Article

# Water productivity and corn yield under different humidity availability

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## Abstract

Experimenting with hybrids for conditions with scarce water is essential for water and food security, integrating crop management with that of water resources. The objective of this work was to define water productivity, grain yield, and hectolitre weight in three environments with different humidity availability: irrigation and rainfed in the FESC-UNAM and irrigation in Texcoco, State of Mexico; using five corn hybrids from UNAM and five from INIFAP, with two planting densities. The experiment was established in complete random blocks and variables were registered during the cycle and at harvest; total water productivity was calculated as the total volume of water between grain yield at 14% humidity. Using SAS, ANOVA was performed to analyze the factors and their interactions, the means were separated with the Tukey test at 5%. The effect of the interaction environment x hybrid and hybrid x planting density was found on the total productivity of the water. In the grain yield, an effect of the interaction environment x hybrid, environment x density and hybrid x density was found. A highly significant effect was found on the hectoliter weight of the environment and the type of hybrid. The interaction of the Atziri Puma hybrid with the environments and with the planting density showed the maximum values of total water productivity and grain yield.

**Keywords:** gross volume, irrigation and rainfed, irrigation plus precipitation, irrigation tip, water use efficiency.

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# Introduction

Efficient use of water in agriculture is interpreted as reaching maximum yields using the same amount or less than in previous years. This is important, since statistics indicate that the agricultural sector consumes 77% of fresh water, also being an activity that contaminates surface and underground currents. In this context, the panorama of food production in Mexico must be aligned to the efficient use of water.

In Mexico, the National Autonomous University of Mexico (FESC-UNAM) and the National Institute of Agricultural and Livestock Forest Research (INIFAP) have joined efforts in genetic improvement of maize to generate hybrids from native materials and improved maize, and to develop materials with high yield potential under conditions of low humidity availability.

UNAM and INIFAP have been working since 1992 to date to include male sterility as an alternative to facilitate seed production (Tadeo *et al*., 2014a), under this scheme, the hybrid H-51 AE was released commercially in 2011 (Espinosa *et al*., 2012), other hybrid maize, H-49 AE and H-47 AE, have also been generated, with the same characteristic of male sterility (Espinosa *et al*., 2008; Espinosa *et al*., 2018; Espinosa *et al*., 2019).

As an alternative to traditional and subsistence agriculture, H-50 and H-51 AE hybrids have been used for years in the High Valleys of the Mexican plateau (González *et al*., 2007; González *et al*., 2008). No recent research on water productivity is found in all of these materials. Water productivity has been managed interchangeably with efficiency at the parcel and physiological level (Lamm, 2001) as the grain yield among the total water used.

However, efficiency includes the amount of water that is stored in the root zone in relation to that which leaves the supply source, implicitly understanding the losses, being a dimensionless parameter that does not have units. In this sense, productivity refers to the amount of water served on the plot in relation to the yield, which is affected by the irrigation method and includes the physiological efficiency expressed in units of mass per unit of volume consumed.

In the case of corn, the FAO (2002) indicates that the water consumption per cycle is between 500 and 800 mm and is the most productive in terms of dry matter compared to other grains. INIFAP (1988) indicates sheets of 540 mm for early varieties and 620 mm for late varieties. Studies on water productivity have a greater impact where the source is mainly from aquifers, such as the arid and semi-arid zones of the High Valleys (Zamora *et al*., 2011).

They mention that water scarcity and year-on-year variation in precipitation are the main characteristics of these regions, where, according to the FAO-AGL (2002), a productivity of corn of 0.8 to 1.6 kg $m^{-3}$ has been identified. For the rational use of water, resource managers need to know their productivity through quantitative indicators that allow generating actions for sustainable practices. For the conditions of the Mexican territory, there is not enough information on the total productivity of water to assess whether the yields correspond to the amount of water used for irrigation.

This indicator is of vital importance in the current panorama of resource scarcity and in the face of public policies where the balance of water is impacting as an indicator of weight in the economy, under this panorama it is urgent to know the indicators for the hybrids that are used by region. The objective of the experiment was to identify the total productivity of water and the main yield variables in three different conditions of moisture availability (environments) of 10 white corn hybrids at two planting densities, to contribute the basis for future actions. in the efficient use of water in the framework of sustainable agriculture.

## Materials and methods

The experiment was developed under three environments related to the availability of humidity; two of them differentiated by the management under irrigation tip (FESC-UNAM irrigation) with planting date of June 07, 2018 and the other under rainfed or dry land (FESC-UNAM rainfed) with planting date of June 12 of the same year, directed at the Faculty of Higher Studies Cuautitlan of UNAM (FESC-UNAM), in Cuautitlan Izcalli, State of Mexico (latitude 19° 41' 49" and longitude -99° 41' 36") at the elevation of 2 250 masl, belonging to an area with normal average precipitation of 705.4 mm and average normal temperature of 15.3 °C according to the National Meteorological Service (SMN, 2017).

The third environment with emergency risks was implemented on June 8, 2018 in the common of San Luis Huexotla, in the Municipality of Texcoco, State of Mexico (latitude 19° 29' 29" and longitude -98° 54' 29") at the elevation of 2 244 masl with a normal average rainfall of 618 mm. Five INIFAP corn trilinear hybrids were used (Espinosa *et al*., 2018; Espinosa *et al*., 2019) H-47 AE, H-45 AE, H-53 AE, H-51 AE whose seeds were obtained using the scheme sterility; the free-pollinated fertile H-50 hybrid and five hybrids generated by UNAM (Tadeo *et al*., 2016a), Tsiri Puma, Tlaoli Puma, Atziri Puma, Ixim Puma and Cuxi Puma were also used to obtain seed through crosses.

The treatments were made up of the evaluation of the three environments (factor A); 10 corn hybrids (factor B) and two planting densities (factor C). Treatments were implemented in uniform experimental units (UE) in each environment with a design in four complete random blocks, the UE or useful plot consisted of a groove 5 m long by 0.8 m wide.

The preparation of the land in the environments consisted of leveling to standardize the slope and benefit irrigation, one step of the disc plow, two steps of cross harrow and the passage of the furrower to form the furrows with 0.8 m separation, in the latter it was used to apply edaphic fertilization with the formula NPK 80-40-00, urea and diammonium phosphate were used as sources of fertilization in the three environments.

The sowing was done manually with a shovel and using the conventional tip irrigation system in the FESC-UNAM environment, irrigation and germination irrigation in Texcoco, in the case of the rainfed FESC-UNAM (rainfed) environment, the seeding humidity corresponded to the precipitation pluvial. In each UE, 50 seeds were uniformly distributed in the distance of 5 m, after seedling emergence, the density was adjusted to 65 000 plants ha$^{-1}$ and 80 000 plants ha$^{-1}$ as appropriate.

Weed control was carried out with the chemical method in which, with wet soil, pre-emergence products were applied, their active ingredients consisted of: Picloram 2,4 D amine (2 L $ha^{-1}$) and Atrazine (2 kg $ha^{-1}$) as a sealant for wide leaf. At 40 days after sowing (DDS) the chemical control was applied again with Picloram 2-4D-amine (2 L $ha^{-1}$) and Atrazine (2 kg $ha^{-1}$) for broadleaf and Nicosulfuron (1.5 L $ha^{-1}$) for control of narrow leaf weeds.

The harvest was done manually in the second week of December 2018, manually harvesting all the ears of each EU to obtain the full weight (PC). From each EU, 240 in total, five with commercial characteristics and adequate sanitation were selected. This sample was used to identify the productivity and yield variables.

With the sample of five ears, they were measured in the laboratory; ear length (LM), rows per ear (HM), number of grains per row (GH), grain weight (PG), grain density (DG), grain moisture (HG), the hectolitric weight (PH) and the weight of 200 grains. The percentage of grain (% G), the number of grains per ear (GM), the percentage of dry matter (DM) and the grain yield (RG) were calculated with the expression adapted from Espinosa *et al*. (2012): RG=(PCxMSxG)xFCx1.14.

Where= PC is the full weight of the total ears harvested in the experimental unit in kg, DM is the dry matter in decimal fraction, G is the grain fraction with respect to the full weight of the cob, FC is the conversion factor to extrapolate the yield of 5 meters of furrow at 12 500 m that corresponds to the total length of furrows per hectare at the separation of 0.8 m, 1.14 is the factor to change the yield of dry matter from grain to yield with 14% commercial humidity.

To identify the total water productivity (PTA), the artificial inflow of water by irrigation (AR) was quantified and the total volume of precipitation water (AP) that was registered at the meteorological station of the National Meteorological Service during the cycle was added. of the crop. To know the PTA value, the following expression was used. $PTA=\frac{RG}{AT}$.

Where= PTA is the total water productivity in kg $m^{-3}$, RG is the grain yield in kg $ha^{-1}$ and AT is the total water used by the crop for its evapotranspiration in $m^3$ $ha^{-1}$, which also includes losses percolation and surface runoff, which are in hydrological balance with the inputs for irrigation and precipitation.

To quantify it, the irrigation time was recorded and the flow rate for the irrigations in the corresponding environments was recorded, and a precipitation record was also kept at the FES weather station Cuautitlan 0015043 and 00015170 Chapingo, to identify the volume for that variable during the crop cycle. In this experiment, the irrigation sheet was not estimated, the process conventionally carried by the irrigators in the two environments under irrigation was observed, which, together with the precipitation, defined the variant of moisture availability.

## Results and discussion

The analysis of variance was performed checking that the precepts of the technique were met under the null hypothesis of the non-existence of effect of the treatments on the response variables. In ANOVA, total water productivity (PTA) resulted in highly significant differences for environments (A) and for hybrids (B).

With significant differences for the interaction environment x hybrid (A x B) and environment x density (B x C). The coefficient of variation for this variable was 17.7% and the general mean of 0.99 kg $m^{-3}$ (Table 1). The interaction between factors indicates that the observed responses are due to the combination of their effects.

**Table 1. Mean squares and significance for water productivity, yield and hectolitric weight in three environments of ten corn hybrids under two planting densities. Spring-summer 2018.**

| Variation source | PTA (kg $m^{-3}$) | RG (t $ha^{-1}$) | PH (kg $hl^{-1}$) |
|---|---|---|---|
| Environment (A) | $2.65^{**}$ | $22.31^{**}$ | $516.34^{**}$ |
| Hybrid (B) | $0.72^{**}$ | $49.61^{**}$ | $65.91^{**}$ |
| Density (C) | 0.02 | 2.4 | 7.1 |
| A x B | $0.05^{*}$ | $4.17^{*}$ | 18.46 |
| A x C | 0.09 | $6.11^{*}$ | 5.02 |
| B x C | $0.06^{*}$ | $3.91^{*}$ | 8.12 |
| A x B x C | 0.02 | 1.26 | 14.84 |
| Mean | 0.99 | 8.1 | 73.64 |
| CV (%) | 17.7 | 17.3 | 4.89 |

$^{*}$, $^{**}$= statistical significance at the level of 0.05 and 0.01, respectively. CV= coefficient of variation; PTA= total water productivity (kg $m^{-3}$); RG= grain yield (kg $ha^{-1}$); PH= hectoliter weight (kg $hl^{-1}$).

The grain yield variable showed highly significant differences in the environment (A) and hybrid (B) factors, a significant difference was also found in the interactions environment x hybrid (A x B), environment x density (A x C) and hybrid x density (B x C), its coefficient of variation was 17.3% and the mean of 8.1 t $ha^{-1}$ (Table 1).

Highly significant differences were found in the hectolitric weight due to the effect of the environmental (A) and hybrid (B) factors, this variable did not show a significant difference in the planting density factor (C) or in the interactions. The above shows the effect of genotypes on grain density and the effect of edaphic and climatic conditions, as also reported by Tadeo *et al*. (2014b).

In the A x B interaction, significant differences were identified in water productivity and grain yield. These results imply the differentiated response of the hybrids according to the environments so that the response variables are influenced by the edaphic and climatic characteristics (Table 1).

The A x C interaction only showed a significant difference in grain yield and the percentage of variation with respect to the general mean of the response variables ranged between 4.89 and 17.7%. In the response to the treatments, the variables of the climate, the soil and the crop generally have influence, when the same hybrids are managed in different environments, there may be interaction and it is mainly the first two groups of variables that insert the variability in the response, this interpretation.

It has been observed in other studies such as that of Martínez *et al*. (2018); Tadeo *et al*. (2014a) developed with some materials such as those used in this research. Due to the Anova results, the means analysis was performed for the factor interactions that resulted with a significant effect on the observed variables.

The comparison of means of the environment x hybrid interaction for the variable total water productivity resulted with significant statistical differences as shown in Table 2, the interaction of the hybrids with the FESC-UNAM environment under showed the highest PTA that in increasing order (0.64 to 1.22 kg $m^{-3}$) they were; H 51 AE, Ixim Puma, H 47 AE, Cuxi Puma, Tsíri Puma, H 45AE, H 53 AE, H-50, Tlaoli Puma and Atziri Puma.

**Table 2. Comparison of means of the observed variables of the environment x hybrid interaction (A x B) of the 2018 spring-summer cycle.**

| Hybrid | PTA (kg $m^{-3}$) | | | RG (t $ha^{-1}$) | | | PH (kg $hl^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | FESC-UNAM | | Texcoco | FESC-UNAM | | Texcoco | FESC-UNAM | | Texcoco |
| | T | R | R | T | R | R | T | R | R |
| H 47 AE | 0.91 bh | 0.71 fl | 0.56 kn | 7.19 dh | 6.68 fh | 8.17 ag | 73.4 af | 72.8 af | 74.5 af |
| H 45 AE | 1.04 ad | 0.77 el | 0.69 fl | 8.19 ag | 7.24 ch | 10.06 ab | 67.9 f | 76 ae | 77.7 ac |
| H 53 AE | 1.12 ab | 0.92 bh | 0.58 jn | 8.81 af | 8.71 af | 8.45 ag | 73.4 af | 74.3 af | 78.3 ab |
| H 51 AE | 0.64 im | 0.33 n | 0.41 mn | 5.06 hi | 3.12 i | 5.97 gh | 70.3 df | 69.4 df | 72.5 af |
| H-50 | 1.14 ab | 0.79 dk | 0.67 gm | 8.98 af | 7.44 bh | 9.86 ac | 68.6 f | 71.5 bf | 74.5 af |
| Tsiri Puma | 0.97 ae | 0.91 bh | 0.56 kn | 7.67 bh | 8.59 ag | 8.23 ag | 73.9 af | 76.6 ad | 79.2 a |
| Tlaoli Puma | 1.15 ab | 0.93 bg | 0.66 hm | 9.06 af | 8.78 af | 9.73 ad | 71.8 bf | 72.8 af | 77.6 ac |
| Atziri Puma | 1.22 a | 1.06 ac | 0.73 el | 9.61 ae | 9.98 ab | 10.74 a | 72.8 af | 73.2 af | 76.3 ad |
| Ixim Puma | 0.89 bi | 0.83 cj | 0.51 ln | 7.02 eh | 7.85 bg | 7.47 bh | 71.1 cf | 72.7 af | 76.3 ad |
| Cuxi Puma | 0.95 bf | 0.89 bi | 0.56 kn | 7.49 bh | 8.41 ag | 8.2 ag | 71.1 cf | 71.9 bf | 77.4 ac |
| DMS | | 0.26 | | | 2.63 | | | 6.77 | |

The means with the same letter within the group of means of the observed variables are statistically equal (Tukey, $p$= 0.05). T= rainfed; R= irrigation; DMS= minimum significant difference; PTA= total water productivity; RG= grain yield; PH= hectoliter weight.

In this interaction, the total volume due to rain and irrigation added 7 888 $m^3$ $ha^{-1}$, as less water enters the system and yields even higher than the interaction with the FESC-UNAM environment under irrigation, the productivity indicator increases as has resulted in other studies (FAO, 2002; Rivetti, 2006; Zamora *et al*., 2011; Saenz *et al*., 2014) in some works the contrast in the responses to the interaction with the edaphic and climatic conditions of the environments is attributed (Zamudio *et al*., 2015; Canales *et al*., 2017; López *et al*., 2017; Martínez *et al*., 2018).

The interaction of the environments with the Atziri Puma and Tlaoli Puma hybrids generated by the UNAM in its maize improvement scheme (Tadeo *et al*., 2016a), showed the highest productivity being an indirect measure of the efficient use of water, therefore, subject to other research on water variables, these hybrids have productive potential in the studied environments of the High Valleys where water availability is limited.

The hybrid H 51 AE in its interaction with the environments showed lower total water productivity (Table 2), generated by INIFAP (Espinosa *et al*., 2012) and its use should be reserved to conditions where the water resource is not limiting. It is also observed that the versions of male sterile hybrids (AE), referred to in other works by Espinosa *et al*. 2009); Tadeo *et al*. (2014b), in the interaction with the environments, they showed low water productivity that according to Tadeo *et al*. (2014a) for other agronomic yield variables may be related to the coincidence of the lines that synthesize their hybrid structure.

The interaction of the Atziri Puma hybrid with the rainfed FESC-UNAM and Texcoco environments showed water productivity and superior yield, respectively. The above coincides with that found in other works (Tadeo *et al*., 2016b; Martínez *et al*., 2018) where similar responses were observed, these results show the opportunity to offer producers an alternative of hybrid corn in the environments studied with competitive economic and agronomic advantages.

In the environment of the FESC-UNAM under rainfed the volume of water due to rain was 7 888 $m^3$ $ha^{-1}$, in FESC-UNAM under irrigation it was 7 888 $m^3$ $ha^{-1}$ of rain plus 1 548 $m^3$ $ha^{-1}$ of irrigation in Texcoco under irrigation were 7 328 $m^3$ $ha^{-1}$ of rain and 7 372.8 $m^3$ $ha^{-1}$ of irrigation. According to the previous data, Table 2 shows that the PTA decreases when the total volume of water used increases, which indicates an inverse relationship.

The averages of PTA and RG of the interactions A x B in the environment of the FESC-UNAM under rainfed were superior with respect to the environment FESC-UNAM under irrigation. This difference may be due to the conditions of humidity availability due to the gap between the sowing dates, the rainfed trial started one week later with the established rainfed having water available in quantity and opportunity, these results contrast with those reported for other studies where supplementary irrigation is provided in quantity according to the requirement (Rivetti, 2006; Avendaño *et al*., 2008; Saenz *et al*., 2014).

However, when the total of the required volumes is added, it does not always coincide with the higher yield and productivity of the water, since when the irrigation efficiency is low, volumes are lost due to runoff or deep percolation. The justification for why the interaction of hybrids with the FESC-UNAM environment under irrigation showed lower total water productivity than the interaction with FESC-UNAM under rainfed conditions.

It is also explained with the indicators of efficiency in water management at the parcel level since the efficiency of application of the requirement (Ear) in an evaluation was 76%, the efficiency of irrigation application (Ea) of 70% and the coefficient Christiansen uniformity (CUC) of 85%. This indicates that the poor distribution of water affects the use by the crop, which implies a waste of water, translating its effect into yield.

An operational variable of irrigation that marks the response to yield is the availability of moisture in a timely manner (Palacios, 2007), therefore, a day of stress below the critical point significantly reduces performance (Allen *et al*., 2006; Ojeda *et al*., 2015). Another aspect related to the effect of irrigation is the change in bulk density due to the saturation and drying cycle of the soil, which is more severe in soil with high clay content (González *et al*., 2009; Madero *et al*., 2012).

Having an effect on initial development and possibly on response variables. In these conditions, for the region of influence of the FESC-UNAM, it is recommended to expertly manage the tap irrigation with the hybrids studied when there are historical records of good weather and availability of information that allows the sowing to be synchronized with the rainy season.

Regarding performance, the interaction of the environment with the hybrid Atziri Puma showed the statistically higher value in Texcoco (10.74 t $ha^{-1}$) and the lowest (3.12 t $ha^{-1}$) in H 51 AE in the FESC-UNAM under irrigation. In the first case, there is a coincidence with studies where a direct relationship has been found between the amount of water supplied and the yield (Zamora *et al*., 2011; López *et al*., 2019).

The interaction of the hybrids with the environments of the FESC-UNAM shows significant differences in PTA and RG, which is why precise studies are required on the effect of tap irrigation in relation to the rainfed since the contribution of water in quantity and opportunity impacts in performance as reported by Allen *et al*. (2006); Ojeda *et al*. (2015).

The interaction of the INIFAP hybrids with the low rainfed environment has a good response in yield (Table 2), therefore, avoiding the tap irrigation in the studied hybrids saves water, in this case 1 548 $m^3$ $ha^{-1}$, which it can be used for other crops increasing marginal productivity or it can be stored in the supply source to be used as a relief irrigation when the interstitial drought worsens in late July and early August. Although tap irrigation is an activity that ensures the establishment of planting, it must be managed with technique when water is a limited resource.

In the Table 3 shows the interaction environment x planting density where it was observed that the total water productivity decreases as the quantity of water supplied increases and the increase in planting density has no significant effect, the condition of availability of moisture is significant and planting density is not. In the case of the yield variable, a significant interaction of the availability of humidity and the planting density is observed.

**Table 3. Comparison of means for the observed variables of the interaction environment x planting density (A x C). Spring-summer 2018 cycle.**

| Density (plants $ha^{-1}$) | PTA (kg $m^{-3}$) | | | RG (t $ha^{-1}$) | | | PH (kg $hl^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | FESC-UNAM | | Texcoco | FESC-UNAM | | Texcoco | FESC-UNAM | | Texcoco |
| | T | R | R | T | R | R | T | R | R |
| 65 000 | 0.97 a | 0.78 b | 0.61 c | 7.68 bc | 7.39 c | 8.91 a | 71.77 b | 73.01 b | 76.66 a |
| 80 000 | 1.03 a | 0.84 b | 0.58 c | 8.14 ac | 7.97 bc | 8.47 ab | 71.03 b | 73.23 b | 76.14 a |
| DMS | | 0.09 | | | 0.894 | | | 2.299 | |

The means with the same letter within the group of means of the observed variables are statistically equal (Tukey, $p$= 0.05). T= rainfed; R= irrigation; DMS= minimum significant difference; PTA= total water productivity; RG= grain yield; PH= hectoliter weight.

These results are similar to those reported by Virgen *et al*. (2016); Canales *et al*. 2017) who point out that the yield increases with increasing population density, as well as Espinosa *et al*. (2012) mentions that genotypes have a good response to the increase in population density.

The means of the hybrid x planting density interaction are shown in Table 4 and significant differences are observed in the total productivity of the water as the hybrids vary in their interaction with the planting densities, resulting in values between 0.44 and 1.01 kg $m^{-3}$, the effect on the response variables inserted by the hybrids is significant and the planting density is also significant.

**Table 4. Comparison of means of the observed variables of the hybrid interaction x planting density (B x C). Spring-summer 2018 cycle.**

| Hybrid | PTA (kg $m^{-3}$) | | RG (t $ha^{-1}$) | | PH | |
|---|---|---|---|---|---|---|
| | Planting density (plants $ha^{-1}$) | | | | | |
| | 65 000 | 80 000 | 65 000 | 80 000 | 65 000 | 80 000 |
| H 47AE | 0.65 de | 0.8 ad | 6.56 de | 8.13 ad | 73.2 ac | 73.9 ac |
| H 45AE | 0.81 ad | 0.86 ac | 8.25 ad | 8.74 ac | 75.2 ab | 72.6 ac |
| H 53AE | 0.81 ad | 0.93 ab | 8.14 ad | 9.17 ab | 75.3 ab | 75.3 ab |
| H 51AE | 0.44 e | 0.48 e | 4.62 e | 4.81 e | 71.8 bc | 69.6 c |
| H-50 | 0.9 ac | 0.84 ad | 9.16 ab | 8.37 ad | 71.6 bc | 71.4 bc |
| Tsiri Puma | 0.77 bd | 0.86 ac | 7.69 bd | 8.64 ac | 76 ab | 77.1 a |
| Tlaoli Puma | 0.92 ac | 0.91 ac | 9.23 ab | 9.15 ab | 73.7 ac | 74.3 ac |
| Atziri Puma | 1.01 a | 1 a | 10.15 a | 10.08 a | 74.3 ac | 73.8 ac |
| Ixim Puma | 0.77 bd | 0.72 cd | 7.88 bd | 7.01 cd | 73.5 ac | 73.3 ac |
| Cuxi Puma | 0.81 ad | 0.79 bd | 8.24 ad | 7.83 bd | 73.7 ac | 73.2 ac |
| DMS | | 0.205 | | 2.031 | | 5225 |

The means with the same letter within the group of means of the observed variables are statistically equal (Tukey, $p$= 0.05). DMS= minimum significant difference; PTA= total water productivity; RG= grain yield and PH= hectoliter weight.

The interaction of Atziri Puma with the two planting densities shows the highest productivity, but there is no significant difference between them, and the same occurs with the yield. In particular, for this interaction it would be convenient to use the lowest planting density which reduces the cost of seed acquisition. The interaction of H 51AE with planting densities produces the lowest productivity and yield averages without showing significant difference.

In the case of the yield variable, a significant interaction of the hybrids with the planting density is observed showing values that vary between 4.62 and 10.15 t $ha^{-1}$. INIFAP hybrids, except for H 51 AE, show higher yield when interacting with the density of 80 000 plants $ha^{-1}$, UNAM hybrids, except for Tsiri Puma, show superior performance in their interaction with the density of 65 000 plants $ha^{-1}$.

## Conclusions

Total average water productivity (0.99 kg $m^{-3}$), average grain yield (10.1 t $ha^{-1}$), and average hectoliter weight (73.64 kg $hl^{-1}$) were identified in three environments differentiated by the availability of humidity (factor A) of 10 white corn hybrids (factor B) under two planting densities (factor C), interactions A x B and B x C were found in PTA and A x B, A x C, B x C in RG. Significant differences were found in the hectolitric weight due to the effect of factors A and B that imply the manifestation of phenotypes and genotypes.

Total water productivity is inversely related to the amount of water entering the production system, the values found are indicators of the low efficiency in the use of water in the interactions of the environments where irrigation was provided. It is recommended to make the estimates of the irrigation requirement in real time and transfer them through technical advice to farmers.

The Atziri Puma hybrid showed higher total water productivity and grain yield in its interaction with the environments and had no significant difference in the interaction with the planting density. This hybrid has the potential to be used in places with characteristics similar to those in this study, where water is a limited resource and therefore valuable due to its scarcity.

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