Drip-tape irrigation depth: water use efficiency, yield and forage quality in maize

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ABSTRACT
Objective: to evaluate the effect of the drip-tape irrigation depth on the efficiency of water use, yield, nutritional quality and profitability of forage maize, a study was established by installing drip-tape at a depths 0.05, 0.15 and 0.30 meters.
Design/Methodology/Approach: a randomized block experimental design was used. Treatments evaluated consisted of the installation of drip-tape at three depths 0.05, 0.15 and 0.30 m; each treatment in three replicates. The experimental unit was a 15 m^2 surface (comprising four 5m-long furrows, with a 0.76 m separation between furrows).
Results: results showed that with the drip-tape installed at a depth of 0.15 m, the highest biomass production and water use efficiency were obtained, without modifying the bromatological quality of the forage. However, the best benefit-cost ratio corresponded to the drip-tape installed at 0.3 m, recovering $1.27 for each MXN peso invested in crop production.
Limitations/Implications of the study: water scarcity in arid and semi-arid regions is a global problem, so it is necessary to use irrigation methods that make water use more efficient without reducing crop yield.
Findings/conclusions: the installation of the drip-tape at a depth of 0.15 m is recommended, due to the improvement in yield and water use efficiency without affecting nutritional quality of the forage or profitability of maize crop.

Keywords: *Zea mays* L., water potential, water use efficiency, profitability.

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INTRODUCTION

The Comarca Lagunera, located between the states of Coahuila and Durango (Mexico) is the main basin destined to dairy production in the country, which demands large amounts of fodder per year, such as maize (*Zea mays* L.), one of the forages with the highest production and largest cultivated area in the region (50 thousand ha). This crop is established in the spring and summer cycles, and is one of the main sources of feed for dairy cattle (SADER, 2021). To produce the large amount of fodder that livestock demands, a high volume of irrigation water is required; because water scarcity, high temperatures, and long periods of drought affect crop development (Moore *et al.*, 2021).

Water scarcity for agricultural use forces the search for irrigation techniques that increase water productivity, as well as crop yields and profitability. Subsurface drip irrigation (SDI) is an irrigation technique that increases crop yields and improves irrigation water use efficiency. Unlike other systems, drip-tape can be installed at different depths of the soil, providing moisture directly to the root zone of the plant and minimizing water losses through direct evaporation, runoff, and percolation (Sandhu *et al.*, 2019).

SDI helps to minimise the negative effects that climatic conditions can have on plant physiology during the production cycle. In addition, different fertilisation doses can be injected in instalments, thus improving nutrient absorption, increasing the production and nutritional quality of forages (Moore *et al.*, 2021). Therefore, this study aimed to evaluate the effect of the drip-tape irrigation depth on water use efficiency, yield, nutritional quality and profitability of forage maize.

MATERIALS AND METHODS

Location of the experiment

The research was established at “La Laguna” (CELALA) Experimental Facilities under the National Institute of Forestry, Agriculture and Livestock Research (INIFAP, in Mexico), located at the geographical coordinates of 25° 32’ N and 103° 14’ W, at an altitude of 1150 m. The climatic conditions correspond to a semi-warm dry climate (Bwh) with low atmospheric humidity, average annual temperature of 22.6 °C; while the average rainfall is 215.5 mm and the average annual evaporation is 2000 mm. The soil has a clay loam texture, alkaline pH, non-saline, low in organic matter content, low in phosphorus and available nitrogen. Land preparation consisted of subsoil plow after fallow, harrowing, leveling and subsurface laying of the drip-tape.

The vegetative material used was the hybrid 20W41 (Syngenta®), an intermediate-cycle variety that is resistant to lodging and has good plant and ear health. Sowing was carried out manually on July 28, 2021 with a plant spacing of 0.12 m and 0.76 m between rows for a population density of 105 thousand plants per ha. The fertilization dose used was 200-100-00 ($N-P_2O_5-K_2O$); $CO(NH_2)_2$ and $(NH_4)_2SO_4$ were used as nitrogenous sources; and $NH_4H_2PO_4$ as a source of phosphorus. All the phosphorus and half of the nitrogen with $CO(NH_2)_2$ were applied at the time of planting and the rest of the nitrogen with $(NH_4)_2SO_4$ was injected every 15 days according to the phenology of the crop by means of a Venturi injector (Zavala-Borrego *et al.*, 2022).

For the SDI, a Ro-DRIP 8(mil) irrigation drip-tape (Rivulis Irrigation Inc., San Diego, CA, USA) was used, with a nominal wall thickness of 0.2 mm, nominal diameter of 16 mm, emitters at 0.2 m separation an a flow rate of 0.5 L h^{-1} per emitter. The SDI operated at a pressure range of 8 PSI with irrigation frequency every third day. The irrigation time was the same for all three depths throughout the cycle, but not for germination. An atmometer (ETgage A model, ETgage Company Loveland, Colorado, USA) located 20 m from the experimental site was used to measure the reference ET, where daily readings were taken and multiplied by the Kc to estimate the ETc. To calculate the Kc, the equation

$$Kc = 1.1705 * NDVI + 0.0535$$

was used for fodder maize with subsurface drip irrigation (Reyes-González *et al.*, 2019a).

Experimental design and treatments

A randomized block experimental design was used, the treatments evaluated consisted of the installation of the drip-tape at three depths 0.05, 0.15 and 0.30 m, each treatment was replicated three times. The experimental unit with a surface of 15 m^2 (four 5m-long furrows with a 0.76 m separation between rows).

Variables evaluated

Plant Height

Plant height was taken at five plants at random from each experimental unit at harvest time (105 days after sowing, DAS). It was measured from the base of the stem to the spike with a measuring tape.

Water Potential

To quantify the water potential, the Scholander pressure pump was used. Two samplings were taken per treatment and repeated between 12:00 and 14:00 h. Each week, the second leaf was selected from the upper part of the crop, taking two leaves per treatment and replicate which were covered with moistened cloth to avoid moisture loss before measurement.

Fresh and Dried Forage Biomass

Crop was harvested at 105 DAS when the maturation of the grain presented an advance of 1/3 of the milk line. For the production of green fodder, a line of three meters was taken as the useful plot per each experimental unit. After weighing, a sample of 500 g was taken and dried in a forced air convection oven (UF 260 Plus, Memmert, Germany) at a temperature of 65 °C until a constant weight was reached, to determine the dry matter (DM) production. With the production of green forage and the percentage of DM, the dry forage yield was estimated (DY).

Water Use Efficiency

Water use efficiency (WUE) was obtained by dividing the harvested dry forage yield (DY, kg) by the total volume of water used (m^3) in each treatment.

Bromatological quality

Bromatological quality was assessed by analysing 200 g-samples of dry forage from each treatment and replicate previously ground and identified. Nutritional content was determined by near-infrared reflectance spectroscopy –NIRS (Valenciaga and Simões, 2006). The parameters evaluated were crude protein (CP), neutral organic matter detergent fiber (NDF_{om}), net lactation energy (NLE), starch, lignin and digestibility of neutral detergent fiber at 30 h of incubation ($NDFD\text{-}_{30\ h}$).

The determination of crude protein (CP) was quantified using the microKjeldhal method (AOAC, 2005); Fat content using the Soxhlet method using a Goldfish extractor (Labconco, USA). The percentages of acid- and neutral detergent fibers (ADF and NDF) were quantified with the detergent fractionation method and subsequent filtration (Van Soest *et al.*, 1978).

Profitability

An estimation of the calculation of the profitability corresponding to the production cycle of the forage corn crop was made by means of the benefit/cost ratio (B/C). In each treatment, the total production costs of the crop were considered, including irrigation water costs and the income from the sale of green fodder obtained per hectare (Megagrams, Mg ha^{-1}). For the income estimation, we used the market price in the growing cycle in which the experiment was established.

Statistical Analysis

To establish whether there were significant differences between the variables evaluated, an analysis of variance was performed using the GLM procedure of SAS© v. 9.3 (SAS Institute Inc., Cary, NC, USA); when statistical differences were detected ($p \leq 0.05$), the Tukey's mean difference test was applied ($p \leq 0.05$).

RESULTS AND DISCUSSION

Leaf Water Potential (Ψh)

The drip-tape buried at 0.30 m provided the best water condition for the crop. While for the treatment with the drip-tape at 0.05 m depth, water potential was −1.4 MPa, the most negative value observed at 82 DAS (Figure 1), which resulted in lower plant height and biomass production. The lower water content with the drip-tape buried at 0.05 m caused water stress in the plant, which was quantified in the leaf, generating inadequate vegetative growth and lower biomass production (May-Lara *et al.*, 2011).

Reyes *et al.* (2019a) reported similar values in the evaluation of the water potential in forage sorghum, obtaining values in a range of −1.0 MPa in treatments with drip-tape compared to treatments with flood irrigation, with average values of −1.5 MPa

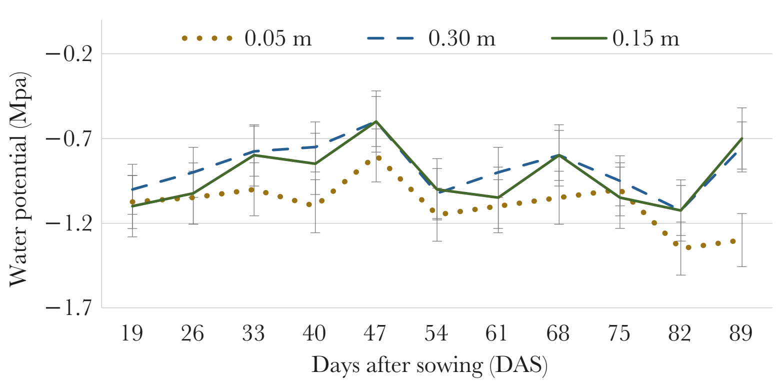

Figure 1. Water Potential values at different drip-tape irrigation depths in forage maize.

during the crop production cycle. More negative values than those found in our study were reported by Zavala-Borrego *et al.* (2022) in the evaluation of SDI with three levels of evapotranspiration and a control with gravity irrigation in the production of forage maize. Those authors found values that varied from −0.6 to −1.92 MPa, during one crop cycle in the Comarca Lagunera.

Plant Height

The height of the plant was not affected ($p \leq 0.05$) by the different depths of the irrigation drip-tape (Table 1). However, results show a trend to higher plant height with the irrigation tape buried at a depth of 0.15 m, with average plant height of 2.20 m. In relation to the drip-tape at a depth of 0.05 m, which obtained a lower height (2.08 m). This was due to greater exposure of the irrigation water to the surface, which increases direct evaporation and decreases water availability in the root zone (Reyes *et al.*, 2019).

On the other hand, Duan *et al.* (2007) mentioned that water stress causes changes in plant structure, which are reflected in a decrease in the growth rate during the crop cycle. Reyes-González *et al.* (2019b) reported that low levels of soil moisture negatively affect plant height. Similar results were reported by Sánchez-Hernández *et al.* (2013) who obtained forage maize heights of 2.44 m using subsurface drip irrigation.

Fresh and Dried Forage Biomass

The different depths of the drip-tape caused differences in the yield of green forage, the highest yields were obtained with the irrigation tape at depths of 0.15 and 0.30 m with 57.93 and 59.39 Mg ha^{-1}, respectively. The treatment with the lowest yield was 0.05 m with 52.20 Mg ha^{-1} (Table 1). Reta-Sánchez *et al.* (2007) found that the increase in biomass is due to the higher rate of leaf area that develops in the early stages of cultivation. Bame *et al.* (2014) pointed out that in the subsurface drip irrigation system, maize production increases due to the higher plant height and the weight of ears per plant.

The results obtained in this study are similar to those reported by Ortiz-Diaz *et al.* (2022), who evaluated irrigation tape depths in forage maize production and reported higher yields with irrigation tape at 0.30 m depth. Douh and Boujelben (2011) evaluated irrigation tape depths in maize cultivation and found that between 20 and 35 cm deep there is a better water distribution and content, therefore, greater use by the plant, which produced high yields. Dry matter production was not affected by the different depths of

Table 1. Plant height (PH), green forage (GF), dry forage yield (DY), net irrigation depth (NID), and water use efficiency (WUE) in forage maize.

Depth (m)	PH (m)	GF (t ha^{-1})	DF (t ha^{-1})	Irrigation (cm)	WUE (kg FS m^{-3})
0.05	2.08 a*	52.20 b	22.37 a	44.0 c	5.08 a
0.15	2.20 a	57.93 a	23.77 a	48.7 b	4.88 a
0.30	2.18 a	59.39 a	23.98 a	54.8 a	4.37 b

PH=Plant height; GF=Green fodder; DF=Dry forage; WUE=Efficient use water. * Different letters indicate significant difference (Tukey; $p \leq 0.05$).

the drip-tape ($p \leq 0.05$). However, as the depth of the irrigation tape increases, higher yields were obtained (Table 1).

These yields are higher than those reported by Gutiérrez-Guzmán *et al.* (2022), who obtained lower dry forage yields in forage corn production with two irrigation systems and three levels of applied evaporation, using irrigation tape installed at a depth of 0.36 m. Similar results were reported by Lamm and Trooien, (2006), where maize production was not affected by the depths of the placement of the irrigation tape, however, a slight trend in increasing yield was observed where the irrigation tape was used at greater depths. This can be explained because favorable conditions of humidity are created, which result in greater biomass production and nutritional quality (Sánchez-Hernández *et al.*, 2013).

Net irrigation depth

The accumulated net irrigation depth (NID) that was used during the production cycle in the evaluated treatments, including precipitation (5.28 cm), is shown in Table 1. The NID applied for the treatment with irrigation tape depth at 0.30 m was 54.8 cm, followed by the treatments with depths at 0.15 and 0.05 m with NID of 48.7 and 44.0 cm, respectively. Those differences can be explained by the fact that, at sowing, the treatment with a 0.05 m drip-tape used less water (2 cm), in relation to the depths of 0.15 and 0.30 m (6.7 and 12.8 cm), probably due to the proximity of the irrigation tape to the soil surface that favored seed germination. Similar values of net irrigation depths were applied by Reyes-González *et al.* (2023) who used the subsurface drip irrigation system at 0.3 m depth with accumulated net irrigation depths of 43.2, 51.8 and 54.2 cm; results of different levels of evapotranspiration in the production of maize for fodder.

Water Use Efficiency (WUE)

The SDI installed at different depths affected the WUE, the highest efficiency corresponded to the treatment with the irrigation tape at a depth of 0.05 m (Table 1), with a WUE of 5.08 kg of DY m^{-3}, followed by the treatment of 0.15 m (4.88 kg of DY m^{-3}), with a very similar saving in irrigation water. However, the treatment with the drip-tape at 0.15 m generated higher yields. The treatment with the drip-tape irrigation depth at 0.30 m was the one that showed the lowest WUE, because it used more irrigation water (54.8 cm). Zavala-Borrego (2022) pointed out that the highest WUE is obtained where less net irrigation depth is used.

The WUE results obtained in this study were superior to those reported by Ortiz-Diaz *et al.* (2022), who recorded average values of 3.42 kg FS m^{-3} in forage maize with irrigation tape depths similar to those established in our study. Those authors reported higher WUE values at depths of 0.05 m; in contrast to Solano *et al.* (2021), who obtained higher WUE in treatments with irrigation tape depths betwen 0.20 and 0.30 m, compared to the depth of 0.10 m. Variations in WUE results can be generated by the variation of climatological conditions in each region, cultural practices, and the irrigation system used in crop production (Reyes-González *et al.*, 2023).

Nutritional Quality

The nutritional quality of the forage was not affected by the different depths of the drip-tape irrigation (Table 2). The highest CP content was found in the treatment with irrigation tape depth at 0.05 m (7.86%), followed by treatments at 0.15 and 0.3 m depth (7.15% and 7.48%). Average crude protein values can range from 7.5 to 8.6% (Silva *et al.*, 2015).

The treatment with irrigation tape depth at 0.05 m showed the best percentages of ADF and NDF (24.47 and 39.35), lower than the treatments with depths at 0.15 and 0.30 m (Table 2). These variables represent the fibrous part of the forages, which is related to feed consumption by livestock. The higher the percentage, the lower the digestibility and acceptance by cattle (Pinos *et al.*, 2002).

Similar results to those in this study (Table 2) were found by Zaragoza-Esparza *et al.* (2019), lower than those obtained by Gutiérrez-Guzmán *et al.* (2022), who reported higher percentages of ADF and NDF ranging from 30.4 to 36.8, and 51.27 to 60.53%, respectively, in forage maize production in the Lagunera Region.

Regarding the yield of starch and lignin (Table 2), very similar percentages were obtained among treatments. Values ranged from 4.71 to 4.77% and from 30.63 to 32.26%, respectively; the treatment with the drip-tape at 0.30 m depth was the one with the lowest percentage in starch and lignin, therefore the one with the highest digestibility. These results coincide with those found by Granados-Niño *et al.* (2022), who obtained percentages of 29.91% (starch) and 4.99% (lignin) during the summer cycle, in the production and nutritional quality of forage maize in the Comarca Lagunera.

Regarding net lactation energy (NLE), the highest values were found in the treatment with drip-tape irrigation depth at 0.05 m (1.59 Mcal kg^{-1}), while in the treatments of 0.15 and 0.30 m depth, lower values were obtained (1.55 Mcal kg^{-1}). This is due to the fact that they obtained greater fiber production, therefore, the energy value was negatively associated with those concentrations, which in turn had an impact on the production of NLE (Gutiérrez-Guzmán *et al.*, 2022). The NLE results of this study are superior to those reported by Yescas *et al.* (2015), who obtained concentrations of 1.36 and 1.08 Mcal kg^{-1} of NLE in their quality evaluation of forage maize at different levels of subsurface drip irrigation.

Profitability

Table 3 shows the total production costs based on the forage maize technology package for the Comarca Lagunera, and the income obtained afther the fodder sale from each

Table 2. Crude protein (CP), acid detergent fiber (ADF), lignin, starch, neutral detergent fiber (NDF), and net lactation energy (NLE), in samples of forage maize.

Depth (m)	CP (%)	ADF (%)	Lignin (%)	Starch (%)	NDF (%)	NEL (Mcal kg^{-1})
0.05	7.86 a*	24.47 a	4.74 a	32.26 a	39.35 a	1.59 a
0.15	7.15 a	25.56 a	4.77 a	30.63 a	41.41 a	1.55 a
0.30	7.48 a	25.69 a	4.71 a	31.01a	41.82 b	1.55 a

CP=Crude protein; ADF=Acid detergent fiber; NDF=Neutral detergent fiber; LNE=Net energy for lactation. * Different letters indicate significant difference (Tukey; $p \leq 0.05$).

Table 3. Benefit-cost (B/C) ratios in forage maize production.

Treatment	Sale price ($ kg^{-1})	Yield ($kg\ ha^{-1}$)	Total income ($)	Production cost ($)	B/C ($)
0.05 m	1.25	52,200	65,250.0	31,754	2.05
0.15 m	1.25	57,930	72,412.5	32,136	2.25
0.30 m	1.25	59,390	74,237.5	32,736	2.27

Source: Data based on the Statistics Yearbook of Agricultural Production, crop cycle 2021. SADER Delegación Comarca Lagunera, Ciudad Lerdo, Durango, Mexico.

of the treatments evaluated. The estimated B/C ratio in the most profitable treatments was 2.25 and 2.27 for the treatments with drip-tape buried at 0.15 and 0.30 m depth, respectively. These values indicate that for each Mexican peso invested in the production of forage maize with subsurface drip irrigation, 2.25 and 2.27 $ MXN were obtained from sales; in regard to the depth at 0.05 m, a lower B/C ratio was obtained (2.05).

Regarding the economic productivity of water use, the cost of gravity irrigation water in the Comarca Lagunera in the current production cycle was \$0.91 m^{-3} (MXN). The production of green forage per m^3 of water used indicated that in the case of the 0.15 m depth treatment, the yield was 13.16 kg GF m^{-3}, this is, higher than those produced at 0.05 and 0.30 m depth treatments (9.5 and 12.19 kg GF m^{-3}), which indicates that for each m^3 of water invested in the production of maize for fodder with drip-tape irrigation at 0.15 m depth, the producer obtained \$15.23 (MXN) of gross profit with the price per kg of GF set at \$1.25 in the production cycle.

CONCLUSIONS

The subsurface drip irrigation system with the drip-tape installed at different depths affects yield and water use efficiency, without affecting forage quality. It is recommended to install the drip-tape at a depth of 0.15 m, due to the improvement in yield and water use efficiency without affecting the nutritional quality of the forage or the crop profitability.

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