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Water use optimization for two commercial maize hybrids for forage production in semi-arid environment

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ABSTRACT. The objective of the study was to determine the effects of different irrigation levels on the yield and quality characteristics of two silage maize hybrids. Hybrids were established under four treatments of irrigation regimes with different tension in the soil: T1) 5–15 cbar, T2) 25–35 and 75–95 cbar, T3) 75–90 and 25–35 cbar, T4) 95–110 cbar. Variables were: dry matter yield (DMY), plant height, efficient irrigation water, efficient use of water resources, crude protein, neutral and acid detergent fibre (NDF and ADF, respectively), and net energy for lactation. Data analysis was undertaken with a randomized block design for each maize hybrid. Subsequently, quadratic equations were made to determine a maximum relative value. Irrigation treatment showed statistical differences between means in all agronomic hybrid characteristics. The best DMY in H-311 hybrid was noted in T1, T2, and T3 treatments (29 756–31 061 kg/ha), for 35p12 hybrid the best was T3 with 30 221 kg/ha. There were no differences in nutritional variables for H-311 hybrid. In 35p12 hybrid, T4 accumulated the highest concentrations of NDF and ADF with 61.83 and 44.19%, respectively. The maximum relative value of efficient use of water resource in H-311 was 4.9 kg/m^3 with 518 mm, and 35p12 showed 5.6 kg/m^3 with 405 mm. So, it is possible to achieve optimal yield and quality forage, reducing the depletion of aquifers.

Introduction

Irrigation of forages is essential to supply feed for livestock systems in arid and semi-arid areas. However, as water is a limiting component, it is necessary to optimize the resource to reduce the abatement of aquifers. To approach the best optimization of irrigation water is indispensable to apply some of the concepts that evaluate biomass production per unit of water, whether water used by the crop or the input of water to the system, for example, water use efficiency, the productivity of water, efficient use of water resource (Taher et al., 2009; Hatfield and Dold, 2019). Different species of crops are utilized for forage production; maize (*Zea mays* L.) is considered for its highest water use efficiency over sudangrass, millet, vetch, pea, and oat (Zhang et al., 2018). Another way to enhance water use efficiency is through the irrigation system. For example, Reyes et al. (2020) found increases in dry matter yield to 0.87 kg/m^3 with drip irrigation in comparison with 2.08 kg/m^3 obtained with flood irrigation. In addition to the system, the hybrid or variety selection of maize is relevant in specific environments. Beyhan et al. (2016) reported ranges of water use efficiency from 3.4 to 4.3 kg/mm in different hybrids; this change was a consequence of dry mater yield variation, from 24.3 to 32.3 t/ha. Water restriction in maize affects forage quality; neutral detergent fibre increases to 14%, and the digestibility of dry matter decreases to 4.8% when irrigation is reduced (Gallo et al., 2014). Hybrid H-311 is a popular maize material used in temperate, semiarid, and arid areas in Mexico; this hybrid has an intermediate-late cycle and produces more than 50 t/ha of fresh forage yield (Martinez et al., 2004; Ruiz et al., 2011). Some farmers have started to use the 35p12 hybrid as an alternative to late sowing. This hybrid has an early cycle and is considered a good material for silage due to the high *in vitro* true digestibility, more than 82% (Smith, 2007). However, there is little information reported on the effect of different irrigations treatments on the yield and quality forage of these two hybrids. Furthermore, there is no information about the optimal water applied for these hybrids.

The objective of this study was to determine the effects of different irrigation levels on the yield and quality characteristics of two silage maize hybrids (H-311 and 35p12), and identify the optimal level of irrigation. The results of this study could be helpful for effective irrigation management of these hybrids under a surface drip system in the arid and semiarid regions.

Material and methods

The experiment was carried out on the Zacatecas Experimental Station – INIFAP (acronym in Spanish for National Research Institute for Livestock, Agriculture and Forestry) on Zacatecas, Mexico, located on coordinates 22º 54'N and 102º 39'W. The altitude is about 2 197 masl with an average annual temperature of 14.6 °C. The annual average precipitation is 416 mm, the rainfall season is from June to September, and the average potential evapotranspiration is 1 609 mm. The soil is a clay loam texture with a pH of 7.9, 2.4% of organic matter, and a bulk density of 1.43 g/cm^3.

Two maize hybrids were established with a seeder precision at a density of 90 000 plants on May 19, 2017, under a split-plot experimental design within a completely randomized block with three replicates. The main plot was H-311 (intermediate growing cycle) and 35p12 (early growing cycle) for maize hybrids. Subplots were four treatments (T) of irrigation regimes according to moisture tension in soil and combination with two crop growth stages. T1 was a non-stressed treatment; tension in the soil during all growing periods was from 5 to 15 cbar. In T2, moisture sensors in the soil were from 25 to 35 cbar in the first growing stage (V0–VT) and 75 to 95 cbar in the second growing stage (R1–R6). T3 moisture sensors were from 75 to 90 cbar in V0–VT and 25 to 35 cbar in R1–R6. T4 was a stress treatment; moisture sensors in the soil were from 95 to 110 cbar during all growing periods (Table 1). Before sowing, 152.2 mm of water was applied for all treatments for pre-sowing, and from June 20, 2017, the irrigation treatments by separated through a surface drip system started. In each plot a volumetric meter connected to a flexible hose and irrigation tapes with 76 cm of separation among them and 20 cm of spacing between emitters with a discharge of 1.02 l/h was installed. Also, duplicate sensors (Watermark® brand) to measure tension in soil were buried per plot at 30 cm of depth. Irrigation was applied when sensors registered the maximum tension limit and were suspended at the time of reaching the minimum limit. The irrigation water amount was calculated with the difference registered in the readings of the volumetric meter. Irrigation water and adequate rainfall, considered when more than 5 mm and only 75% of precipitation (Serna et al., 2011), were used to determine total water applied (TWA), irrigation plus adequate rainfall. Fertilization doses were: 224 kg of nitrogen, 76 kg of phosphorus, and 48 kg of potassium; doses were defined according to soil analysis, carried out at Zacatecas Experimental Station soil laboratory. The experimental plot was 10 rows spaced at 0.76 m, and 15 m long; two middle rows of 7 m long for each plot were evaluated. The plots were harvested at 1/4 milk line stage of maturity (Serbester et al., 2015). Agronomic variables measured were: dry matter yield (DMY), plant height (PH), efficient irrigation water (EIW), efficient use of water resource (EUWR). Nutritional characteristics taken were: crude protein (CP), neutral and acid detergent fibre (NDF and ADF, respectively) and net energy for lactation (NE_L). For DMY the two middle rows of each plot were cut to 0.15 m above ground and weighed to estimate fresh forage production. A sample of two plants was taken randomly and placed in a forced-air oven for 72 h at 55 °C to ensure the sample was dehydrated and then reweighed to determine dry matter percentage. DMY was calculated from a percentage of dry matter from the sample multiplied by the fresh forage production value. PH was measured with a stadal from the ground level to the tip of the inflorescence. EIW was determined

Table 1. Irrigation treatments with different soil tension at growth stages, precipitation, and water applied in H-311 and 35p132 maize hybrids for forage production in Zacatecas, Mexico

	Growth stages of maize		Rainfall, mm		Irrigation water, mm		Total water applied, mm	
T	V0–VT	R1–R6	H-311	35p12	H-311	35p12	H-311	35p12
T1	5–15	5–15			710	451	935	631
T2	25–35	75–90	225	180	468	363	693	543
T3	75–90	25–35			436	360	661	540
T4	95–110	75–110			273	220	498	400

T – irrigation treatment, T1: 5–15 cbar, T2: 25–35 and 75–95 cbar, T3: 75–90 and 25–35 cbar, T4: 95–110 cbar; V0–VT – vegetative stages; R1–R6 – reproductive stages

by dividing DMY by irrigation applied, and EUWR was determined by dividing DMY by total applied water (irrigation and rainfall). Dried samples were ground on Zacatecas Experimental Station with a Willy mill and passed through a one mm sieve to determine the nutritional value of forage. Nutritional variables were determined at nutricional laboratory of the faculty of veterinary medicine in Zacatecas. CP was defined by Dumas combustion by AOAC method (AOAC International, 1995), using LECO equipment. NDF and ADF samples were determined with the detergent technique through a fibre ANKOM analyzer (Georing and Van Soest, 1970). NE_l was calculated with the equations suggested by Horroks and Vallentine (1999). Data analysis was undertaken using the 'PROC GLM' procedure with a randomized block design for each maize hybrid. Means were compared and separated through the Lsmeans test at 5% probability (SAS, 2011). Subsequently, two quadratic equations were made with DMY-TWA and EUWR-TWA, then the second derivative was used to determine a maximum relative value for each one (R Core Team, 2016).

Results

Irrigation treatment shows different ($P < 0.05$) means in all agronomic characteristics for both hybrids (Table 2). The tallest plants were noted in irrigation treatments T1 and T2 overcoming ($P < 0.05$) T4 with 12 and 10% in H-311 and 35p12, respectively. The irrigation treatment with the least amount of water showed the lowest ($P < 0.05$) DMY in two hybrids, less than 23 712 kg/ha, while the other treatments obtained values greater than 26 756 kg/ha. Nevertheless, in treatment T1, which represented the most significant amount of water used, the lowest efficiency ($P < 0.05$) both in irrigation water and in the use of water resources was reported: 4.19 and 3.2 km/m^3 for H-311, and 5.8 and 4.2 kg/m^3 for 35p15.

Irrigation treatments did not show an effect ($P > 0.05$) for nutritional variables (Table 3) in H-311 hybrid. Nevertheless, in 35p12 hybrid there were effects ($P < 0.05$) in CP, NDF and ADF. CP accumulation in 35p12 was higher in the treatment where less water (T4) was applied (8.69%). While NDF and ADF showed low fibre content under irrigation treatment with greater amount of water (T1), accumulations were 58.49 and 41.36%, respectively.

DMY of H-311 hybrid was 31 876 kg/ha and reached the maximum relative value with 784 mm of TWA. At the same time, efficient use of water resources was 4.9 kg/m^3 with 518 mm and reported 24 915 kg/ha of DMY. Quadratic models for both hybrids were statistically significant ($P < 0.001$), with a good regression coefficient >0.97 (Figure 1a). For 35p12 hybrid, DMY obtained the maximum value at 28 919 kg/ha with 537 mm of TWA. Concerning efficient use of water resources, 405 mm of total water applied got 5.6 kg/m^3, and DMY was 24 027 kg/ha. Quadratic models were significant ($P > 0.001$); these showed an R^2 greater than 0.84 (Figure 1b).

Table 2. Agronomic characteristics of H-311 and 35p12 maize hybrids under different irrigation treatments in Zacatecas, Mexico

	PH, cm		DMY, kg/ha		EIW, kg/m^3		EUWR, kg/m^3	
T	H-311	35p12	H-311	35p12	H-311	35p12	H-311	35p12
T1	357^a	269^a	29 756^a	26 756^{ab}	4.19^c	5.8^c	3.2^b	4.2^c
T2	356^a	268^a	30 338^a	27 571^{ab}	6.47^b	7.6^b	4.4^a	5.1^{bc}
T3	336^{ab}	258^{ab}	31 061^a	30 221^a	7.13^b	8.4^b	4.7^a	5.6^{ab}
T4	317^b	242^b	23 712^b	23 633^b	8.67^a	10.7^b	4.8^a	5.9^a
P-value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

T – irrigation treatment, T1: 5–15 cbar, T2: 25–35 and 75–95 cbar, T3: 75–90 and 25–35 cbar, T4: 95–110 cbar; PH – plant height; DMY – dry matter yield; EIW – efficient irrigation water; EUWR – efficient use of water resources; [abc] means within the row with different superscripts are significantly different at $P < 0.05$

Table 3. Nutritional variables in H-311 and 35p12 maize hybrids under different irrigation treatments in Zacatecas, Mexico

	CP, %		NDF, %		ADF, %		NE_L, Mcal/kg	
T	H-311	35p12	H-311	35p12	H-311	35p12	H-311	35p12
T1	8.2[a]	7.95[b]	58.89[a]	58.49[b]	40.2[a]	41.36[b]	1.24[a]	1.22[a]
T2	8.4[a]	8.37[ab]	57.48[a]	61.7[ab]	38.3[a]	43.48[ab]	1.29[a]	1.16[a]
T3	8.1[a]	8.31[ab]	56.7[a]	60.13[ab]	38.2[a]	43.03[ab]	1.29[a]	1.18[a]
T4	8.56[a]	8.69[a]	56.8[a]	61.83[a]	37.9[a]	44.19[a]	1.3[a]	1.14[a]
P-value	>0.05	<0.05	>0.05	<0.05	>0.05	<0.05	>0.05	>0.05

T – irrigation treatment, T1: 5–15 cbar, T2: 25–35 and 75–95 cbar, T3: 75–90 and 25–35 cbar, T4: 95–110 cbar; CP – crude protein; NDF – neutral detergent fibre; ADF – acid detergent fibre; NE_L – net energy for lactation; [ab] means within the row with different superscripts are significantly different at $P < 0.05$

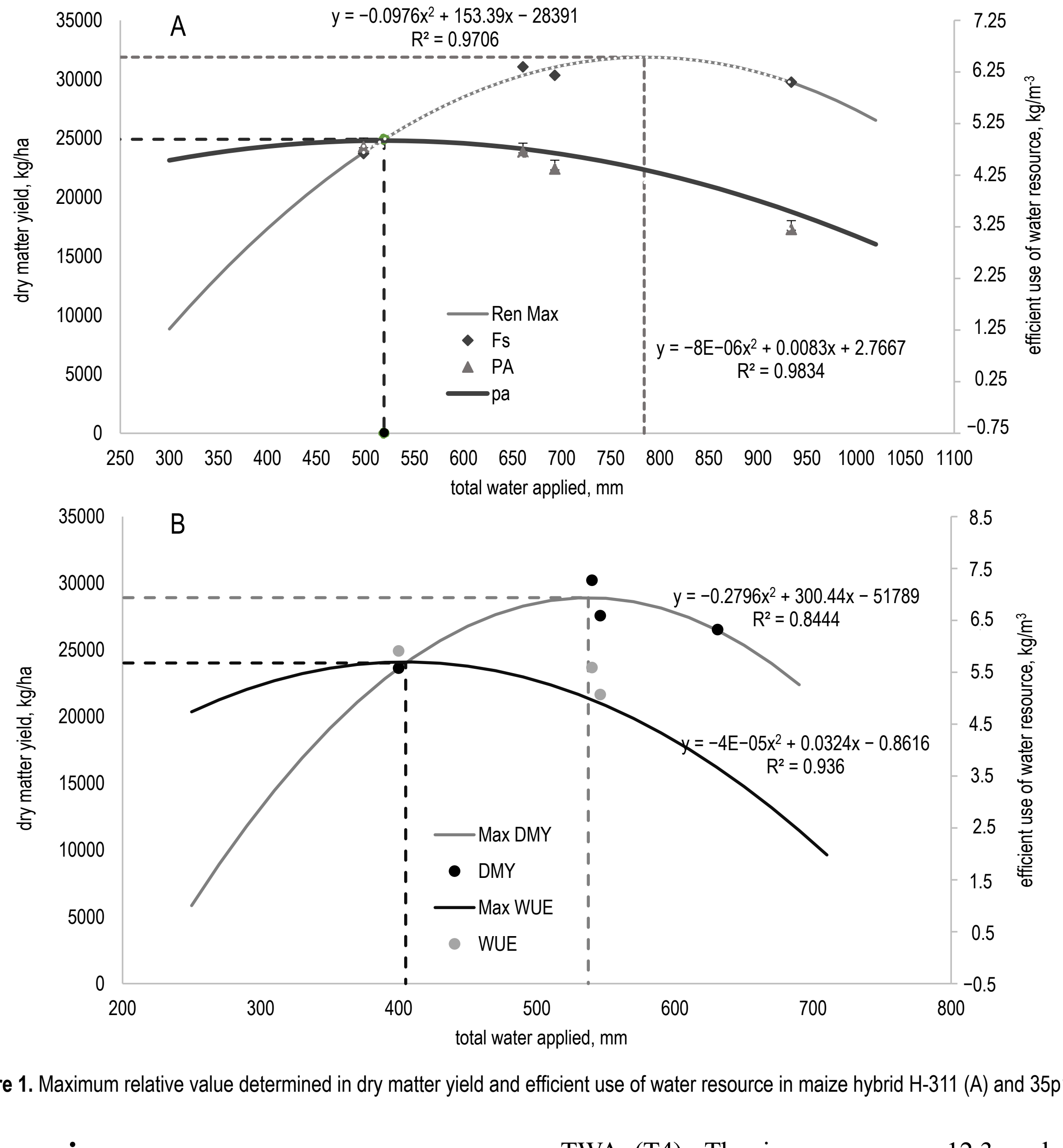

Figure 1. Maximum relative value determined in dry matter yield and efficient use of water resource in maize hybrid H-311 (A) and 35p12 (B)

Discussion

In the present study, H-311 and 35p12 hybrids show differences in PH and DMY with the greater water application of 935 and 631 mm, respectively, in comparison to the irrigation treatment with less water, 498 and 400 mm, respectively, of TWA (T4). The increases were 12.3 and 10.7% in PH, and 25 and 27.9% in DMY for H-311 and 35p12 hybrids, respectively. The above could be attributed to low soil moisture or water deficit that by blocking nutrient uptakes in plants, caused low leaf area and, therefore low yields (Seif et al., 2016; Demir et al., 2020). Notwithstanding differences in plant height were noted between irrigation treatments: hybrid H-311 was superior to 15 hybrids evaluated on Zacatecas Experimental Station-INIFAP, the ranges were from 2.47 to 2.45 m (Flores and Figueroa, 2010), but these 15 hybrids were similar to 35p12, despite that it is a material of early growing cycle. On the other hand, for our hybrids we have reported higher DMY than other states in the north of Mexico, less than 22 t/ha (Nuñez et al., 2010; Peña et al., 2012). However, hybrids are similar to those reported by Flores and Figueroa (2010), who observed the best hybrids with about 29.9 t/ha. Another factor why producers continue planting these hybrids is the low cost of the seed and its constant yield. Although in our study, efficient use of water resources was determined through the application of water, supported by a sensor in soil and precipitation, results are similar to several hybrids evaluated in Mexico under subsurface drip irrigation, where the reported range of water use efficiency was from 2.7 to 5.72 kg/m^3 (Guevara et al., 2005; Pedroza et al., 2014). Therefore, sensors could be an alternative to measure water efficiency.

Jahansouz et al. (2014) mentioned that in late-season hybrids is possible to obtain up to 11% more forage than in early-season hybrids; these results agree with the outcomes of this investigation. Despite this, hybrid 35p12 showed a greater value of efficient use of water resources; as a result, this early-season material is more efficient to transform water resources to forage and could be a good option under T3 irrigation treatments. Also, some authors mentioned a critical period of accumulative biomass from flowering to the ending stage (Shahrabian and Soleymani, 2011; Gheysari et al., 2017), therefore T3 could avoid forage losses due to minimizing stress after the flowering stage.

Differences in the quality of forage were not observed as the amount of total water applied ranged 498-935 mm, therefore the forage produced in such a manner will assure the same animal performance. Therefore it is essential to achieve the highest yields with less water so that T3 is the best irrigation treatment. These results are similar to other studies where water applied is reduced but quality of forage is not affected in some late-season hybrids (Yescas et al., 2015). Nevertheless, treatment of 35p12 hybrid with slow TWA (400 mm) could stress the plants, exert specific effects on cell wall ants, thereby increase NDF and ADF.

Crude protein values in both hybrids were considered similar to populations of varieties evaluated at Pabellón, Aguascalientes, México and Torreon, Coahuila, Mexico (Peña et al., 2012). However, our hybrids contain more NDF and ADF than materials evaluated in North-Central Mexico, since Peña et al. (2002) reported 50.3 and 27.7% for intermediate-season varieties, and 49.7 and 26.4% for early-season varieties, respectively. Net energy for lactation of all treatments was lower than those obtained by 21 hybrids; ranges reported were from 1.41 to 1.62 Mcal/kg (Nuñez et al., 2010). An alternative to improve the fibres and digestibility of these hybrids would be to find the optimum cutting height, where the yield is sacrificed as little as possible, avoiding stems that are poorly digestible (Morand and Balbi, 2020).

In our research quadratic function was used to find the maximum value of water use efficiency; an optimum irrigation was set on 520 mm (Ahmad et al., 2018). Also, Nagore et al. (2017) found that a potential yield of 25.1 kg/ha of grain could be obtained with 400 mm with new breed hybrids. Other authors reported that a lineal regression model incrementally influenced DMY (Gozubuyuk et al., 2020; Buyuktas et al., 2021). The results of our study are in agreement with these previous results concerning the amount of total water applied for optimization. On the other hand, in this study is important to know the relationship between yield and water savings, in H-311 hybrid, water was reduced by 33.92%, but dry matter yield decreased by 21.8%. In 35p12, the reduction of water was 24.58%, and the decrease was 16.9% in DMY. The balance equation can maximize the yield per unit of water used without affecting forage quality. Therefore, applying this irrigation technology may help reduce water depletion of the 89 314 ha dedicated to the yield of maize forage in north-central Mexico. Potential water savings could be 23 757.5 m^3 with H-311 and 11 789.4 m^3 with 35p12; with these savings, the aquifers would be less depleted, achieving less environmental impact with animal production (Blummel et al., 2014; Heinke et al., 2020) or increasing agricultural area for feed production for livestock.

Conclusions

Dry matter yield of H-311 maize hybrid was affected when the application of water decrease 500 mm, nutritional variables did not show effects with the application of water from 498 to 935 mm. In 35p12 hybrid the best production was obtained with 540 mm of total water applied. The maximum relative value of efficient use of water resource for H-311 was 4.9 kg/m^3, it was achieved with 518 mm water, while for 35p12 it was 405 mm or 5.6 kg/m^3. With the application of efficient use of water resources, the production and quality of maize forage will be optimized, saving a considerable amount of water that would help reduce the depletion of aquifers or increase the agricultural area for livestock feed.

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Conflict of interest

The Authors declare that there is no conflict of interest.

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