain yield showed an overall average of 4.8 Mg ha<sup>-1</sup>. In hectolitre weight, a significant difference was found in the environment and hybrid factors, with an overall average of 73.8 kg hL<sup>-1</sup>. Total water productivity was higher in the FESC-UNAM environment where irrigation was not provided, with no significant difference in grain yield.

**Keywords:** *Zea mays*, nitrogen levels, water productivity, grain yield.

## INTRODUCTION

Water availability is a determining factor in maize productivity. As the water stored in the root zone of the plant is depleted and the absence of rainfall and irrigation is accentuated, the plant begins to undergo metabolic and physiological changes. In maize, it is difficult to compensate for the loss in productivity even after the period of water stress is overcome by irrigation or precipitation (Steduto *et al.*, 2012).

**Citation:** Alonso-Sánchez H, Tadeo-Robledo M, Espinosa-Calderón A, Zamudio-González B, Zaragoza-Esparza J, López-López C. 2022. Water and agronomic evaluation of maize hybrids in response to different environments and nitrogen doses. *Agrociencia* <https://doi.org/10.47163/agrociencia.v56i1.2698>

**Editor in Chief:**  
Dr. Fernando C. Gómez Merino

Received: April 16, 2021.  
Approved: January 31, 2022.

**Estimated publication date:**  
February 14, 2022.

This work is licensed under a Creative Commons Attribution-Non-Commercial 4.0 International license.



The relationship of essential elements for cultivated plants with moisture availability to improve water productivity has long been investigated (Navarro and Navarro, 2013). This is intended to develop hybrid materials for water and nitrogen deficient conditions. The effect of moisture and nitrogen (N) levels on the performance of modern hybrids, old hybrids and creole maize has been studied (Kibet *et al.*, 2009). Total water productivity in relation to nitrogen fertilization in maize hybrids has also been addressed (Díaz *et al.*, 2014). Likewise, special protocols have been developed to know the effect of nitrogen fertilization in maize hybrids (Zamudio *et al.*, 2018; Cervantes-Ortiz *et al.*, 2013).

Mineral nutrient deficiency has remarkable impact on maize productivity and the most common deficiency is nitrogen. N is the macronutrient with the highest demand and most deficiencies in most production systems, which directly affects yield variables, and N edaphic utilization is related to soil moisture availability (Navarro and Navarro, 2013). Therefore, in order to stimulate maize production, the N contribution to the crop during the growth and production cycle should be between 180 and 340 kg ha<sup>-1</sup> (Steduto *et al.*, 2012).

In Mexico, maize is remarkable for its socioeconomic importance and recent research on total water productivity (PTA) in relation to N contribution in materials from Valles Altos is scarce. In addition, it is required to compare the performance of several hybrids in a complete study of each of them to know their yield and infer their productivity (Noriega-Navarrete *et al.*, 2021). The objective of this study was to identify the total water productivity of 10 white maize hybrids in relation to nitrogen fertilization in two environments in the Valles Altos, Mexico. The hypothesis was that some of the hybrids show higher total water productivity when the amount of water entering the production system is lower, and denser grains are present, but yield is reduced; the nitrogen dose increases total water productivity.

## MATERIALS AND METHODS

### Experimental sites

One experiment was set up in each environment under field conditions. The first one, was established on June 25, 2019, at the Experimental Field of the Cuautitlán Higher Studies Faculty under the Autonomous National University of Mexico (FESC-UNAM), in Cuautitlán Izcalli, State of Mexico (19° 41' 49" LN and 99° 41' 36" LW), at an altitude of 2250 m. The area has a normal average rainfall of 705.4 mm and a normal average temperature of 15.3 °C. The second environment was planted on June 20, 2019, at the Experimental Campus Valle de México (CEVAMEX) under the National Institute of Forestry, Agricultural and Livestock Research (INIFAP), in Santa Lucia, Texcoco, State of Mexico (19° 29' 29" N and 98° 54' 29" W), at 2244 m of altitude, with mean normal precipitation of 618 mm and mean annual temperature of 16.0 °C.

### Genetic material and experimental design

Five three-lineal maize hybrids from INIFAP were planted in the two environments: H-50, H-47 AE, H-45 AE, H-53 AE, H-51 AE; also, five hybrids from UNAM; Tsiri

Puma, Tlaoli Puma, Atziri Puma, Ixim Puma and Cuxi Puma. The treatments were formed with the evaluation of the two environments (factor A), 10 maize hybrids (factor B) and two levels of nitrogen (factor C) as edaphic fertilization with 80 kg ha<sup>-1</sup> of N (low N, NB) and 160 kg ha<sup>-1</sup> of N (high N, NA). In each environment, treatments were implemented in uniform experimental units (UE) with a randomized complete block design in a factorial arrangement with four replications. The UE consisted of a 5.0 m long by 0.8 m wide furrow, which is an adequate size defined in several works (Escobar, 1981).

In the conventional system and as traditionally done at each site, sowing was done by hand when the soil was dry. In each UE, 50 seeds were uniformly distributed over a 5 m length. Each UE was adjusted to obtain a population density of 65 000 plants ha<sup>-1</sup>. At FESC-UNAM, due to lack of water for irrigation, moisture corresponded only to that available from precipitation (459 mm) during the entire cycle, while at CEVAMEX there was 603 mm of precipitation. In addition, as conventional management, irrigation was applied for germination and two auxiliary irrigations. For fertilization, only urea was used and in both environments one third was applied at sowing and the rest 40 days after sowing (dds).

#### Response variables

In both environments, harvesting was carried out in December 2019. Cobs were harvested manually to obtain field weight (PC). From each UE, 160 in total, five cobs with commercial characteristics and adequate health were selected. This sample was used to calculate grain yield (GR) in Mg ha<sup>-1</sup> with the procedure used by Alonso-Sánchez *et al.* (2020):

$$RG = PC \times MS \times G \times FC \times 1.14$$

where: PC is the field weight of the cobs of the experimental unit in Mg, SM is the dry matter in decimal fraction determined by difference by measuring the moisture content of the sample with a DICKEY-Jhon model GAC 2100 equipment, G is the fraction of grain with respect to the whole cob weight, FC is the conversion factor to infer the yield from the UE (5 m) to 12 500 m which corresponds to the total length of furrows per hectare with the spacing of 0.80 m, 1.14 is the factor to convert grain dry matter yield to yield at 14 % commercial moisture.

To identify the PTA, the volume of water per irrigation (AR) was quantified with irrigation flow rate and irrigation time. The total volume of precipitation water (AP) recorded during the crop cycle at the National Meteorological Service (SMN) stations FES-Cuautitlán (0015043) and Chapingo (0015170) was added; the AR input was only counted in the CEVAMEX environment, since this is where irrigation was applied. The PTA value was calculated with the following formula:

$$PTA = \frac{RG}{AT}$$

where PTA is total water productivity in  $\text{kg m}^{-3}$ , RG is grain yield in  $\text{kg ha}^{-1}$  and AT is total water entering the field in  $\text{m}^3 \text{ha}^{-1}$ , comprising irrigation (AR) and precipitation (AP) inputs.

Individual and combined analyses of variance were performed for the environments in SAS version 9.0 (SAS Inc., 2002). Comparison of means was performed for each variable with Tukey's test ( $p \leq 0.05$ ).

## RESULTS AND DISCUSSION

The volume of water from rainfall accumulated  $4598 \text{ m}^3 \text{ha}^{-1}$  in the FESC-UNAM environment and in CEVAMEX the total volume accumulated totalled  $9378 \text{ m}^3 \text{ha}^{-1}$ , which corresponded to  $6030 \text{ m}^3 \text{ha}^{-1}$  from rainfall and  $3348 \text{ m}^3 \text{ha}^{-1}$  from irrigation. In the first site, no water was available for irrigation and in the second, water was applied according to conventional irrigation management at the site.

### Total water productivity

In the combined statistical analysis of the data, total water productivity (PTA) showed significant differences in the factors environments (A), hybrids (B) and nitrogen fertilization (C). The coefficient of variation was 19.7 % with an overall mean of  $0.78 \text{ kg m}^{-3}$ . In the case of FESC-UNAM, no effect of factors (B) and (C) or their interaction was found; the coefficient of variation was 19.88 % and the general mean was  $1.04 \text{ kg m}^{-3}$  (Table 1).

In CEVAMEX factors (B) and (C) resulted with significant effect without showing interaction between them, with a coefficient of variation of 12.3 % and the overall mean of  $0.52 \text{ kg m}^{-3}$ ; the above may be due to the effect of nitrogen fertilization on PTA, especially when irrigation is applied and when nitrogen doses do not exceed  $300 \text{ kg ha}^{-1}$  (Díaz *et al.*, 2008; Díaz *et al.*, 2014). The result of PTA in the environments coincided with what was reported by Alonso-Sánchez *et al.* (2020) as the location with lower water availability (rainfed) resulted with higher productivity, the opposite of the irrigated location. The above results show that water is used with low productivity when irrigation is applied in a conventional manner and without the use of irrigation scheduling dates and irrigation sheets.

### Grain yield

Grain yield was significant for factors (B) and (C), although there was a significant interaction ( $A \times B$ ) and ( $A \times C$ ). Thus, the effect of factor B and C is not attributed solely to the hybrid or nitrogen fertilization, but to the combination of their effects with the environment; the overall mean resulted lower ( $4.83 \text{ Mg ha}^{-1}$ ) than the  $10.1 \text{ Mg ha}^{-1}$  identified by Alonso-Sánchez *et al.* (2020) for higher water availability in the same

**Table 1.** Mean squares and significance for water productivity, yield and hectolitre weight of ten maize hybrids in two environments with two nitrogen doses. Valles Altos, Mexico. Spring-Fall 2019 cycle.

Source of variation	Variables		
	Total water productivity (kg m <sup>-3</sup> )	Grain yield (Mg ha <sup>-1</sup> )	Hectolitre weight (kg hL <sup>-1</sup> )
COMBINED			
Environment (A)	11.34*	0.02	419.90*
Hybrid (B)	0.26*	12.72 *	140.66*
Nitrogen (C)	0.35*	25.28*	67.34
A × B	0.03	2.94*	65.76
A × C	0.01	14.61*	40.20
B × C	0.02	0.53	23.05
A × B × C	0.03	0.75	34.26
CV (%)	19.70	16.48	8.38
Mean	0.78	4.83	73.80
FESC-UNAM			
B	0.15	3.17*	41.28
C	0.03	0.72	1.74
B × C	0.04	0.85	19.4
CV (%)	19.88	19.88	6.37
Mean	1.04	4.82	75.42
CEVAMEX			
B	0.14*	12.49*	165.14*
C	0.43*	39.17*	105.8
B × C	0.01	0.43	37.91
CV (%)	12.3	12.2	10.12
Mean	0.52	4.84	72.18

\* $p \leq 0.05$ ; CV: Variation coefficient (%).

environments. This result indicates an increase in yield when more water is available, but further studies are needed to demonstrate that this variation is not linear.

At FESC-UNAM, only factor (B) had a significant effect; no interaction between factors (B × C) was found and the overall mean was 4.82 Mg ha<sup>-1</sup>. In CEVAMEX, significant differences were found in factors (B) and (C), with no interaction between them, and the overall mean was 4.84 Mg ha<sup>-1</sup>. In the grain yield of the hybrids used in this study, significant differences were found that are attributed in particular to genotypes, as stated by Tadeo-Robledo *et al.* (2018) and Martínez-Gutiérrez *et al.* (2018).

### Hectolitre weight

The hectolitre weight (PH) showed significant difference among environments and hybrids, but not in the factor (C), as also observed by Cervantes-Ortiz *et al.* (2013) in maize hybrids under nitrogen fertilization and Zamudio *et al.* (2018) in hybrids planted in Valles Altos. However, in the latter study there were significant differences when

different nitrogen sources were tested. This response may be related to the timing of water availability (Navarro and Navarro, 2013), which under rainfed conditions is random and limits the fertilizer potential. Factor interactions were not significant for this variable; its coefficient of variation was 8.38 % and the overall mean was 73.8 kg hL<sup>-1</sup> which is ideal for the maize industrialization process as referred by Zamudio *et al.* (2018) and López-López *et al.* (2020).

At FESC-UNAM, no significant effect of the factors or interaction on PH was found; the coefficient of variation resulted in 6.37 % and the overall mean was 75.42 kg hL<sup>-1</sup>. On the other hand, in CEVAMEX the effect of factor (B) on PH was significant. The dose of nitrogen fertilization had no effect on this variable. The interaction of the factors (B × C) showed no effect, the coefficient of variation was 10.12 %, and the overall mean in this environment was 72.18 kg hL<sup>-1</sup>. The effect of environments by moisture availability, which defines N utilization, and evapotranspiration, inserts variability in PH due to different edaphic and climatic conditions, according to Tadeo-Robledo *et al.* (2018) and Martínez-Gutiérrez *et al.* (2018). In addition, in CEVAMEX it is possible that irrigation management related to antecedent moisture condition may also influence.

#### Comparison of means

PTA was lower in CEVAMEX, where more water entered (9378 m<sup>3</sup> ha<sup>-1</sup>), this water availability resulted in an increase of 4.1 % in the RG, while productivity was higher in FESC-UNAM by 103.92 %; the difference in the amount of water corresponded to 103.96 % higher in CEVAMEX compared to FESC-UNAM, which represented 4780 m<sup>3</sup> ha<sup>-1</sup>. However, the water input from rainfall was higher in CEVAMEX and without applying irrigation 3348 m<sup>3</sup> ha<sup>-1</sup> would be saved. The application of irrigation in CEVAMEX was done by conventional irrigation management at the site when the plants showed water stress since rainfall was random. Although no significant difference was observed in regard to FESC-UNAM, it is possible that yield decreased when irrigation was not applied. In this study, a possibility of saving water by increasing PTA and maintaining yield was observed. It is even possible to conserve productivity by dispensing irrigation in the evaluated environments as also reported by Alonso-Sánchez *et al.* (2020). Further studies are needed to identify the point of maximum PTA to conserve yield without significant difference. Since, as reported by Noriega-Navarrete *et al.* (2021), maize yield stability in the future is possible in scenarios where the amount of applied water and nutrition are controlled.

The PH showed significant difference and it was observed that, under conditions of lower water availability, the weight was higher 4.48 % in FESC-UNAM compared to CEVAMEX, generating heavier grains. These results coincide with what was reported by Zamudio *et al.* (2018) for Valles Altos hybrids, since when moisture availability is limited, the cycle is reduced, the grain dehydrates faster and presents higher density. The response of maize hybrids to low moisture availability has also been observed in other studies such as Zamora-Salgado *et al.* (2011) as hybrids that received less water showed better productivity when 85 % of evapotranspiration was provided.

Sáenz *et al.* (2014) also found better productivity in maize hybrids when 50 % of evapotranspiration was supplied. In the hybrids there was a direct relationship with RG, although the values of PTA and RG were lower than those reported by Alonso-Sánchez *et al.* (2020) for the same materials with higher water availability in the same environments. In this study they ranged from 0.63 to 1.03 kg m<sup>-3</sup> and from 4.03 to 6.7 Mg ha<sup>-1</sup> respectively. These results show that the higher the grain yield and lower the amount of water, the higher the total water productivity (Table 2). The PH in the hybrids ranged from 68.55 to 77.44 kg hL<sup>-1</sup> related to their genetic singularity; these values coincide with those reported by Zamudio *et al.* (2018) for hybrids established in the vicinity of Toluca, State of Mexico.

FESC-UNAM hybrids with average PTA values of 0.82 kg m<sup>-3</sup>, RG of 5.18 Mg ha<sup>-1</sup> and PH of 74.72 kg hL<sup>-1</sup>, were superior to those of CEVAMEX with PTA of 0.73 kg m<sup>-3</sup>, RG of 4.49 Mg ha<sup>-1</sup>, and PH of 72.9 kg hL<sup>-1</sup>. Of note were the hybrids Cuxi Puma and Atziri Puma, which also excelled in those researches of Alonso-Sánchez *et al.* (2020) and Martínez-Gutiérrez *et al.* (2018) in similar environments. In contrast, Puma and H-47 AE showed lower values of PTA, RG and PH. These responses are related to genotypes according to López-López *et al.* (2017) and Martínez-Gutiérrez *et al.* (2018),

**Table 2.** Comparison of means of the factors environment, hybrid and nitrogen dose in Valles Altos, Mexico. Spring-Fall 2019 cycle.

Factor levels	Variable		
	Total water productivity (kg m <sup>-3</sup> )	Grain yield (Mg ha <sup>-1</sup> )	Hectoliter weight (kg hL <sup>-1</sup> )
ENVIRONMENT			
FESC-UNAM	1.04 a	4.82 a	75.42 a
CEVAMEX	0.51 b	4.84 a	72.18 b
DSH	0.0 5	0.24	1.936
HYBRID			
H-47 AE	0.69 cd	4.11 de	68.55 b
H-45 AE	0.74 cd	4.51 ce	76.29 a
H-53 AE	0.86 ac	5.38 bc	76.39 a
H-51 AE	0.68 d	4.25 de	71.98 ab
H-50	0.70 cd	4.18 de	71.20 ab
Tsíri Puma	0.79 bd	4.95 cd	75.27 ab
Tlaoli Puma	0.71 cd	4.33 de	71.56 ab
Atziri Puma	0.94 ab	5.87 ab	77.44 a
Ixim Puma	0.63 d	4.03 e	72.85 ab
Cuxi Puma	1.03 a	6.7 a	76.48 a
DSH	0.18	0.9	7.05
NITROGEN DOSE			
80 kg ha <sup>-1</sup>	0.73 b	4.43 b	73.15 a
160 kg ha <sup>-1</sup>	0.82 a	5.23 a	74.45 a
DSH	0.04	0.24	1.93

Means with different letters in the columns within each variation factor indicate statistical difference (Tukey;  $p \leq 0.05$ ); DSH: honest significant difference.

although it is also possible that they are related to the responses of old and modern hybrids. In fact, it has been proven that modern hybrids show better yields under marginal conditions (Kibet *et al.*, 2009).

The dose of nitrogen fertilization benefited PTA significantly, which coincided with what Diaz *et al.* (2008) reported for maize hybrids under irrigated conditions. This response is related to the effect of water regime on nitrogen availability for crops (Navarro and Navarro, 2013). In the case of RG, the difference in means is not directly attributed to this factor since interaction between factors (A) and (C) was found; that is, water availability and nitrogen dose inserted joint variability. In addition, edaphic effects, such as soil water storage characteristics and climatic factors, such as the variation of climate elements that define evapotranspiration at each site, insert effect on the response, as it was also reported by Díaz-Valdés *et al.* (2014) for an experiment in an arid zone on the effect of nitrogen fertilization on maize hybrids. In this study, no significant effect of nitrogen dose on PH was found, which coincides with the results of Zamudio *et al.* (2018) when they applied urea to hybrid materials from Valles Altos.

#### **Comparison of means between environments**

In the FESC-UNAM environment, the hybrids showed three groups of means in PTA and RG, with respective values from 0.82 to 1.26 kg m<sup>-3</sup> and 3.77 to 5.82 Mg ha<sup>-1</sup>. The hybrids Cuxi Puma, Atziri Puma and H-53 AE showed significant higher values as in Martínez-Gutiérrez *et al.* (2018); Zamudio *et al.* (2018) and Alonso-Sánchez *et al.* (2020) for RG of the same hybrids in Valles Altos environments. In contrast, the hybrid Ixim Puma showed the lowest values (Table 3). No significant difference was found in PH between hybrids, nor was any effect of nitrogen fertilization observed, which is related to the low amount of water that entered the site and reduced N utilization.

In CEVAMEX, the results of PTA and RG of the hybrids ranged from 0.38 to 0.81 kg m<sup>-3</sup> and from 3.59 to 7.58 Mg ha<sup>-1</sup>. Significant differences were found among them, where the hybrids Cuxi Puma, Atziri Puma and H-53 AE also stood out; H-47 AE presented the lowest values in this environment. The PH of the hybrids did not reach significant differences, which shows that under homogeneous water conditions this variable is stabilized in the hybrids used. Nitrogen fertilization had a significant effect on PTA and RG, which may be related to the greater quantity and timeliness of the water provided, as reported by Navarro and Navarro (2013), which allows an adequate soil moisture content for nitrogen absorption.

PTA and RG only formed three groups of means in FESC-UNAM while in CEVAMEX four groups were defined. These contrasts were probably due to the differentiated response of N according to the water conditions at each site since this factor only showed significant difference in the means of the variables PT and RG in CEVAMEX where a greater total volume of water entered.

#### **Comparison of means between nitrogen levels and nitrate levels**

The effect of low (80 kg ha<sup>-1</sup>) and high (160 kg ha<sup>-1</sup>) N levels per environment resulted in such a way that at FESC-UNAM no significant difference was found in the means

**Table 3.** Comparison of means of the variables for the effect of the hybrid and nitrogen dose factors in the FESC-UNAMAM and CEVAMEX environments. Valles Altos, Mexico. Spring-Fall 2019 cycle.

Factor levels	Variable		
	Total water productivity (kg m <sup>-3</sup> )	Grain yield (Mg ha <sup>-1</sup> )	Hectolitre weight (kg hL <sup>-1</sup> )
FESC-UNAM HYBIRDS			
H-47 AE	1.00 ac	4.63 ac	71.25 a
H-45 AE	1.05 ac	4.83 ac	76.18 a
H-53 AE	1.14 ac	5.27 ac	77.17 a
H-51 AE	0.9 bc	4.14 bc	73.71 a
H-50	1.01 ac	4.68 ac	75.32 a
Tsíri Puma	1.03 ac	4.75 ac	76.46 a
Tlaoli Puma	1.00 ac	4.63 ac	77.28 a
Atziri Puma	1.23 ab	5.66 ab	77.33 a
Ixim Puma	0.82 c	3.77 c	72.17 a
Cuxi Puma	1.26 a	5.82 a	77.33 a
DSH	0.34	1.57	7.89
FESC-UNAM NITROGEN DOSE			
80 kg ha <sup>-1</sup>	1.02 a	4.72 a	75.27 a
160 kg ha <sup>-1</sup>	1.06 a	4.91 a	75.57 a
DSH	0.09	0.42	2.15
CEVAMEX HYBRIDS			
H-47 AE	0.38 d	3.59 d	65.85 a
H-45 AE	0.44 cd	4.19 cd	76.4 a
H-53 AE	0.58 b	5.49 b	76.61 a
H-51 AE	0.46 cd	4.36 cd	70.25 a
H-50	0.39 d	3.68 d	67.07 a
Tsíri Puma	0.55 bc	5.14 cb	74.08 a
Tlaoli Puma	0.43 d	4.03 d	65.85 a
Atziri Puma	0.64 b	6.07 b	77.55 a
Ixim Puma	0.45 cd	4.28 cd	73.53 a
Cuxi Puma	0.81 a	7.58 a	75.63 a
DSH	0.1	0.97	12.00
CEVAMEX NITROGEN DOSE			
80 kg ha <sup>-1</sup>	0.59 a	4.14 b	71.03 a
160 kg ha <sup>-1</sup>	0.44 b	5.54 a	73.33 a
DSH	0.028	0.26	3.26

Means with different letters in the columns within each variation factor indicate statistical difference (Tukey;  $p \leq 0.05$ ); DSH: honest significant difference.

of the observed variables of the hybrids, which shows the impact of the water deficit on the soil moisture levels that limit N utilization, since the precipitation observed during the cycle totalled 4598 m<sup>3</sup> ha<sup>-1</sup>; while in CEVAMEX the variables PTA, RG and PH showed significant differences due to fertilization (Table 4), with intervals in low nitrogen levels (0.31 to 0.73 kg m<sup>-3</sup>; 2.87 to 6.82 Mg ha<sup>-1</sup>; 64.4 to 77.37 kg hL<sup>-1</sup>) and high (0.46 to 0.89 kg m<sup>-3</sup>; 4.32 to 8.35 Mg ha<sup>-1</sup>; 66.35 to 77.72 kg hL<sup>-1</sup>). This behaviour, when

**Table 4.** Comparison of means of observed variables of low and high nitrogen levels of CEVAMEX. Valles Altos, Mexico. Spring-Fall 2019 cycle.

Hybrid	Variables		
	Total water productivity (kg m <sup>3</sup> )	Grain yield (Mg ha <sup>-1</sup> )	Hectolitre weight (kg hL <sup>-1</sup> )
CEVAMEX LOW NITROGEN			
H-47 AE	0.31 f	2.87 f	65.35 bc
H-45 AE	0.39 df	3.62 df	76.72 a
H-53 AE	0.53 bc	4.99 bc	75.00 a
H-51 AE	0.42 ce	3.96 ce	71.10 ab
H-50	0.31 ef	2.91 ef	64.40 c
Tsíri Puma	0.45 cd	4.25 cd	72.92 a
Tlaoli Puma	0.39 df	3.60 df	74.10 a
Atziri Puma	0.57 b	5.34 b	77.37 a
Ixim Puma	0.33 ef	3.12 ef	73.17 a
Cuxi Puma	0.73 a	6.82 a	75.20 a
DSH	0.11	1.09	6.579
CEVAMEX HIGH NITROGEN			
H-47 AE	0.46 d	4.32 d	66.35 c
H-45 AE	0.51 cd	4.76 cd	76.07 a
H-53 AE	0.64 bd	6.00 bd	76.22 a
H-51 AE	0.51 cd	4.76 cd	69.40 bc
H-50	0.48 cd	4.47 cd	69.75 bc
Tsíri Puma	0.65 bc	6.05 bc	75.25 ab
Tlaoli Puma	0.48 cd	4.48 cd	72.60 ab
Atziri Puma	0.73 ab	6.81 ab	77.72 a
Ixim Puma	0.58 bd	5.46 bd	73.90 ab
Cuxi Puma	0.89 a	8.35 a	76.07 a
DSH (0.05)	0.18	1.69	6.012

Means with different letters in the columns within each variation factor indicate statistical difference (Tukey;  $p \leq 0.05$ ); DSH: honest significant difference.

there is higher water availability, has also been reported by Tadeo-Robledo *et al.* (2018) and Zamudio *et al.* (2018) for maize hybrids planted in Valles Altos.

Hybrid means showed significant differences in CEVAMEX; Cuxi Puma and Atziri Puma stood out in PTA and RG, which is associated with maximum PH values. The low level generated six groups of means and the high level generated four groups. This difference may be related to the greater effect of low nitrogen inputs with respect to high ones as theoretically referred by Navarro and Navarro (2013). The reason is likely due to the differentiated response of genotypes in terms of their ability to absorb N at different soil moisture levels conducive to irrigation management, occurrence of precipitation and variation of climate elements that determine evapotranspiration. The results of this study contribute to offer solutions to the current problems on maize production raised by Zamudio *et al.* (2018) and Tadeo-Robledo *et al.* (2018) in a scenario of greater water scarcity in the future as proposed by (Noriega-Navarrete *et al.*, 2021); questions are also generated to conduct new research in the field of water and food

security for both Mexico and the world. The threshold of maximum reduction of water provided through deficit conditions without yield reduction should be investigated.

### CONCLUSIONS

The total water productivity of the hybrids was higher in the FESC-UNAM environment where irrigation was not provided, and no significant reductions in grain yield were observed.

The effect of nitrogen dose was related to water availability. The high nitrogen dose generated higher productivity and grain yield and was directly related to water quantity; at FESC-UNAM, with lower water quantity, no effect was found.

The hybrids Cuxi Puma and Atziri Puma surpassed in total water productivity, grain yield and hectolitre weight. Therefore, they are an alternative for producers in Valles Altos, Mexico under conditions of low water availability.

### ACKNOWLEDGEMENTS

To the Autonomous National University of Mexico (UNAM), for supporting this research as part of the Support Program to Technological Research and Innovation Projects (PAPIIT: IA208519). To Dr. Gustavo Mercado Mancera, from the Cuautitlán Higher Studies Faculty, for providing useful climate information data collected at the Weather Station at Cuautitlán Higher Studies Faculty.

### REFERENCES

- Alonso-Sánchez H, Tadeo-Robledo M, Espinosa-Calderón A, Zaragoza-Esparza J, López-López C. 2020. Productividad del agua y rendimiento de maíz bajo diferente disponibilidad de humedad. *Revista Mexicana de Ciencias Agrícolas* 11: 1005-1016. <https://doi.org/10.29312/remexca.v11i5.2118>
- Cervantes-Ortiz F, Covarrubias-Prieto J, Rangel-Lucio JA, Terrón-Ibarra AD, Mendoza-Elos M, Preciado-Ortiz RE. 2013. Densidad de población y fertilización nitrogenada en la producción de semilla híbrida de maíz. *Agronomía Mesoamericana* 24: 101-110.
- Díaz-Valdés T, Partidas-Rubalcaba L, Suárez-Fernández YE, Lizárraga-Jiménez R, López-López A. 2014. Uso eficiente del agua y producción óptima en maíz, con el uso de cuatro dosis de nitrógeno. *Revista Ciencias Técnicas Agropecuarias* 23: 32-36.
- Díaz VT, Pérez D NW, López G A, Partidas R L, Suárez YE. 2008. Manejo sostenible del agua en zonas semiáridas: evaluación de dos técnicas de riego y fertilización nitrogenada en Sinaloa, México. *Revista Ciencias Técnicas Agropecuarias* 17: 53-56.
- Escobar C. 1981. Estimación del tamaño óptimo de parcela experimental para ensayos de rendimiento con maíz. *Revista Facultad Nacional de Agronomía Medellín* 34 (1): 31-36.
- Kibet-Serrem C, López-Castañeda C, Kohashi-Shibata J. 2009. Efecto del nivel de humedad y nitrógeno en el suelo en el comportamiento de maíces híbridos y criollos de los valles altos de México. *Agronomía Costarricense* 33: 103-120.
- López-López C, Tadeo-Robledo M, Espinosa-Calderón A, García-Zavala J, Benítez-Riquelme I, Vázquez-Carrillo M, Carrillo-Salazar J. 2017. Productividad de cruza simple de maíz con calidad de proteína en Valles Altos de México, México. *Revista Mexicana de Ciencias Agrícolas* 8: 559-570. <https://doi.org/10.29312/remexca.v8i3.31>
- López-López C, Espinosa-Calderón A, Tadeo-Robledo M, Vázquez-Carrillo MG, García-Zavala JJ. 2020. Rendimiento y calidad intrínseca de cruza de maíz de calidad proteínica en ambientes de Valles Altos de México. *Agrociencia* 54: 1079-1090.
- Martínez-Gutiérrez A, Zamudio-González B, Tadeo-Robledo M, Espinosa-Calderón A, Cardoso-Galva J, Vázquez-Carrillo G, Turrent-Fernández A. 2018. Rendimiento de híbridos de maíz grano blanco en cinco localidades de Valles Altos de México. *Revista Mexicana de Ciencias Agrícolas* 9: 1447-1458. <https://doi.org/10.29312/remexca.v9i7.1357>

- Navarro BS, Navarro GG. 2013. *Química Agrícola* (Tercera edición). Mundi-Prensa: Madrid, España. 479 p.
- Noriega-Navarrete JL, Salazar-Moreno R, López-Cruz IL. 2021. Revisión: modelos de crecimiento y rendimiento de maíz en escenarios de cambio climático. *Revista Mexicana de Ciencias Agrícolas* 12: 127-140. <https://doi.org/10.29312/remexca.v12i1.2552>
- Sáenz CA, Gómez H V, Frigerio K L, Morábito J A, Terenti O A, Cortes M P. 2014. Rendimiento de grano y eficiencia en el uso del agua en maíz bajo riego complementario con agua salina. *Revista de Investigaciones Agropecuarias* 40: 252-259.
- SAS Institute Inc. 2002. *Statistical Analysis System User's Guide*. SAS Institute, Inc. Cary, NC, USA. 956 p.
- Steduto P, Hsiao TC, Fereres D E. 2012. *Respuesta del Rendimiento de los Cultivos al Agua Vol.66. Organización de las Naciones Unidas para la Agricultura y la Alimentación Roma, Italia*. 510 p.
- Tadeo-Robledo M, Espinosa-Calderón A, Arteaga-Escamilla I, Trejo-Pastor V, Sierra-Macias M, Valdivia-Bernal R, Zamudio-González B. 2018. Productividad de variedades precoces de maíz de grano amarillo para Valles Altos. *Revista Mexicana de Ciencias Agrícolas* 7:1417-1423. <https://doi.org/10.29312/remexca.v3i7.1347>
- Zamora-Salgado S, Ruíz-Espinosa I, Beltrán-Morales F, Fenech-Larios L, Murillo-Amador B, Loya-Ramírez J, Troyo-Diéguez E. 2011. Régimen hídrico del maíz en una zona árida, determinado en porcentajes de evaporación. *Tropical and Subtropical Agroecosystems* 13: 181-186.
- Zamudio GB, Félix R A, Martínez G A, Cardoso G JC, Espinosa CA, Tadeo RM. 2018. Producción de híbridos de maíz con urea estabilizada y nutrición foliar. *Revista Mexicana de Ciencias Agrícolas* 9: 1231-1244. <https://doi.org/10.29312/remexca.v9i6.407>