Article

Forage corn production with two irrigation systems and three levels of applied evaporation

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Abstract

The efficiency in the use of water to produce forage groups a series of components related to the crop and the irrigation system, which consists of obtaining a greater production per unit of water consumed. The objective of the work was to know the yield, nutritional quality and water use efficiency (WUE) of the forage corn (*Zea mays* L.) culture in two irrigation systems under three levels of applied evaporation. The work was established on April 19, 2019, at the La Laguna Experimental Field (CELALA) of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP), located in Matamoros, Coahuila, Mexico. The irrigation systems evaluated were: subsurface drip and surface irrigation. In both systems, the applied sheets corresponded to 100, 75 and 50% of free evaporation of the class 'A' evaporimeter pan. The harvest was carried out when the grain was in the R3 milky grain stage. The experimental design used was split plots with four repetitions. The interaction of subsurface drip irrigation system -100% evaporation was higher ($p< 0.05$) in the variables of height with 2.05 m, green forage yield with 55.08 t and dry forage yield 14.85 t. The combination with the best behavior in WUE in yield with 1.98 kg m^{-3} and the highest values in WUE in forage quality was surface irrigation system -75% evaporation. There were significant differences between irrigation systems in the quality variables with better results in the surface irrigation system.

Keywords: *Zea mays* L., subsurface drip, surface irrigation, water use efficiency.

Reception date: May 2022
Acceptance date: August 2022

Introduction

Agriculture represents 72% of all surface and groundwater withdrawals globally, mainly for irrigation purposes, FAO (2021). Growth in livestock product consumption is forecast to persist to 2030 and beyond, but its pace will vary. In high-income countries, where population growth is slow, there will be less room for growth because the consumption of livestock products (meat and milk) is already very high (305 kg per capita). In contrast, in low and middle income countries, per capita consumption is 60 kg, while the global average is 115 kg (FAO, 2011).

The intensive milk production system is the main user of irrigation water in the main dairy basins of Mexico. Of the water used in dairy farms, that related to the production of forage represents the largest amount, that used in milking and drinking troughs constitutes a small portion of that destined for milk production (Herrero *et al*., 2000). Efficiency in the use of water for forage production groups a series of components related to the crop and the irrigation system, which consists of increasing agronomic and economic productivity so that a greater production per unit of water consumed is obtained (FAO, 2011).

A research strategy has been to evaluate the water use efficiency (WUE) of the most common species in the region and their nutritional quality (Cruz *et al*., 2012). Another strategy has been the study of irrigation systems with high efficiency in the application of water for the production of the region's crop pattern.

In the Lagunera Region, surface irrigation systems are the most common, with application efficiencies of 40 to 65% in irrigation districts in the country, mainly because there are no incentives for them to carry out actions to improve this efficiency (Mejía *et al*., 2002). On the other hand, studies have shown that the underground drip irrigation system allows achieving an average water saving of 23% compared to the surface irrigation system, maintaining more constant moisture levels without compromising yield, which increases water use efficiency, WUE (Martínez-Gimeno *et al*., 2018).

Forage corn is one of the three most important forage crops in the region because of the high energy value it provides to the rations of dairy cattle. The area sown in 2021 was 56 105 ha, followed by alfalfa 51 321.2 ha and forage sorghum with 35 397.5 ha. The use of corn in animal feed has a great versatility since it can be consumed in green, silage or dry (Reta *et al*., 2002).

It is necessary to optimize agronomic processes such as efficiency in the conduction and application of irrigation water in forage corn to produce the highest quantity and quality of forage with the best efficiency in the use of irrigation water. In this sense, the interaction of irrigation systems∗level of evaporation could generate positive effects on crop productivity. The objective of the work was to know the yield, nutritional quality and water use efficiency (WUE) of the forage corn culture in two irrigation systems under three levels of applied evaporation.

Materials and methods

The research work was carried out at the facilities of the La Laguna Experimental Field (CELALA, for its acronym in Spanish) of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP, for its acronym in Spanish), located in Matamoros, Coahuila, Mexico, at an altitude of 1 150 m, between the parallels 25° 32' north latitude and the meridians 103° 14' west longitude. The sowing was carried out wet on April 19, 2019, in a clay-textured soil, with an electrical conductivity of 1.78 dS m^{-1}, field capacity of 34%, permanent wilting point of 20%, bulk density of 1.26 g cm^{-3} and 2.42% of organic matter. The corn variety used was Syngenta 8285 of early cycle, with a sowing density of 100 000 plants ha^{-1} and a furrow separation of 0.76 m.

The experiment consisted of two irrigation systems: subsurface drip irrigation system and surface irrigation system. Three irrigation sheets were evaluated in the two systems. The irrigation sheets corresponded to 100, 75 and 50% free evaporation of the class 'A' evaporimeter pan. For the subsurface drip irrigation system, the irrigation sheets were 93.5 (100%), 70.4 (75%) and 47.2 cm (50%), Ro-Drip drip tape was used as irrigation lines, with a wall thickness of 0.2 mm, caliber 8 000, inner diameter of 16 mm, with drippers spaced at 20 cm and an expenditure of 5 L h^{-1} m^{-1} at an operating pressure of eight PSI, installed at 0.36 m depth of the ground. The irrigations were applied with a frequency of three times a week (Monday, Wednesday and Friday) and the number of irrigations was the same for all treatments. A surface irrigation (waterlogging) was applied 10 days before sowing.

In the surface irrigation system, the irrigation of the experimental plots was carried out with pressurized conduction through pipes with a multi-gate system. Irrigation sheets that corresponded to 94.5 (100%), 70.4 (75%) and 53.3 cm (50%) were applied. The number of irrigations ranged from four to six applications. The first irrigation of waterlogging was at 10 days before sowing, treatments were applied from 28 days after sowing (das). The number of supplemental irrigations was as follows: 100% (five irrigations), 75% (four irrigations), 50% (three irrigations).

Soil moisture samplings were performed before each irrigation to ensure that moisture remained at usable moisture. For the precise application of the volume of water to each irrigation unit, there were pressure gauges and control valves that allowed regulating the pressure in the irrigation system, guaranteeing the expenditure and load of operation.

In the installation of the irrigation system, an evaluation and test of the system were carried out, in addition, a previously calibrated volumetric meter was used. The fertilization dose was 280-80-00 N-P-K. Half of the N and all the P were applied at the time of sowing in both systems. The other half of N was applied in the first supplemental irrigation in the surface irrigation system. In the subsurface drip irrigation system, the other half of N was applied through the irrigation system with the help of a Venturi. The fertilization sources were Urea, UAN-32 and MAP. The experimental plots were 24.32 m^2. The useful plot was 7.6 m^2 to estimate the green forage yield (GFY) (t ha^{-1}).

The harvest was carried out when the grain was in the R3 milky grain stage, which occurred at 105 das for the surface irrigation system and 109 das for the subsurface drip irrigation system. Subsequently, a one-kilogram sample was taken and dried in a forced-air oven at a temperature of 65 °C for 72 h to determine the percentage of dry matter (DM) and estimate the dry forage yield (DFY) (t ha^{-1}).

For the evaluation of nutritional quality, complete plant samples of about one kilogram were taken and the same drying process was followed. The following were determined: crude protein (CP) content, according to established and standardized techniques for the analysis of forage, AOAC (2000). Neutral detergent fiber (NDF), acid detergent fiber (ADF), non-fibrous carbohydrates (NFC), lignin (LIG), total digestible nutrients (TDN) and net energy of lactation (NEL) by near-infrared spectroscopy (NIRS) previously calibrated using the procedures reported by Van Soest *et al*. (1994).

To estimate the water use efficiency (WUE) in the quality variables, the yield of the variable in kg was considered: DFY, CP, ADF, NDF, LIG, NFC, TDN and NEL in Mcal by the volume of water applied (m^3). To do this, the volume of water applied was determined with the following equation: V= IS∗A. Where: V= volume of water applied (m^3); IS= irrigation sheet (m); and A= area (m^2). To determine the WUE in DFY, the following equation was used: WUE DFY= DFY/V. Where: WUE DFY= water use efficiency in dry forage yield (kg m^{-3}); DFY= dry forage yield (kg); and V= volume of water applied (m^3).

To determine the WUE in the variables of quality (CP, ADF, NDF, LIG, NFC and TDN), the kg ha^{-1} and then the kg m^{-3} were determined. The following equations were used: kg ha^{-1}= (%∗DFY)/100. Where: kg ha^{-1}= kg of the variable of quality per ha (kg ha^{-1}); %= percentage of the variable; and DFY= dry forage yield (kg); kg m^{-3}= kg ha^{-1}/V. Where: kg m^{-3}= kg of the variable of quality per m^3 (kg m^{-3}); kg ha^{-1}= kg of the variable of quality per ha (kg ha^{-1}); and V= volume of water applied (m^3). To determine the WUE in NEL, the following equation was used: WUE NEL= (DFY∗NEL)/V. Where WUE NEL= water use efficiency in net energy of lactation (Mcal m^{-3}), DFY= dry forage yield (kg); NEL= net energy of lactation (Mcal kg^{-1}); and V= volume of water applied (m^3). Height data were taken on five plants at the time of harvest. The experimental design that was used was split plots with four repetitions. An analysis of variance was performed with the SAS 9.2 program under the procedures of GLM and multiple comparison of means for each of the variables.

Results and discussion

When evaluating the production of forage corn with two irrigation systems and three percentages of evaporation, a highly significant difference ($p< 0.01$) was found between percentages of evaporation and a significant difference ($p< 0.05$) was obtained in the interaction of system∗evaporation, mainly in the variables of plant height, green forage yield (GFY) and dry forage yield (DFY) (Table 1).

In plant height, the combination of subsurface drip irrigation system -100% evaporation and surface irrigation system -75% evaporation were higher ($p< 0.05$) than the other treatments, which obtained height values of 2.05 and 1.86 m (Table 1), these values differ from those obtained by Montemayor-Trejo *et al*. (2012), who, when comparing three irrigation systems, obtained 2.89 m in the subsurface drip irrigation system and 1.58 m in the surface irrigation system.

Table 1. Response of agronomic variables in forage corn depending on the irrigation system and evaporation.

System	Evaporation (%)	Height (m)	GFY (t)	DFY (t)	DM (%)
SD	100	2.05 a	55.08 a	14.85 a	26.79 a
	75	1.73 ab	41.09 bc	9.35 b	23.1 a
	50	1.38 b	36.78 bc	8.46 b	22.42 a
SI	100	1.66 ab	43.45 abc	11.91 ab	27.85 a
	75	1.86 a	49.26 ab	13.87 ab	28.24 a
	50	1.67 ab	32.8 c	8.67 b	26.43 a
System		ns	ns	ns	ns
Evaporation		**	**	**	**
Syst∗Eva		**	**	*	*

SD= subsurface drip; SI= surface irrigation; GFY= green forage yield; DFY= dry forage yield; DM= percentage of dry matter; [abc]= means in the same column without a common literal are different ($p< 0.05$); [*], [**]= $p\leq 0.01$ and 0.05, respectively; ns= not significant.

For the GFY variable, there was a significant difference in the interaction of subsurface drip irrigation system -100% evaporation, which obtained the highest production with 55.08 t ha^{-1}, the lowest production was observed in the combination of surface irrigation system -50% evaporation with 32.8 t ha^{-1}. These results show the same trend as those reported by Yescas *et al*. (2015), who found that by increasing irrigation as evapotranspiration increases (from 60 to 100%), they obtained yields from 47.6 to 57.6 t ha^{-1}. These results demonstrate the influence of the amount of water applied and the irrigation system used in the production of forage corn.

Something similar was observed in the DFY variable, in which the combination of subsurface drip irrigation system -100% evaporation was higher than the others ($p< 0.05$), with 14.85 t ha^{-1} and the lowest yield was obtained in surface irrigation system -50% evaporation with 8.67 t ha^{-1} (Table 1). Similar values were reported by Yescas *et al*. (2015); Wang *et al*. (2022), who mention that the highest DFY values were obtained in the treatment with irrigation sheet corresponding to 100% of the daily evapotranspiration with 14.78 t ha^{-1} and that the DFY in the drip irrigation system was 16.24% higher than that of the flood irrigation system.

Regarding DM, there were no significant differences between irrigation systems, evaporation and interactions of system∗evaporation, the range was from 22.42 to 28.24%, the average of 25.8% (Table 1), values below what was recommended by Núñez *et al*. (2005) to carry out the harvest of corn for silage, with which the highest nutritional quality and the highest yield in dry matter are obtained. In the agronomic results obtained in this experiment, two phenomena are evident, one is that there is no significant difference between irrigation systems, this means that they behaved in a similar way; however, highly significant differences ($p< 0.01$) were observed between evaporation levels and significant differences ($p< 0.05$) in the interaction of system∗evaporation.

The other phenomenon is that there is interaction between the subsurface drip irrigation system with 100% applied evaporation in plant height, GFY and DFY; that is, the highest values in productivity were obtained. This may be mainly due to the fact that, in the subsurface drip irrigation system, water is more available to the plant more frequently and the transpiration process increases, which affects carbon dioxide exchange and therefore greater biomass production (Coelho and Or, 1999).

As for the WUE variable, the combination that proved to be statistically superior ($p< 0.05$) was surface irrigation system -75% evaporation with 1.98 kg m^{-3}. The interactions that were less efficient were subsurface drip irrigation system -75% evaporation and surface irrigation system -100% evaporation, which proved to be statistically similar with 1.34 and 1.27 kg m^{-3} (Figure 1). No significant differences were found between irrigation systems, so the positive effect of surface irrigation was caused by evaporation levels and the interaction of system∗evaporation. In addition, these results suggest that, by increasing the water sheet applied, a decrease in WUE is observed.

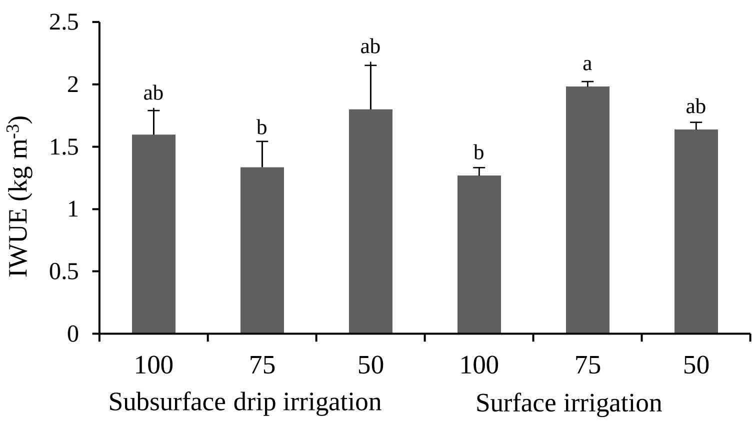

Figure 1. Water use efficiency in yield of forage corn depending on the irrigation system and evaporation.

These results differ from those found by Montemayor-Trejo *et al*. (2012); Salomó *et al*. (2019), who indicate that the highest production of corn forage per unit of applied volume of water was 2.7 to 4.07 kg m^{-3} using subsurface drip irrigation system compared to surface irrigation with 1.8 kg m^{-3} and 2.84 to 3.24 kg m^{-3} applying sheets that fluctuated from 60 to 100% of potential evapotranspiration (Yescas *et al*., 2015).

In response to nutritional quality variables in corn forage, there were highly significant differences ($p< 0.01$) between irrigation systems in acid detergent fiber (ADF), neutral detergent fiber (NDF), lignin (LIG), total digestible nutrients (TDN) and net energy of lactation (NEL). For the variables of neutral detergent fiber (NDF), total digestible nutrients (TDN) and net energy of lactation (NEL), significant differences ($p< 0.05$) were observed between the interactions of system∗evaporation. On the contrary, in the variables of crude protein (CP) and non-fibrous carbohydrates (NFC), no significant differences were observed between irrigation systems, % evaporation and the interaction of system∗evaporation (Table 2).

Table 2. Response of nutritional quality variables in forage corn depending on the irrigation system and evaporation.

System	Evaporation (%)	CP	ADF	NDF	LIG	NFC	TDN	NEL
		(%)						(Mcal kg^{-1})
SD	100	10.36 a	32.98 ab	53.17 ab	4.66 abc	30.09 a	61.95 abc	1.36 ab
	75	9.52 a	36.83 a	60.53 a	4.85 ab	22.15 a	56.72 c	1.25 b
	50	10.92 a	35.14 ab	58.13 ab	5.18 a	22.99 a	57.45 bc	1.27 b
SI	100	10.05 a	30.81 b	52.48 ab	3.92 bc	31.06 a	63.2 a	1.39 a
	75	10.51 a	31.04 ab	51.88 ab	3.68 c	30.8 a	62.8 ab	1.39 a
	50	10.15 a	30.44 b	51.27 b	3.62 c	31.77 a	63.8 a	1.41 a
System		ns	**	**	**	ns	**	**
Evaporation		ns	ns	ns	ns	ns	ns	*
Syst*Eva		ns	ns	*	ns	ns	*	*

SD= subsurface drip; SI= surface irrigation; CP= crude protein; ADF= acid detergent fiber; NDF= neutral detergent fiber; LIG= lignin; NFC= non-fibrous carbohydrates; TDN= total digestible nutrients; NEL= net energy of lactation; ^{abc}= means in the same column without a common literal are different (p< 0.05); *, **= $p\leq$ 0.01 and 0.05, respectively; ns= not significant.

There was no significant difference (p< 0.05) in CP concentrations, which ranged from 9.52 to 10.92% in the interactions evaluated (Table 2). These values exceed what was reported by (Zaragoza-Esparza *et al*., 2019), who mention having obtained a range from 7.8 to 9% and those considered average values in good quality corn silage, which vary in a range from 7.5 to 8.6 (Mábio *et al*., 2015). Herrera (1999); Peña *et al*. (2002) mention that a high-quality forage corn is considered one that has ADF values of 25 to 32%. Similar results were observed in the surface irrigation system, their figures proved to be in the high-quality range. The values ranged from 30.44 to 31.04% (Table 2). These values were similar to those reported by Sánchez and Hidalgo-Ardón (2018), which ranged between 29.9 and 36.6%.

In the experiment, NDF values ranged from 51.27 to 60.53% and demonstrated a significant difference (p< 0.05), the interaction with the highest value was subsurface drip irrigation system -75% evaporation, while the lowest was surface irrigation system -50% evaporation (Table 2). These results coincide with those obtained by Zaragoza-Esparza *et al*. (2019) and were higher than those reported by (Núñez *et al*., 2006; Juráček *et al*., 2012), whose values ranged from 44 to 48%.

The values considered of high quality are from 40 to 52% (Herrera, 1999). The high contents of NDF result in a decrease in the digestibility of the forage, for this reason, the treatments with higher NDF in the experiment showed low levels of digestibility, this results in a decrease in the consumption of silage by the animal, which causes milk production to decrease.

A high concentration of lignin in forage crops is undesirable as it resists microbial digestion in the rumen and therefore reduces enzyme access to the structural carbohydrates of cells (Cherney *et al*., 1991). Reducing lignin concentration results in increased digestion of forage fiber, thus increasing weight gain and milk production per unit of mass of forage fed. The analysis of variance showed a highly significant difference between irrigation systems in LIG, the highest values were obtained in the subsurface drip irrigation system, with values from 4.66 to 5.18%. The range in the surface irrigation system was from 3.62 to 3.92% (Table 2). Behavior similar to that reported by Carvalho *et al*. (2016), in which they mention that the best water conditions provide corn with rapid cell expansion, in anticipation of the tissue lignification process.

For the TDN variable, significant differences were found between associations. Surface irrigation system -100% evaporation and surface irrigation system -50% evaporation obtained the highest values in digestibility with 63.2 and 63.8%, without significant difference between them. The lowest value was observed in subsurface drip irrigation system -75% evaporation with 56.72% (Table 2). These results are similar to those obtained by (Núñez-Hernández *et al*., 2015), who report that in vitro digestibility values range from 62.6 to 67.8% in intermediate cycle hybrids and from 67.2 to 73.2% in early hybrids.

In a study carried out with lactating cows, it has been concluded that the digestibility of fiber is potentially the most important indicator that determines the nutritional quality of corn for silage, because when the availability of energy in more digestible fiber increases, the consumption of dry matter also increases (Núñez *et al*., 2015), which causes a higher milk production.

In net energy of lactation (NEL), a highly significant difference between irrigation systems ($p<$ 0.01) was obtained, the highest values were found in the surface irrigation system without finding difference between them. The values were 1.39, 1.39 and 1.41 Mcal kg^{-1} for 100, 75 and 50% evaporation applied, respectively (Table 2). These results are superior to those found by Yescas *et al*. (2015), whose values fluctuated between 1.036 and 1.08 Mcal kg^{-1}. The energy value of corn can be negatively associated with fibrous concentrations and dry forage production, this could cause treatments high in fiber and low in production to be low in digestibility and net energy of lactation.

No significant differences were found between irrigation systems, evaporation and interaction of system∗evaporation for the variable of non-fibrous carbohydrates ($p<$ 0.05), the values ranged between 22.15 and 31.77 %. Results similar to those reported by Moreno-Reséndez *et al*. (2017), whose values were 21.2 and 31.4%. On the other hand, in the experiment, there were no significant differences between irrigation systems for the variables of WUE in CP, ADF, NDF, NFC, TDN and NEL. The variables that obtained significant differences in the interactions evaluated in WUE in nutritional quality of forage corn were CP, ADF, NDF, LIG, TDN and NEL. In the analysis of variance for NFC, there were no significant differences between systems, evaporations and interactions (Table 3).

In CP, the interaction of surface irrigation system -75% evaporation was higher than the others with a total of 0.21 kg m^{-3} (Table 3). Different authors have attributed the increase in CP to the increase in the dose of nitrogen fertilizer in the soil (Cox and Charney, 2001; Islam *et al*., 2012). In this research, fertilization dose was not an evaluation parameter, so water volume and irrigation system influenced CP content.

Table 3. Water use efficiency of the variables of nutritional quality in forage corn depending on the irrigation system and evaporation.

System	Evaporation (%)	CP	ADF	NDF	LIG	NFC	TDN	NEL
		(kg m^{-3})						(Mcal m^{-3})
SD	100	0.16 ab	0.52 ab	0.83 ab	0.07 ab	0.5 a	1 ab	2.2 ab
	75	0.13 b	0.49 ab	0.81 ab	0.06 ab	0.3 a	0.76 b	1.69 b
	50	0.19 ab	0.6 a	0.99 a	0.09 a	0.48 a	1.07 ab	2.37 ab
SI	100	0.13 b	0.39 b	0.66 b	0.05 b	0.39 a	0.8 b	1.77 b
	75	0.21 a	0.62 a	1.03 a	0.07 ab	0.61 a	1.24 a	2.75 a
	50	0.16 ab	0.49 ab	0.83 ab	0.06 b	0.54 a	1.05 ab	2.33 ab
System		ns	ns	ns	**	ns	ns	ns
Evaporation		ns	ns	ns	*	ns	ns	ns
Syst*Eva		**	*	*	*	ns	**	**

SD= subsurface drip; SI= surface irrigation; CP= crude protein; ADF= acid detergent fiber; NDF= neutral detergent fiber; LIG= lignin; NFC= non-fibrous carbohydrates; TDN= total digestible nutrients; NEL= net energy of lactation; ^{abc}= means in the same column without a common literal are different ($p< 0.05$); *, **= $p\leq 0.01$ and 0.05, respectively; ns= not significant.

The variables of ADF and NDF had similar behavior, the highest values statistically and numerically were obtained in the combinations of subsurface drip irrigation system -50% evaporation and surface irrigation system -75% evaporation with 0.6 and 0.62 kg m^{-3} for ADF and 0.99 and 1.03 kg m^{-3} for NDF. The interactions with the lowest amount of fibers was surface irrigation system -100% evaporation with 0.39 and 0.66 kg m^{-3} in ADF and NDF, respectively (Table 3).

The combination of subsurface drip irrigation system -50% evaporation obtained the highest value in LIG with 0.09 kg m^{-3}, the lowest values occurred in the interactions of surface irrigation system -100% evaporation and surface irrigation system -50% evaporation with 0.05 and 0.06 kg m^{-3}. It is worth mentioning that there were significant differences between irrigation systems, with higher values in the subsurface drip irrigation system (Table 3).

The behavior of the variables of TDN and NEL was similar, a significant difference was observed between combinations in which surface irrigation system - 75% evaporation was statistically higher ($p< 0.05$) with 1.24 kg m^{-3} and 2.75 Mcal m^{-3}. This behavior may be due to the significant correlation between starch concentration and DM (r= 0.47) and DMD (r= 0. 36), which indicates that as grains move towards physiological maturity, digestibility and energy content increase in the whole the plant, a desirable outcome for silage as livestock feed (Guayader *et al*., 2018). The interactions that showed the lowest values were subsurface drip irrigation system -75% evaporation and surface irrigation system -100% evaporation (Table 3).

Conclusions

Irrigation systems and evaporation levels affected forage corn yield, nutritional quality and water use efficiency. The application of 100% evaporation with the subsurface drip irrigation system improved the productive capacity of the crop, which had positive effects on height, green forage yield and dry forage yield. The interaction of surface irrigation system -75% evaporation achieved the highest values in water use efficiency in yield and water use efficiency in forage quality. The best quality values in terms of acid detergent fiber, neutral detergent fiber, lignins, total digestible nutrients and net energy of lactation were obtained in the surface irrigation system. The interaction with the best behavior was surface irrigation system with 75% evaporation, in yield it was surpassed only by subsurface drip irrigation system -100% evaporation, however, considering its efficiency in the use of water, the use of the surface irrigation system with 75% of the free evaporation of the class ‘A’ evaporimeter pan is recommended.

Cited literature

AOAC. 2012. Official methods of analysis of AOAC international 19 Ed. Vol. 1. Washington, DC. USA. 672 p.

Carvalho, I. R.; Souza, V. Q.; Follmann, D. N.; Nardino, M.; Pelegrin, A. J.; Ferrari, M.; Konflanz, V. A.; Lazzari, R. and Uczay, J. 2016. Silage production and bromatological constitution effects of corn hybrids in different environments. Portugal. Rev. de Ciências Agrárias. 2(39):242-250.

Cherney, J. H.; Cherney, D. J. R.; Akin, D. E. and Axtell, J. D. 1991. Potential of brown-midrib, low-lignin mutants for improving forage quality. EE.UU. Advances in agronomy. 46:157-198.

Coelho, E. F. and Or, D. 1999. Root distribution and water uptake patterns of corn under surface and subsurface drip irrigation. Suiza. Plant Soil. 2(206):123-136.

Cox, W. J. and Charney, D. J. R. 2001. Row spacing, plant density, and nitrogen effect on corn silage. USA. Agron. J. 3(93):597-602.

Cruz, J. J.; Sánchez, J. I.; Faz, R. y Núñez, G. 2012. Manejo integrado de tecnologías para mejorar el rendimiento, calidad y uso del agua en forrajes. México. Agrofaz. 4(12):113-123.

Guayader, J. X.; Baron, V. S. and Beauchemin, K. A. 2018. Corn forage yield and quality for silage in short growing season areas of the canadian prairies. Canada. Agronomy. 9(8):164-171.

Herrera, S. R. 1999. La importancia de los maíces y sorgos mejorados para la producción de ensilaje. *In*: 2º taller nacional de especialidades de maíz. UAAAN Saltillo, Coahuila, México. 133-137 pp.

Herrero, M. A.; Maldonado, V.; Sardi, G.; Flores, M.; Orlando, A. y Carbó, L. 2000. Distribución de la calidad del agua subterránea en sistemas de producción agropecuarios bonaerenses. I. Calidad fisicoquímica y utilización del agua. Argentina. Rev. Arg. Prod. Animal. 3-4(20):229-236.

Islam, M. R.; García, S. C. and Horadagoda, A. 2012. Effect of irrigation and rates and timing of nitrogen fertilizer on dry matter yield, proportions of plant fractions of maize and nutritive value and *in vitro* gas production characteristic of whole crop maize silage. Animal Feed Sci. Technol. 3-4(172):125-135.

Juráček, M.; Bíro, D.; Šimko, M.; Gálik, B. and Rolinec, M. 2012. The quality of maize silages from west Region of Slovakia. J. Central Eur. Agric. 4(13):695-703.

Martínez, G. M.; Bonet, L.; Provenzano, G.; Badal, E.; Nortes, P. A.; Intrigliolo, D. S. y Ballester, C. 2018. Estrategias de riego por goteo superficial y subterráneo para incrementar la eficiencia en el uso del agua de los cítricos. España. Levante Agrícola. Rev. Inter. Cítricos. 442:168-173.

Mejía, E.; Palacios, E.; Exebio, A. y Santos A. L. 2002. Problemas operativos en el manejo del agua en distritos de riego. México. Terra Latinoam. 2(20):217-225.

Montemayor, T. J. A.; Lara, M. J. L.; Woo, R. J. L.; Munguía, L. J.; Rivera, G. M. y Trucíos, C. R. 2012. Producción de maíz forrajero (*Zea mays* L.) en tres sistemas de irrigación en la Comarca Lagunera de Coahuila y Durango, México. México. Agrociencia. 3(46):267-278).

Moreno, R. A.; Cantú, J. E.; Carrillo, R. J. L. and Contreras, V. V. 2017. Forage maize nutritional quality according to organic and inorganic fertilization. Perú. Scientia Agropecuaria. 2(8):127-135.

Núñez, G.; Faz, R.; González, F. y Peña, A. 2005. Madurez de híbridos de maíz a la cosecha para mejorar la producción y calidad del forraje. México. Técnica. Pec. Méx. 1(43):69-78).

Núñez, G.; Peña, A.; González, F. y Faz, R. 2006. Características de híbridos de maíz de alta calidad nutricional de forraje. *In*: maíz forrajero de alto rendimiento y calidad nutricional. Núñez, G. (Comp.). Libro científico núm. 13. INIFAP-CIRNOC-CELALA. Matamoros, Coahuila, México. 45-97 pp.

Núñez, H. G.; Anaya, S. A.; Faz, C. R. y Serrato, M. H. A. 2015. Híbridos de maíz forrajero con alto potencial de producción de leche de bovino. México. Agrofaz. 1(15):47-56.

FAO. 2011. Organización de las Naciones Unidas para la Agricultura y la Alimentación. El estado de los recursos de tierras y aguas del mundo para la alimentación y la agricultura. La gestión de los sistemas en situación de riesgo. Roma y Mundi-Prensa, Madrid.

FAO. 2021. Organización de las Naciones Unidas para la Alimentación y la Agricultura. El estado de los recursos de tierras y aguas del mundo para la alimentación y la agricultura-sistemas al límite. Informe de síntesis 2021. Rome. https://doi.org/10.4060/cb7654es.

Peña, A.; Núñez, G. y González, F. 2002. Potencial forrajero de poblaciones de maíz y relación entre atributos agronómicos con la calidad. México. Téc. Pec. Méx. 3(40):215-228.

Reta, S. D. J.; Carrillo, S. A.; Gaytán, M. E.; Castro, M. y Cueto, W. J. A. 2002. Guía para cultivar maíz forrajero en surcos estrechos. INIFAP-CIRNOC-CELALA. Matamoros, Coahuila. México.

Salomó, J.; Sanmartín, J. M.; Pérez, C.; Maresma, A. y Lloveras, J. 2019. Riego por goteo subterráneo en cultivos de maíz y alfalfa. Estudio técnico-económico comparativo entre riego por inundación y riego por goteo enterrado. Vida Rural. 1:43-48.

Sánchez, W. X. e Hidalgo, A. C. 2018. Potencial forrajero de nueve híbridos de maíz en la zona alta lechera de costa rica. Costa Rica. Agron. Mesoam. 1(29):153-164.

Van, S. P. J. 1994. Nutritional ecology of the ruminant. 2nd Ed. Cornell University Press. Ithaca, New York, USA. 476 p.

Wang, L.; Ren, B.; Zhao, B.; Liu, P. and Zhang, J. 2022. Comparative yield and photosynthetic characteristics of two corn (*Zea mays* L.) hybrids differing in maturity under different irrigation treatments. Suiza. Agriculture. 3(12):365).

Yescas, C. P.; Segura, M. A.; Martínez, L.; Álvarez, V. P.; Montemayor, J. A.; Orozco, J. A. y Frías, J. E. 2015. Rendimiento y calidad de maíz forrajero (*Zea mays* L.) con diferentes niveles de riego por goteo subsuperficial y densidad de plantas. Argentina. Phyton. 2(84):272-279.

Zaragoza, E. J.; Tadeo, R. M.; Espinoza, C. A.; López, L. C.; García, E. J. C.; Zamudio, G. B.; Turrent, F. A. y Rosado, N. F. 2019. Rendimiento y calidad de forraje de híbridos de maíz en Valles Altos de México. México. Rev. Mex. Cienc. Agríc. 1(10):101-111.