Article

Effect of evapotranspiration rate on leaf area, water potential and yield of forage corn

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Abstract

Due to the growing demand for fresh water, it is necessary to improve the efficiency in the use of water in agriculture. The objective of this work was to determine the effect of different irrigation sheets on the leaf area index (LAI), leaf temperature (Lt), leaf water potential (ψ_w) and yield in forage corn (*Zea mays* L.) under a drip irrigation system. The study was conducted in the summer of 2019 at the facilities of the La Laguna Experimental Field in Matamoros, Coahuila, Mexico. Three levels of evapotranspiration (ET) (60, 80 and 100%) and one control treatment (flood irrigation) were evaluated. Three drought-tolerant, high-yielding corn varieties were used. The experimental design used was randomized complete blocks with four repetitions, with an arrangement of treatments in split plots. The main plot was the irrigation treatments, and the secondary plot was the corn varieties. The variables measured were leaf area index (LAI), leaf temperature (Lt), leaf water potential (ψ_w), dry forage yield and water use efficiency. The different levels of ET affected the LAI, ψ_w, Lt and yields of the crop, conditioning the biomass production of the crop. The results indicated that the volume of water applied in the treatments with subsurface drip irrigation was 27 to 40% lower with respect to flood irrigation. The efficiency in the use of water was evaluated, the best results were obtained when the water was applied according to the phenological stage of the crop with the treatment of 100% ET affected by a crop coefficient (Kc).

Keywords: *Zea mays* L., drip irrigation, dry matter, thermal differential.

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Introduction

The effects of climate change on the behavior of hydrological sources are disconcerting. Therefore, regional studies on water have become essential, with the purpose of strengthening scientific certainty about the knowledge of eco-agrological systems and responding to the objectives of rational use for the mitigation of crop damage. Researchers on water resource management indicate that the demand for water in the world has often increased exponentially as an effect of population growth, with agriculture being the largest consumer of water in the world, using 80% of water for irrigation uses (CONAGUA, 2016).

So future predictions are not entirely favorable, since the estimated world population for 2050 will be 10 to 12 billion people, which would cause a shortage in the water supply since the water resource decreases over time. Water quality is also a factor that limits the use of water for agriculture in the Comarca Lagunera. Azpilcueta *et al*. (2017) found that the high contents of salt, sodium and heavy metals in the groundwater of the Comarca Lagunera exceed the maximum limits permissible by the official standard of water for agricultural use and with the consequent risk to human health and the environment.

The problem of the availability and quality of water for agriculture is because other sectors such as the population, industry and livestock farming have increased, generating a greater demand for water and reducing the volume of water destined for agriculture. Likewise, the low efficiency in the use of water, by applying volumes greater than those required by the crop, aggravates the problem (Reyes *et al*., 2019a). One of the main factors that influence plant growth and can cause economic losses for farmers is water stress (Gao *et al*., 2007).

The dynamics of water studies have also been directed towards the livestock system. Corn is used as green fodder or silage, which serves as feed for cattle (Piccioni, 1970). In the United States of America, Argentina and in some European countries, the use of corn for silage is common, due to its high yield ranging from 40 to 95 t ha^{-1} (Aldrich and Leng, 1974; Wang *et al*., 1995). Short-term production and excellent nutritional value make corn a crop suitable for fodder (Aldrich and Leng, 1974).

Notwithstanding the methodological diversity, for an accurate evaluation of the water status of the plant, values taken from the water potential of the leaf should be considered, since the leaf part is the one that controls the movement of water at the cellular level, in the tissue and organs of the plant (Liu *et al*., 2012). The distribution of the leaf area and the radiation within the canopy of the plant are some of the factors that affect the photosynthetic processes of the plant that directly affect the yield of the forage corn, the greater the light energy captured, the greater the photosynthetic efficiency of the plant (Wall and Kanemasu, 1990).

If one wants to measure the total amount of photosynthetic radiation absorbed by the plant, it is essential to consider the leaf area index (LAI) as a parameter. The LAI and biomass production are closely linked, if the LAI increases, biomass production will increase (Lucchesi, 1978; Acosta and Adamas, 1991).

As water stress increases due to the restriction of moisture in the crop, the values for the water potential of the leaf are also more negative, generating inadequate vegetative growth and lower biomass production (Ismail, 2010; May *et al*., 2011). Transpiration, stomatal conductance and temperature of the leaf are some of the different variables that serve as parameters to estimate the water status of plants (Gálvez *et al*., 2011). Rada *et al*. (2005) comment that the leaf temperature increases to the degree of causing heat damage, because water stress increases reducing the stomatal conductance of the leaf.

The temperature of the leaf is a function of the solar radiation that it intercepts, the more radiation the leaf captures, the greater its temperature, since the temperature of the leaf conditions the energy balance of the canopy (Panda *et al*., 2003). Jarma *et al*. (2012) point out that high ambient temperatures generate high temperatures inside the plant, affecting net photosynthesis (with high temperatures, it is reduced by the effect of increased photorespiration), respiration, water relationships, membrane stability, hormonal regulation, secondary metabolism, reducing the growth of plants, especially those categorized within the group of C3 plants (Chaves *et al*., 2017).

In this scenario, the Comarca Lagunera belongs to the irrigation district 017 and has an area for irrigation of 167 thousand ha, where the predominant crops are fodder such as: corn, alfalfa, sorghum and oats. Forage corn has been the main crop in the region in the last four years, with a current area of 54 thousand ha (SADER, 2019).

Consequently, the objective of this research was to evaluate the effect of different levels of evapotranspiration on the leaf area index, leaf temperature, leaf water potential and yield in forage corn under the drip irrigation system in an arid climate such as the Comarca Lagunera, in order to estimate the irrigation regime that is more related to the efficient use of water, relating the final dry matter production and the total volume of water used.

Materials and methods

The study was carried out at the facilities of the La Laguna Experimental Field, located in Matamoros, Coahuila, Mexico. This region is located between 102° 00’ and 104° 47’ west latitude and 24° 22’ and 26° 23’ north latitude. Maximum temperatures of up to 45 degrees can be reached, minimum temperatures range from 8 to 0 degrees with an average annual temperature of 24 °C, average annual rainfall is 242 mm per year and relative humidity varies from 31% in April to 60% from August to October. The Comarca Lagunera is an area that is characterized by its limited water resources, by its very hot dry climate in summer and with cold winters. The sowing was carried out in a soil of clayey-sandy crumb texture, in dry, placing a seed at a sowing distance of 12 cm and 76 cm of separation between furrows to reach a population density of 105 thousand plants ha^{-1}. The corn varieties used were MH 431, MH 383 and SB 302.

The fertilization dose that was used was: 200-100-00 (NPK), this is 200 units of nitrogen, 100 units of phosphorus per hectare, using urea and ammonium sulfate as a source of nitrogen and MAP as a source of phosphorus. All phosphorus and half of the nitrogen with 46% urea were applied at the time of sowing and the rest of the nitrogen with ammonium sulfate, being injected every 15 days according to the phenology of the crop through the drip irrigation system using a Venturi injector. In the control treatment by flood, the other half of nitrogen was applied manually 35 days after sowing (DAS), using ammonium sulfate as a source of nitrogen.

The experimental design used was randomized complete blocks with four repetitions, with an arrangement of treatments in split plots. The main plot was irrigation treatments, and the secondary plot was corn varieties (MH 431, MH 383 and SB 302). The secondary plots were four furrows 5 m long (15 m^2). The irrigation treatments were subsurface drip irrigation (SDI), where 60, 80 and 100% of the evapotranspiration (ET) was applied, and a control that was the irrigation with border irrigated by gravity, in this treatment the frequency of irrigation was every 15 days, applying a total of seven irrigations with an average sheet of 100 mm. The treatment of 100% ET was multiplied by the daily Kc to apply the current ET. The Kc used was developed locally by Reyes *et al*. (2019a) for forage corn. The reference ET was taken from an atmometer.

The SDI infrastructure included a tape buried at 0.3 m, with a spacing between lines of 0.76 m. The tape used was the RO DRIP 8 thousand with wall thickness of 0.2 mm and inner diameter of 16 mm, with emitters at 0.2 m and a discharge of 2.5 L h^{-1} per linear meter. The operating pressure of the irrigation system was 8 PSI. The frequency of irrigation with the SDI was every third day. As for gravity irrigation, a border of 15 m wide by 30 m long was designed. Seven supplemental irrigations were given with an average sheet of 100 mm each. The leaf area index (LAI) was measured using the ACcuPAR PAR/LAI ceptometer model Lp-80 (Decagon Devices, Inc. Pullman, WA, USA). The ceptometer bar was placed at a 45° angle through the crop furrow to measure the interception of photosynthetically active radiation (PAR).

PAR interception was measured in each plot and in each treatment at three points and three repetitions per point above and below the crop canopy. The readings were taken between 12:00 and 14:00 h on clear days to minimize diffuse radiation of the sky by clouds (Stewart *et al*., 2003). LAI measurements were performed weekly. For the measurement of the leaf temperature of the crop, a digital infrared thermometer model 42530 (Extech instruments Inc., Boston, MA, USA) was used. The readings were taken every seven days from July 23 (36 DAS), when corn had a height of 1.2 m, LAI of 4 m^2 m^{-2} and a groundcover of 100%.

The measurements were taken during days without clouds and with little wind, 20 cm above the aerial part of the crop with an angle of inclination towards the crop of 15 degrees with respect to the perpendicular level of the canopy of the crop oriented from north to south. Two readings per treatment and repetition were taken and averaged. The infrared thermometer has a field of view of 8:1 (8 feet (2.4 m) away, the measured area is 1 foot (0.3 m) in diameter). The leaf water potential (ψ_w) was measured with the pressure pump according to Scholander *et al*. (1964). Measurements were made between 12:00 and 14:00 each week. These were made on the second top leaf of the crop, taking two leaves per treatment and repetition.

The harvest was carried out at 92 DAS in drip irrigation and at 99 DAS in the flood system. The production of green fodder was calculated by weighing three linear meters in the two central furrows of each treatment (4.56 m^2), then a sample of 700 g was taken and dried in a forced air oven at a temperature of 65 °C for 72 h, to later determine the production of dry matter. Water use efficiency was determined by dividing the dry matter weight (kg ha^{-1}) by the total volume of water applied (m^3) during the cycle. The data were processed using analysis of variance and the means of the treatment were compared using the Tukey test ($p\leq 0.05$), with the SAS 9.3 statistical package (SAS Institute Inc., Cary, NC. USA).

Results and discussion

Of a total area for irrigation of 167 thousand ha, where the predominant fodder crops were corn, alfalfa, sorghum and oats; forage corn was studied, in an area of 0.12 ha, the attributes of leaf area index, leaf temperature, leaf water potential, irrigation sheets and yield of forage corn in a spatial arrangement of the experimental plots (Figure 1). For the treatments of 100, 80 and 60% ET, water volumes of 5 180, 5 420 and 4 320 m^3 were applied, respectively, while for the flood irrigation treatment, the volume was 7 100 m^3.

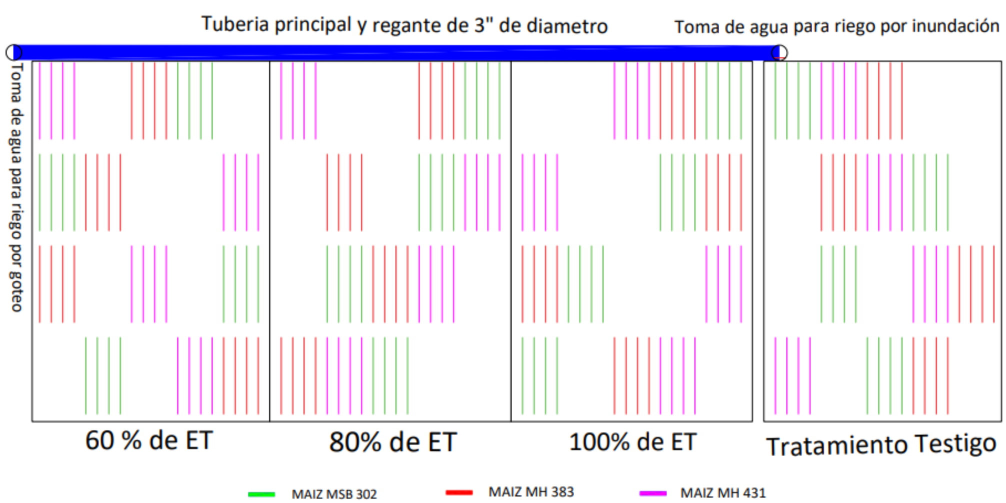

Figure 1. Sketch of the experiment for three corn varieties with different levels of irrigation in the Laguna Experimental Field of INIFAP, Matamoros, Coahuila, Mexico.

Leaf area index

Figure 2a showed that the three varieties behave similarly with the treatment of 100% ET, with the variety H-431 having slightly higher values between 70 and 80 DAS. In Figure 2b and 2c, the variety H-383 was the one that registered the highest values compared to the other two varieties, registered between 55 and 70 DAS. In the flood irrigation treatment (Figure 2d), a maximum LAI value of 6.12 was found at 70 DAS with the variety H-383. The treatments of 60% ET and flood were those that showed the lowest LAI values compared to the treatments of 80 and 100% ET. By subjecting the LAI results obtained to statistical analysis, it was determined that there is no significant difference between the treatments of 80 and 100% ET; however, these were different from the treatment of 60% ET and flood irrigation ($p< 0.05$) (Table 1).

Table 1. Comparison of means of the variables measured between irrigation treatments, 2019.

	Treatment	LAI	WP	°C	DM	EUW
T1	SDI, 100% ET	4.5 a	-1.04 a	30.97 a	18.98 a	3.66 a
T2	SDI, 80% ET	44.77 a	-1.08 a	30.84 a	19.57 a	3.61 a
T3	SDI, 60% ET	4.12 b	-1.23 b	32.71 b	15.63 b	3.62 a
T4	Flood	3.46 c	-137 c	30.85 a	15.68 b	2.21 b
	CV (%)	12	3.15	0.71	12.65	12.4

LAI= leaf area index; WP= water potential; °C= leaf temperature; DM= dry matter; EUW= efficiency in the use of water. The letters (a, b, c) in each column indicate significant differences between the means of the treatments (Tukey, $p \leq 0.05$).

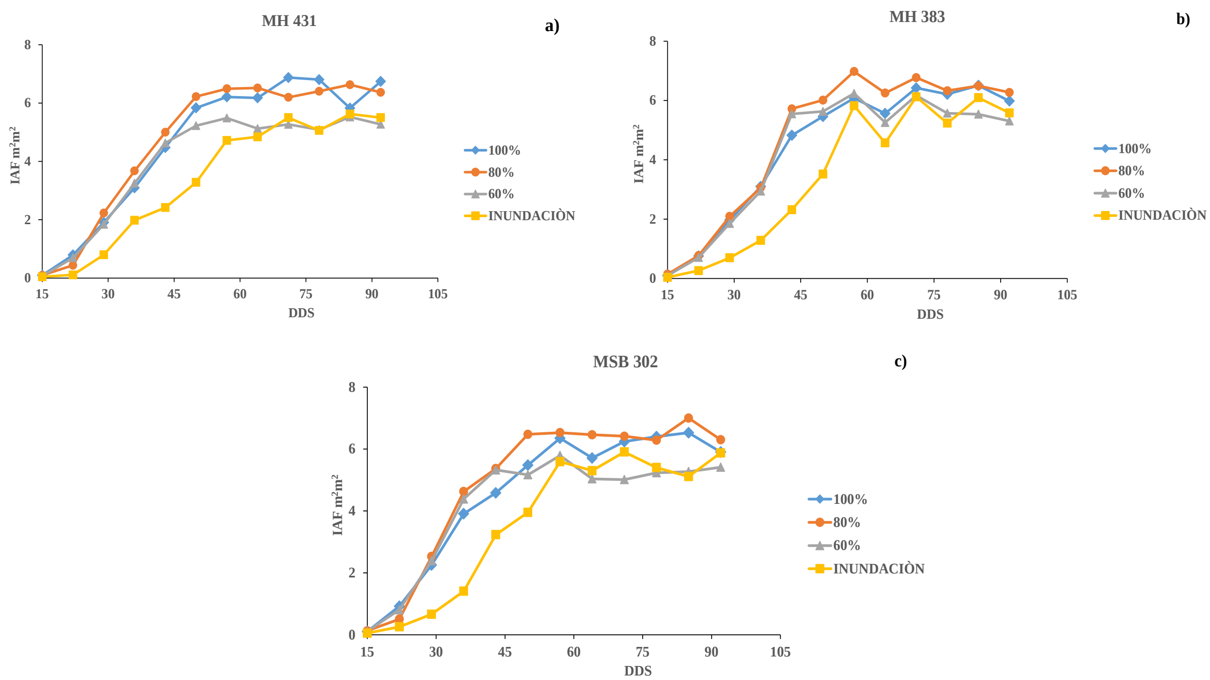

Figure 2. Leaf area index (LAI, in Spanish IAF) values for three corn varieties with different irrigation levels in the Laguna Experimental Field of INIFAP, Matamoros, Coahuila, Mexico.

The data suggest that, in the treatments of 80 and 100%, the plants had enough soil moisture to continue growing during the crop cycle, while the plants in the treatments of 60% and flood were limited by soil moisture. Similar results were reported by Reyes *et al*. (2019b), who found low LAI values in treatments where there was restriction of soil moisture in a corn sown in eastern South Dakota, USA, they observed the correlation between the LAI, yield and accumulation of biomass of corn for grain (density of 71 000 plants ha^{-1}), the relationship was direct when LAI increased by one unit, with an increase in production of up to 567 kg ha^{-1}. Yoshida (1972) mentions that biomass production and the LAI are related, the greater the plant area, the greater the light energy capture and the greater the biomass production with optimal LAI values of 5 for corn.

The LAI values observed in the present study (6.12) are higher than those reported by Yoshida (1972) and Montemayor *et al*. (2012), the latter reported maximum values of LAI (5) in corn irrigated with drip irrigation in the Comarca Lagunera. It is established that the maximum LAI is reached in the flowering stage of the corn plant, which coincides with the stage of greatest value for the LAI. After the plant reaches the maximum LAI value, it stops increasing and its tendency is linear as a kind of plateau (Figure 2).

Leaf temperature

When analyzing the leaf temperature data, it was determined that there is no difference between the treatments of irrigation at 80, 100% and flood irrigation. However, there was a significant difference when comparing them with the treatment at 60% ($p< 0.05$) (Table 1).

Figure 3a, with the treatment at 100% ET, the surface temperature of the leaf ranged between 29 and 33 °C, the variety that had the highest temperature in most of the readings was H-383, reaching a maximum value of 33 °C in the final stage of the crop. The lowest temperatures occurred in the early stages of development of the crop, with values ranging between 26.9 and 30 °C. The treatment with 80% ET (Figure 3b) presented a variability in the temperature of the leaf, where the minimum temperature was 27.23 °C in the variety MH-431 obtained at 43 DAS, while the maximum temperature was 32.8 °C, registered at 71 DAS in the variety MSB-302.

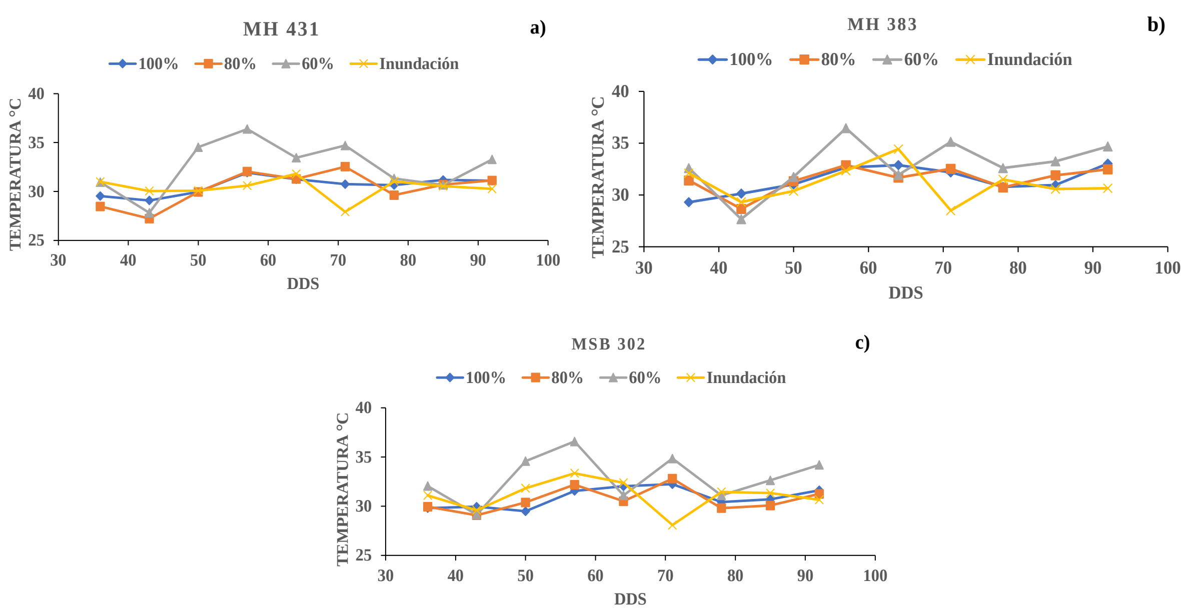

Figure 3. Leaf temperature values for three corn varieties with different irrigation levels in the Laguna Experimental Field of INIFAP, Matamoros, Coahuila, Mexico.

Figure 3c with the treatment at 60% ET, the minimum temperature value occurred in the variety MH-383 with 27.67 °C at 43 DAS and the maximum occurred in the variety MSB-302 with 36.58 °C at 53 DAS, this treatment was the one that showed the greatest variability with a value of 8.9 °C between the maximum and minimum readings. The temperature values obtained in the flood irrigation treatment are shown in Figure 3c, where it is observed that the maximum value recorded was in the variety MH-431 with 34.43 °C at 64 DAS, on the contrary, the minimum value observed was in the variety MH-431 with 27.93 °C at 71 DAS. This last value confirms what the literature indicates regarding the variety MH-431, which is a variety tolerant to high temperatures, which is an advantage against the climate of the Comarca Lagunera.

Porter and Delecolle (1988) determined that temperature and photoperiod are two climatic factors that strongly affect the growth and development of crops, if we compare this conclusion with what was observed in our experiment, we can notice that it is the same trend, because as the temperature of the leaf increases, the production of dry matter decreases, this was observed in the treatment with 60% ET. Kinirya and Bonhomme (1991) mention that the maximum temperature that affects the development of corn is between 40 and 44 ºC.

Leaf water potential

According to the statistical analysis (Table 1), the comparisons of means between the irrigation treatments showed no significant difference between the treatments of irrigation at 80 and 100%. However, the treatment of irrigation at 60% and flood irrigation were statistically different from the treatments of 80 and 100% ($p< 0.05$).

In Figure 4a, which correspond to the treatment of 100% ET, it is seen that the most critical values are in the range of -1.45 to -1.57 MPa. These values occurred at 71 DAS, for the three varieties under study, with MH-431 being above the two varieties with the least critical value of -1.45 MPa. The variety MH-383 was the best behaved, showing a minimum critical value of -0.6 MPa at 85 DAS. In the treatment at 80% (Figure 4b), the most critical values were higher than those observed in the treatment of 100%, these are in a range of -1.57 to -1.7 MPa, observed at 71 DAS, with MH-431 being the variety that had the most critical value with -1.7 MPa.

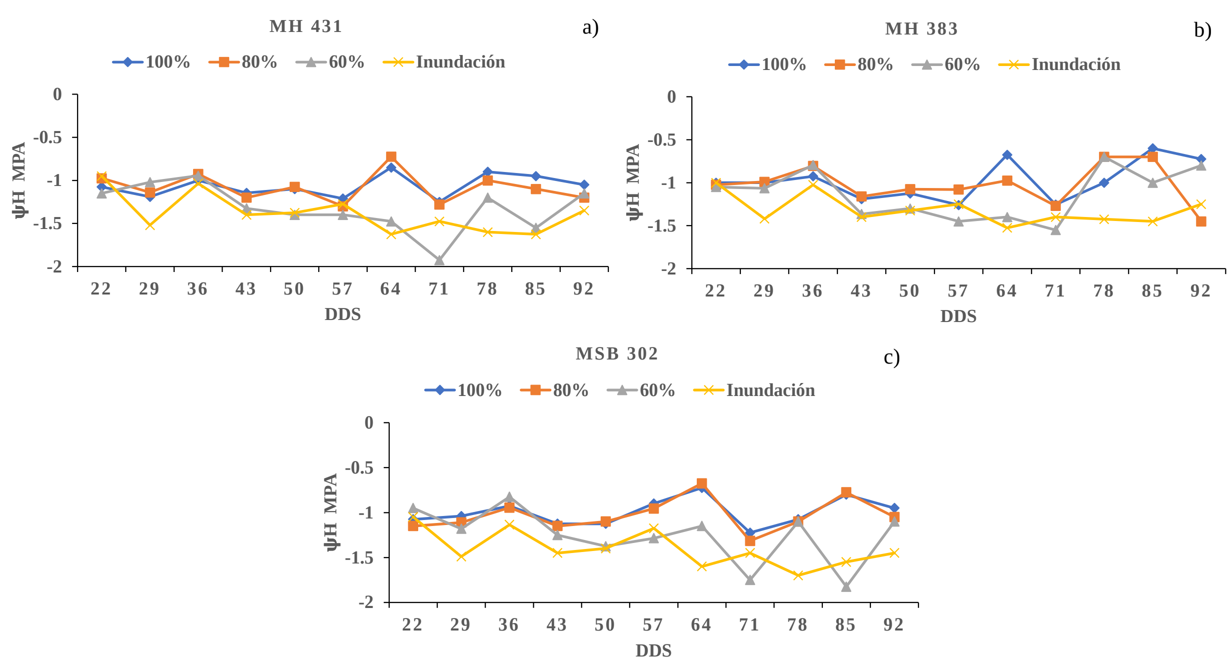

Figure 4. Leaf water potential values for three corn varieties with different irrigation levels in the Laguna Experimental Field of INIFAP, Matamoros, Coahuila, Mexico.

The variety MH-383 was the one that had the least negative value with -0.07 MPa, which remained from 78 to 85 DAS. In Figure 4c with the treatment at 60% ET, the variety MH-431 is seen as the most susceptible to water restriction, having a more critical negative value of -1.93 MPa observed at 71 DAS and at 85 DAS the variety MSB-302 with -1.8 MPa. In the flood irrigation treatment (Figure 4c), the values of water potential have practically the same trend, however, the most critical negative value occurred in the variety MSB-302 with -1.7 MPa at 78 DAS, and the least negative value occurred in the varieties MH-431 and MH-383 with values of -0.95 and -1 MPa, respectively, at 22 DAS.

It is worth mentioning that the most negative values in drip irrigation at 71 DAS were due to water shortage problems. In general, in the treatments of 80 and 100%, the water potential was in a range of -1 MPa, while in the treatments of 60% and flood, they were at -1.5 MPa, this after 40 DAS. On the other hand, Castro *et al*. (2009) carried out an *in vitro* test on corn with different concentrations of polyethylene glycol (PEG-8000), recording values of the water potential in the leaf tissue between -1.3 to -2.3 MPa, which conditioned the growth of the shoots unfavorably. Villalobos *et al*. (2016) reported water potential values ranging between -0.1 and -2.9 MPa in a study carried out in corn with four irrigation treatments and two doses of fertilization, concluding that hybrids that maintained high values of water potential (-2.9 MPa), turgor and relative water content are the ones that responded best to water stress and fertilization doses.

The values of water potential for this study varied from -0.6 to -1.92 MPa, when the most negative value was reached, the corn plant suffered morphological alterations that conditioned the final accumulation of biomass. Similar results of water potential were reported by Reyes *et al*. (2011) in an experiment of forage oats with drip irrigation, reporting values ranging from -0.7 to -1.9 MPa during the crop cycle.

Yields of forage corn

Figure 5 presents the results of the dry matter production of three corn varieties with four irrigation treatments. The variety MSB-302 showed the highest dry matter yield in the treatment of 100% with an approximate production of 20 t ha^{-1} and the lowest yield was obtained in the treatment of irrigation at 60% with a production of 15.5 t ha^{-1}. The corn variety MH-431, compared to the treatment of irrigation at 80%, showed the highest dry matter yield (21 t ha^{-1}) and the lowest occurred with flood irrigation (15.3 t ha^{-1}). Finally, the variety MH 383 showed its highest yield in the treatment of irrigation at 80% with a production of 17.7 t ha^{-1} and the lowest was found in the treatment of irrigation at 60% with a production of 13.5 t ha^{-1}.

The results obtained in this research are similar to those reported by Amador and Boschini (2000), with an average production of 14.3 t ha^{-1}, and to those obtained by Zaragoza *et al*. (2019), with an average production of 23.6 t ha^{-1} in the spring-summer cycle. Regarding the production of dry matter with surface irrigation, the results obtained in this research are superior to those found by Montemayor *et al*. (2007) (8.08 t ha^{-1}), but similar to those reported by Rivera *et al*. (2013) (17.58 t ha^{-1}).

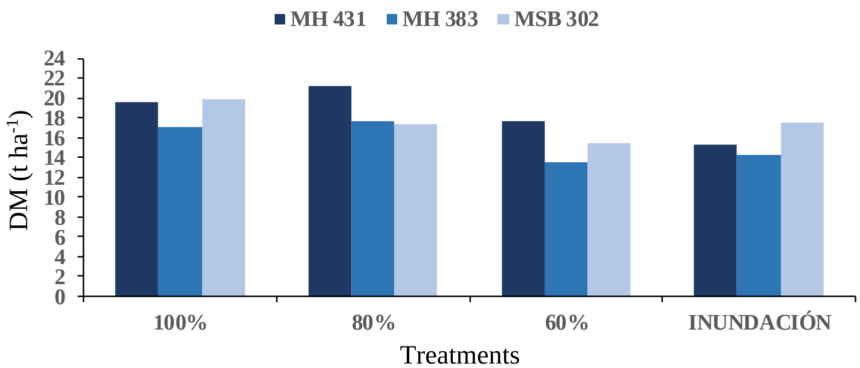

Figure 5. Graphs of the dry matter yield of three corn varieties with different irrigation treatments in the Laguna Experimental Field of INIFAP, Matamoros, Coahuila, Mexico. 2019.

When subjecting the results obtained of the variable 'dry matter' to statistical analysis, significant differences can be observed between the treatments of irrigation at 100 and 80% with respect to the treatments of irrigation at 60% and flood irrigation, however, no significant differences are observed when comparing the treatments of 100 and 80%, nor when comparing the treatment of irrigation at 60% against flood irrigation (Table 1). Similar results are reported by Montemayor *et al*. (2012) and Rivera *et al*. (2013), who reported a statistical difference between drip irrigation with different levels of ET and flood irrigation in forage corn. The results of the research demonstrate that the highest dry matter yields were obtained with the treatment of 100% ET, being 20% higher than the flood irrigation system. In other words, the dry matter yield was higher when the irrigations were scheduled according to the phenological stage of the crop.

Efficiency in the use of water

Table 1 shows the results of the comparisons of the variables measured within the irrigation treatments used in the experiment. The test used for the comparisons was the Tukey test, with an alpha confidence level of 0.05.

Figure 6 presents the results of the efficiency in the use of water (EUW) obtained from three corn varieties in four irrigation treatments. The variety MH-431, with the treatment of irrigation at 60% ET, obtained the highest EUW (4.12 kg m^{-3}), while the variety MH-383 with the flood irrigation treatment was the lowest (2.01 kg m^{-3}). These results are consistent with those reported in the literature, where greater EUW is obtained in drip irrigation compared to flood irrigation. The highest efficiencies were obtained with the treatments where a lower irrigation sheet was used (60% ET). The variety MH-431 was the one that showed the greatest EUW compared to the other two varieties, since this variety is more tolerant to high temperatures.

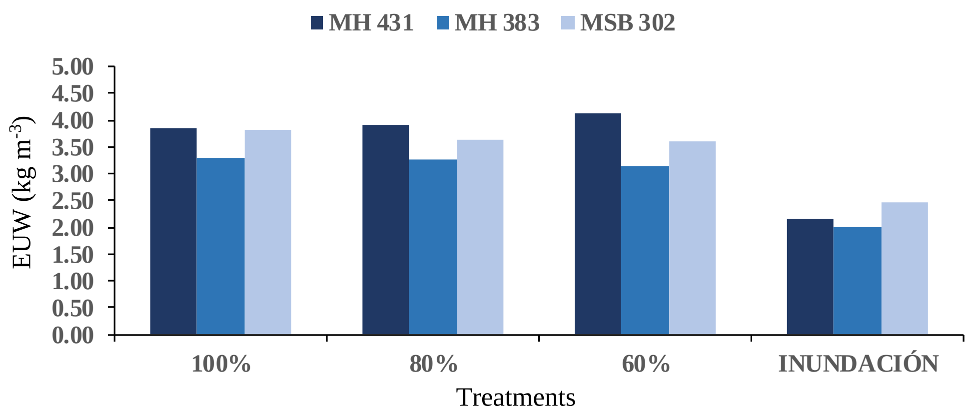

Figure 6. Graphs of water use efficiency of three corn varieties and four irrigation treatments in the Laguna Experimental Field of INIFAP, Matamoros, Coahuila, Mexico. 2019.

Similar EUW results are reported by Montemayor *et al*. (2006), who conducted an experiment to determine the efficient use of water in corn using the drip irrigation system, in which they report average EUW values of 2.9 kg m^{-3}. Zamora *et al*. (2007), in another study conducted in corn using low drip irrigation by different levels of ET, report values ranging from 1.9 to 2.96 kg m^{-3}, where the highest EUW is obtained at 80% ET and the lowest occurs with the treatment at 115% ET. Which is consistent with what was observed in this experiment, applying larger volumes of water will not always increase water use efficiency.

The treatments of irrigation at 100, 80 and 60% showed similar values of EUW with 3.66, 3.60 and 3.62 kg m^{-3}, respectively, with no significant difference between them; however, these were different from flood irrigation (2.21 kg m^{-3}) (Table 1). Howell *et al*. (2008), in corn, obtained 3.63 kg m^{-3} in the efficiency of the use of water in 2006 and 3.64 kg m^{-3} in 2007. These values were similar to those observed in our experiment. Although higher than those reported by Yescas *et al*. (2015), who report values that fluctuated between 2.84 and 3.21 kg m^{-3} in forage corn with different irrigation treatments. For the treatments of 100, 80 and 60% ET, water volumes of 5 180, 5 420 and 4 320 m^3 were applied, respectively, while for the flood irrigation treatment, the volume was 7 100 m^3.

Conclusions

This study evaluated the effect of different levels of evapotranspiration on the leaf area index (LAI), leaf temperature (Lt), leaf water potential (ψ_w), and yield of forage corn (DM) under the drip irrigation system, in order to estimate the irrigation regime that is most closely related to the efficient use of water in arid climates. The most valuable thing about the evaluation was that it was demonstrated that the moisture restriction in the crop affected the LAI and ψ_w because the Lt conditioned the proper development of the leaves, which directly affected the production of dry fodder, because it led to have a negative impact on the photosynthetic process of the plants.

Thus, the best water use efficiency was obtained when the water was applied according to the phenological stage of the crop with the treatment of 100% ET multiplied by the crop coefficient (Kc). The results indicated that the volume of water applied in the treatments with subsurface drip irrigation was 27 to 40% lower compared to flood irrigation.

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