

## Assessment of fodder corn grown under surface and subsurface drip irrigation in Mendoza, Argentina

### Evaluación del maíz forrajero regado por goteo superficial y subterráneo en Mendoza, Argentina

Richard José Ortega Justavino <sup>1</sup>, Pablo Fernando Loyola <sup>2</sup>, Joaquín Antonio Llera Giménez <sup>3</sup>

Originales: Recepción: 12/02/2021 - Aceptación: 07/06/2021

#### ABSTRACT

Surface (DI) and subsurface (SDI) drip irrigation constitute one advantageous system that increases both irrigation and water use efficiency. The objective of this research was to assess and compare the response of fodder corn to DI and two different depths of SDI, in Mendoza. We used a factorial experimental design with randomized blocks and repeated measures. Tests were run in two consecutive cycles. Germination percentage (GP), yield, water use efficiency (WUE) and water productivity (WP), were assessed. High yields ranging from 70,214 to 105,771 kg ha<sup>-1</sup> of green matter and 10,020 to 22,476 kg ha<sup>-1</sup> of dry matter (DM) were obtained in both cycles, respectively. DM after the first sowing was significantly higher in both cycles under SDI than under DI. No significant differences in WP, WUE, GP or soil moisture (SM) could be found among treatments, but significant differences were found in SM ( $p < 0.0001$ ) between the first soil layer and the other two layers.

#### Keywords

*Zea mays* L. • subsurface drip irrigation • localized irrigation • yield • water use efficiency • water productivity

---

1 Universidad de Panamá. Facultad de Ciencias Agropecuarias. Departamento de Suelos y Aguas. Panamá. richard.ortega@up.ac.pa

2 Universidad Nacional de Cuyo. Facultad de Ciencias Agrarias. Departamento de Producción Agropecuaria. Cátedra de Horticultura y Floricultura. Almirante Brown 500. Chacras de Coria - Luján de Cuyo. CPA M5528AHB. Mendoza. Argentina.

3 Universidad Nacional de Cuyo. Facultad de Ciencias Agrarias. Departamento de Biomatemática y Físico-Química. Mendoza. Argentina.

## RESUMEN

El riego por goteo -superficial (RG) y subterráneo (RGS)- es uno de los medios para aumentar la eficiencia de riego y del uso de agua. El objetivo de la investigación fue evaluar en Mendoza, la respuesta de maíz forrajero a tratamientos de riego por goteo a dos profundidades respecto del goteo superficial. El diseño experimental fue factorial con parcelas completamente al azar y medidas repetidas en el tiempo. Los ensayos se realizaron en dos ciclos consecutivos. Se evaluó el porcentaje de germinación (PG), el rendimiento, la eficiencia de uso del agua (WUE) y la productividad (WP). Se lograron altos rendimientos: 70,214 a 105,771 kg ha<sup>-1</sup> de materia verde y 10,020 a 22,476 kg ha<sup>-1</sup> de materia seca (MS), respectivamente en ambos ciclos. La producción de MS de la primera siembra resultó significativamente mayor para los dos tratamientos de riego por goteo subterráneo respecto del riego por goteo superficial. No se encontraron diferencias significativas en la WP ni en la WUE. El PG y la humedad del suelo (HS), no presentaron diferencias entre tratamientos y sí hubo diferencias significativas ( $p < 0,0001$ ) de la HS entre el primer estrato de suelo y los otros dos restantes.

**Palabras clave**

*Zea mays L.* • riego por goteo enterrado • riego localizado • rendimiento • eficiencia del uso de agua • productividad del agua

## INTRODUCTION

Corn cultivation is of great economic importance worldwide. It is valued for human food, fodder, and raw material for different industries. By 2026, production of fodder corn is expected to achieve 695 million tons, representing an increase of 86 million tons (38). Corn production estimates for Argentina, for the 2020-2021 period, predict 50 million tons from a cultivated area of 7 million hectares (7). Production of fodder corn in Mendoza has increased after the expansion of local cattle farming as consequence of the increase of agriculture in Argentina, which has displaced cattle raising to extra-Pampean regions (21). According to the Los Andes newspaper (2017), this production grew by 40% in a cultivated area of about 3,500 ha in Valle de Uco and San Rafael, located in the central and southern oases of Mendoza.

Currently, increasing surface and groundwater use efficiency (WUE), meeting water demand (for agricultural, industrial, and urban uses) while avoiding conflicts among users (15), has become crucial. Additionally, climate change scenarios predict increasing extreme events in a large part of the planet that may lead to reduced water availability (35). Agriculture is a major water consumer; current irrigation efficiency should be improved for water conservation and availability for other purposes (51). In the province of Mendoza, water availability is a limiting factor for agricultural expansion due to large water demands from human consumption (drinkable water), industry, and hydropower generation (31).

According to the FAO (2015), 40,000 hectares of Mendoza's 268,300 irrigated area are under DI (44), and 3,750 hectares are irrigated with center pivot systems (32). In Mendoza, SI mean application efficiency (AE) is 64% without drainage, and 39% with drainage. The AE for DI and center pivot irrigation is 90%, and 80%, respectively (44). In this context, localized irrigation is an essential technology package for competitive production, both in terms of quantity and quality (18). Localized irrigation systems contribute to a substantial increase in efficiency since they allow watering according to crop needs, reducing deep percolation and runoff at the furrow end (45). However, evaporation losses can still be detected.

Subsurface drip irrigation (SDI) reduces evaporation and is highly effective (23), but its maximum efficiency will depend on water meeting crop requirements (13). In Mendoza, SDI could be implemented for corn production, a rotation alternative to extensive and intensive crops. Nevertheless, in arid areas like Mendoza (poorly structured saline and alkaline soils with reduced organic matter), where integrated irrigation is required, SDI could affect seedling emergence and increase soil salinization. In this sense, such areas should be assessed for sustainability.

### Background information

Previous research on corn using laterals spaced at 1.5, 2.3 and 3.0 m and buried at depths of 0.40-0.45 m, showed that the highest yields were obtained at 1.5 m (23). These authors point out that this system is expensive but explain that using a wider lateral spacing may lower costs. Severina *et al.* (2016) state that laterals represent 70% of a project's initial cost. For corn grown in clay soils, a 1.4 m spacing between laterals produced higher yields than 0.70 or 2.10 m spacing (10). Regarding depth, Lamm and Trooien (2005) tested 0.20, 0.30, 0.41, 0.51 and 0.61 m without finding significant differences in yield. However, they noticed that, when compared to a four-year production, yields were significantly lower with laterals buried at 0.61 m. In brief, depth defines soil moisture distribution and affects optimum seed germination. In arid areas with integrated irrigation, too deep laterals hinder seed germination. Even though corn can reach effective rooting depths of 2.8 m or more during maturity, in regions with stratified soils and low organic matter content, like Mendoza, rooting depths are in-between 1.5 and 2 m (46).

On the other hand, few references on SDI refer to arid areas with integrated irrigation, where seed germination may be jeopardized by the lack of proper moisture. Lamm and Trooien (2005) and Camp (1998) state that if irrigation is required for seed germination or plant growth, SDI may not be the best method. Additionally, Neufeld *et al.* (2004) consider that seed germination with SDI systems is highly site-specific, depending on soil texture, spacing, lateral depth and emitter flow.

### Objectives

- Assess green and dry matter yields, water use efficiencies (WUE) and water productivity (WP) of fodder corn irrigated with DI and SDI.
- Compare field emergence percentages of fodder corn with DI and SDI.

### MATERIALS AND METHODS

A factorial experimental design was applied to a completely randomized plot with replicated measurements. Three treatments were applied: surface drip irrigation (T1), subsurface drip irrigation at 0.20 m (T2), and subsurface drip irrigation at 0.40 m (T3), with four replications and two crop cycles. Yields were measured after 30, 45, 60, 75 and 95 days in the first cycle and after 30, 45, 60 and 105 days in the second cycle.

The plots were 3 m wide and 50 m long. Three irrigation laterals were spaced at 1 m, with 6 rows of plants at 0.25 m on both sides of each lateral. The two central rows of plants constituted the minimum plot size and the four remaining rows -2 on each side- the edging. Fodder corn (Aca vg 48rr2 variety) was planted at 0.30 m between plants and 0.50 m between rows. Two seeds were placed at each sowing point achieving a sowing density of 133,333 plants per hectare. DI and SDI with 2.1 L h<sup>-1</sup> emitters placed 0.50 m apart, administered 4.2 mm.h<sup>-1</sup>. Weed control was carried out by one glyphosate application. Fertigation was performed through 3 applications of 50 kg of nitrogen and 45 kg of phosphorous per hectare 15, 30 and 45 days after sowing.

Irrigation distribution uniformity (DU) (11) was measured in the four DI replications with the middle lateral of each plot in four positions: head, 1/3, 2/3 and end. Also, salinity expressed as apparent electrical conductivity (ECa), possible electrical conductivity, probable salts, pH, chlorides, carbonates, bicarbonates, sulfates, calcium and magnesium (Ca<sup>+2</sup>+Mg<sup>+2</sup>), sodium (Na<sup>+</sup>) and Sodium Adsorption Ratio (SAR) were determined for the irrigation water. All analyses were run using official and standard methods (3). Reference crop evapotranspiration (ET<sub>o</sub>) was calculated according to Penman-Monteith (1) and the CROPWAT-FAO 8.0 model (48). ET<sub>o</sub> was affected by a reduction coefficient due to a decrease in solar radiation caused by the anti-hail netting that covered the field. Daily soil moisture balance included: reference crop evapotranspiration (ET<sub>o</sub>), crop coefficient (kc), effective rainfall (P<sub>pe</sub>), crop evapotranspiration (ET<sub>c</sub>), root depth (D) and allowable depletion level (AD) (17).

A daily irrigation schedule was controlled by gravimetric soil moisture determination and properly installed sensors. Irrigation timing was determined after soil water status and drip lines water application intensity, affected by the uniformity coefficient. Water application intensity was calculated as a quotient between emitter average flow and the irrigated area by each emitter.

Before sowing, a 1 m deep test pit was dug in the middle of the plot and apparent soil density was determined using the core method (6) at three depths: 0-0.20, 0.20-0.40 and 0.40-0.60 m. For organic matter, fertility and soil salinity assessment, random sub-samples were collected from different points throughout the plot.

Soil samples were obtained from six points and three different depths: 0-0.30; 0.30-0.60 and 0.60-0.90 m. Texture was determined with the sedimentation volume method (37). A densitometry study determined sand, lime and clay percentages (9). Before sowing and after the last harvest, infiltration tests were run at three points in the plot (head, middle and end) using the double-ring infiltrometer method (19).

Soil moisture was determined by two methods: a) *Decagon* 10HS sensors in six points (2 per treatment and at 3 depths: 0.30, 0.60 and 0.90 m) recorded soil moisture hourly during the two crop cycles; b) soil moisture was randomly and weekly monitored at the three above-mentioned depths (0.25 m from the irrigation lateral at the center of each replication) by the gravimetric method with a soil auger and a weighing bottle. Soil moisture sensors provided accurate and continuous records at the already stated depths. On the other hand, weekly gravimetric measurements were conducted by randomly sampling the whole profile between 0-0.30, 0.30-0.60 and 0.60-0.90 m. WUE and WP for green and dry matter were determined at the end of each cycle using the following equations (32, 49):

$$\mathbf{WUE} = \frac{\mathbf{Y}}{\mathbf{I} + (\mathbf{Ppe})} \pm \text{moisture difference} \quad (1)$$

Where:

WUE = water use efficiency ( $\text{kg m}^{-3}$ ),

Y = Yield (kg),

I = Irrigation ( $\text{m}^3$ ),

Ppe = Effective precipitation ( $\text{m}^3$ ).

$$\mathbf{WP} = \frac{\mathbf{Y}}{\mathbf{ETc}} \quad (2)$$

Where:

WP = Water productivity ( $\text{kg m}^{-3}$ ),

Y = Yield (kg),

ETc = Crop evapotranspiration ( $\text{m}^3$ ).

Results were analyzed with InfoStat 2017 statistical software (14). For yield and moisture data, "General and Mixed Linear Models", with first-order autoregressive structure, were used among the errors of the same plot since the periods were not equidistant. Corrected means were compared by LSD Fisher test ( $p \leq 0.05$ ). For efficiency, productivity, and germination, ANOVA was conducted, and means were analyzed by Duncan's multiple comparison test ( $p \leq 0.05$ ).

## RESULTS AND DISCUSSION

Table 1 (page 136) shows the main chemical parameters of the irrigation water. According to Riverside classification, modified by Thorne and Peterson (4, 50), water is classified as C-3 (medium salinity), *i.e.*, moderately saline, and suitable for irrigating all crops. In terms of  $\text{Na}^+$  concentrations, classified as S1. Its high pH may lead to precipitates that might cause emitter clogging.

Sediment volume estimation revealed silty loam and silty clay. Soil densitometry confirmed silty clay texture. The soil was classified as non-saline, non-sodic and moderately alkaline. Table 2 (page 136) shows the main soil parameters. Stony subsoil was found below a depth of 0.60 m with 23% of stones. This was considered when calculating available water depth. Contents of  $\text{N}^+$  and  $\text{P}^+$  were within the acceptable range.  $\text{K}^+$  resulted high according to the Departamento de Edafología de la Facultad de Ciencias Agrarias de la UNCuyo.

**Table 1.** Chemical parameters of irrigation water.**Tabla 1.** Parámetros químicos del agua de riego.

Parameter	Value
Salinity expressed as apparent electrical conductivity CEA [dS m <sup>-1</sup> ]	0.78
Salinity expressed as probable electrical conductivity CEP [dS m <sup>-1</sup> ]	0.97
Probable salts [me L <sup>-1</sup> ]	8.0
pH	8.1
Chlorides (Cl <sup>-1</sup> ) [me L <sup>-1</sup> ]	1.6
Carbonates (CO <sub>3</sub> <sup>-2</sup> ) [me L <sup>-1</sup> ]	0
Bicarbonates (HCO <sub>3</sub> <sup>-1</sup> ) [me L <sup>-1</sup> ]	2.1
Sulfates (SO <sub>4</sub> <sup>-2</sup> ) [me L <sup>-1</sup> ]	5.3
Calcium (Ca <sup>+2</sup> ) [me L <sup>-1</sup> ]	5
Magnesium (Mg <sup>+2</sup> ) [me L <sup>-1</sup> ]	2.4
Sodium (Na <sup>+</sup> ) [me L <sup>-1</sup> ]	1.7
SAR	0.9
Adjusted SAR	1

**Table 2.** Main soil parameters.**Tabla 2.** Principales parámetros del suelo.

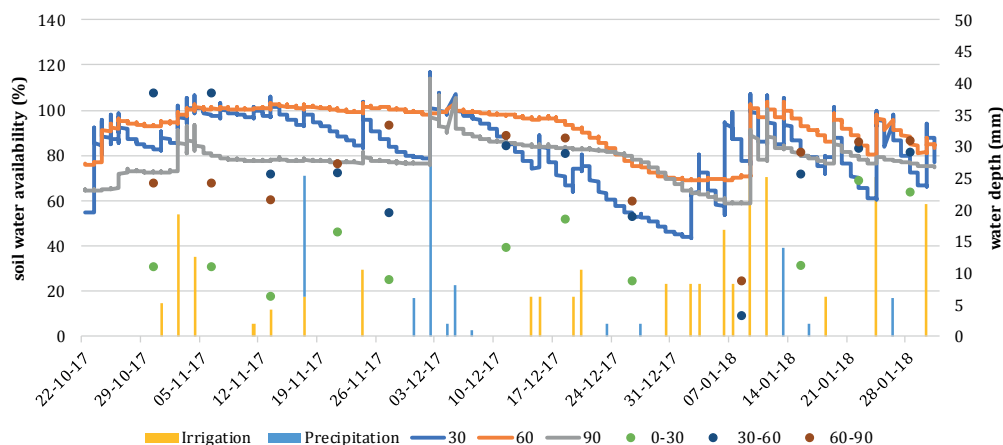
Field capacity from soil moisture characteristic curve (g% g dry soil)	29.3 - 33.7
Permanent wilting point from soil moisture characteristic curve (g% g dry soil)	11.2 -15.2
Total nitrogen (N) (ppm)	952
Phosphorous (P)(ppm)	6.1
Exchangeable potassium (K <sup>+</sup> ) (ppm)	340
Organic matter (%)	15
Electrical conductivity (dS.m <sup>-1</sup> )	1.3
Calcium + Magnesium (Ca <sup>2</sup> + Mg <sup>+2</sup> ) (me L <sup>-1</sup> )	11.6
Sodium (Na <sup>+</sup> ) (me L <sup>-1</sup> )	1.8
Chloride (Cl <sup>-</sup> ) (me L <sup>-1</sup> )	3.5
SAR	0.8
Basic infiltration (mm h <sup>-1</sup> )	13 (±11)
Infiltration at 100 minutes (I <sub>100, min</sub> )	66 (±59)

Emitter average flow rate ranged between 2.12-2.2 L h<sup>-1</sup> and distribution uniformity varied from 92% to 95%. Table 3 shows crop main water balance parameters.

**Table 3.** Main data on both sowings.**Tabla 3.** Principales datos de las dos siembras realizadas.

Sowing and harvest dates	First (sowing) (10/21/17 to 2/2/18)	Second (sowing) (2/13/18 to 5/23/18)
ETo (mm)	486	304
Adjusted ETo (mm)	464	290
ETc (mm)	417	251
Total irrigation water depth (mm)	289.5	197.4
Total rainfall (mm)	165.6	16.7
Effective rainfall (mm)	101	7
Water used (mm)	417	251
Soil moisture variation (mm)	26.5	46.6

Figure 1 shows, for T3, soil moisture content using sensors and weekly gravimetric sampling during the first sowing. Bars represent effective rainfall or irrigation in mm. In this treatment, moisture was recorded by the sensor at 0.60 m given that the irrigation lateral is at 0.40 m. At 0.3 m, the sensor showed greater variability since it was affected by soil evaporation and crop water use, while at 0.90 m, a layer of less moisture-retentive soil results in less water content. In general, there is good correspondence between moisture records (sensors and gravimetric samplings) and soil wetting, either by rainfall or by irrigation. From early December, the three sensors detected soil moisture reductions due to higher crop water use, coinciding with significant crop production.



**Figure 1.** Variations in soil water availability measured at three depths (continuous line of sensors and gravimetric points) and rainfall and irrigation records during the first sowing.

**Figura 1.** Variación del agua disponible en el suelo medida a tres profundidades (línea continua (sensores) y puntos (gravimetría)) y registro de lluvias y riegos de la primera siembra.

Wetting patterns around a surface drip line relative to a subsurface line, coincided with lateral proximity (20). On the other hand, root distribution around drip lines coincides with wetting patterns. Andreau *et al.* (2012) found that larger wet bulbs and higher moisture contents were obtained with subsurface drip irrigation than with surface drip irrigation.

**Germination percentage**

The highest germination percentage was found with T 1 (97%) and the lowest (93%) with T2 and T3. Although differences were not statistically significant, germination percentages obtained with this irrigation method is one debated issue and considered a limiting factor (table 4).

**Table 4.** Mean emergence percentage (%) during the two sowings.

**Tabla 4.** Promedio del porcentaje de emergencia (%) durante las dos siembras.

Sowing/Treatment	1	2	3	Average
1	96	96	94	95
2	98	90	92	93
<b>Mean</b>	97	93	93	
<b>Overall Mean</b>	94			

The relationship between drip line depth and emergence percentage has been a matter of great concern among researchers around the world. SDI could hinder direct seeding given the minimum ascending movement of water affecting emergence, especially in coarse-textured soils (5). Emergence percentage is mostly affected by the distance between seeds and drip lines, closely related to lateral depth (40, 41). In California, less than 10 percent of farmers adopted SDI with laterals at depths of up to 10 cm for seed germination (12). For emergence uniformity with SDI, an adequate amount of water should be applied

around the seed at sowing (8, 26). Sprinkler irrigation systems may ensure germination by placing subsurface laterals on V-shaped impermeable materials, increasing the wetted width, reducing deep percolation and, finally, allowing germination. After seed germination, a deeper drip line does offer many advantages.

### Green and dry matter yields

As shown in Table 5, significant differences were only found for dry matter (table 6). Yields from the first sowing were significantly higher in relation to buried drip irrigation. In this sense, another experiment with fodder corn compared drip irrigation with lines buried at 0.40 m and different lateral spacing (0.8-0.9 y 1,0), with surface irrigation. The study found green matter yields of 70,190- 55,370 and 42,400 kg ha<sup>-1</sup> with subsurface irrigation, and 27,800 kg ha<sup>-1</sup> with surface irrigation for a sowing density of 104,000 plants per hectare (29). These results reveal that fodder production with surface irrigation was 150, 96 and 56 % less than with drip irrigation using laterals spaced at 0.8, 0.9 and 1.0 m respectively. On the other hand, for this study, mean yields from the first and second sowings (105,771 - 70,214 kg ha<sup>-1</sup>) (table 5) were higher than those reported by Montemayor *et al.* (2007). With respect to dry matter forage, these authors obtained maximum yields of 20,190 kg ha<sup>-1</sup> with laterals spaced at 0.8 m and yields of 15,880 - 12,160 kg ha<sup>-1</sup> with laterals spaced at 0.9 and 1.0 m, respectively, while 8,080 kg ha<sup>-1</sup> were obtained with surface irrigation. In the first sowing, with 1 m spacing, we obtained from 19,165 to 24,681 kg ha<sup>-1</sup>. However, in the second sowing, crop cycle could not be completed due to the onset of winter, obtaining 8,823 to 11,439 kg ha<sup>-1</sup> (table 6). At the same time, yields of fodder corn were higher than those reported by Lamm *et al.* (1992) and Oktem *et al.* (2003) with subsurface drip irrigation. These authors pointed out that their results were influenced by lateral spacing, plant density and irrigation water depth. Additionally, according to Montemayor *et al.* (2006) lateral depth did not affect corn fodder weight. In another study in Mendoza, two corn fodder tests using surface irrigation recorded mean green matter yields of 58,390-73,760 kg ha<sup>-1</sup> during the 2015-2016 season and mean dry matter yields of 21,789-23,493 kg ha<sup>-1</sup> in 2016-2017 (43). These green yields were smaller than those recorded in this test. However, dry matter resulted similarly to those obtained from the first sowing, probably given to irrigation method, sowing density and corn variety.

**Table 5.** Mean green matter yield, (kg ha<sup>-1</sup>).

**Tabla 5.** Promedio del rendimiento en materia verde en kg ha<sup>-1</sup>.

Sowing/Treatment	1	2	3	Mean
1	95,575 (a)	108,488 (a)	113,250 (a)	105,771
2	74,635 (a)	74,415 (a)	61,593 (a)	70,214
<b>Mean</b>	85,105	91,451	87,421	
<b>Overall Mean</b>	87,993			

**Table 6.** Mean Dry Matter Yield, (kg ha<sup>-1</sup>).

**Tabla 6.** Promedio del Rendimiento en materia seca en kg ha<sup>-1</sup>.

Sowing/Treatment	1	2	3	Mean
1	19,165 (b)	23,582 (a)	24,681 (a)	22,476
2	11,439 (a)	9,798 (a)	8,823 (a)	10,020
<b>Mean</b>	15,302	16,690	16,752	
<b>Overall Mean</b>	16,248			

### Water Use Efficiency (WUE) and Water Productivity (WP)

The highest WUE value was obtained under T2 in the second sowing (37 kg m<sup>-3</sup>) while the lowest value was recorded under T1 in the first sowing (27.2 kg m<sup>-3</sup>). On average, treatments yielded 29.7 kg m<sup>-3</sup> in the first sowing and 34.8 kg m<sup>-3</sup> in the second sowing. The overall mean was 32.2 kg m<sup>-3</sup>. As for dry matter, the highest WUE value reached 6.89 kg m<sup>-3</sup> in the first sowing under T3, while the lowest resulted in 4.37 kg m<sup>-3</sup> for the second sowing, under T3. The overall mean under all treatments and sowings reached 5.64 kg m<sup>-3</sup>.

Table 7 shows the effect of WP on green matter. The highest value (27.14 kg m<sup>-3</sup>) was obtained under T3 while the lowest (22.91 kg m<sup>-3</sup>) was found under T1. In the second sowing date, the highest WP (29.70 kg m<sup>-3</sup>) was achieved under T1 and the lowest (24.51 kg m<sup>-3</sup>) under T3, with an overall mean of 26.65 kg m<sup>-3</sup>.

**Table 7.** Water productivity based on green matter (kg m<sup>-3</sup>) in both sowing dates.

**Tabla 7.** Productividad del agua en materia verde (kg m<sup>-3</sup>) para las dos fechas de siembra.

Sowing/Treatment	1	2	3	Mean
1	22.91(a)	26.00(a)	27.14(a)	25.35(a)
2	29.70(a)	29.61(a)	24.51(a)	27.94(a)
Mean	26.31(a)	27.81(a)	25.83(a)	
Overall Mean	26.65			

Regarding dry matter, table 8 summarizes WP data for both sowing dates. The highest value for the first sowing corresponded to T3 (5.92 kg m<sup>-3</sup>) and the lowest to T1 (4.59 kg m<sup>-3</sup>). Analyzing all treatments in both sowing dates, revealed the best result under T2 (4.78 kg m<sup>-3</sup>), followed by T3 (4.72 kg m<sup>-3</sup>). The lowest value was obtained under T1 (4.57 kg m<sup>-3</sup>).

**Table 8.** Water productivity based on green matter (kg m<sup>-3</sup>) in both sowing dates.

**Tabla 8.** Productividad del agua en materia Seca (kg m<sup>-3</sup>) en las dos siembras.

Sowing/Treatment	1	2	3	Mean
1	4.59(a)	5.65(a)	5.92(a)	5,39(a)
2	4.55(a)	3.90(a)	3.51(a)	3,99(a)
Mean	4.57(a)	4.78(a)	4.72(a)	
Overall Mean	4.69			

With respect to WUE and WP, no significant differences were found among treatments. Given that WUE and WP are usually expressed as grain yield, few references mention these specific parameters for green fodder. Yescas *et al.* (2015) found dry matter WUE values of 2.84 - 3.24 kg m<sup>-3</sup> in fodder corn under subsurface irrigation at a depth of 0.40 cm. Other tests ranged from 2.0 to 4.5 kg m<sup>-3</sup> for WUE expressed as dry matter (29, 47). Montemayor *et al.* (2012) reported that dry matter WUE for fodder corn under arid conditions and subsurface drip irrigation was 4.07 kg m<sup>-3</sup>, lower than the 6.89 kg m<sup>-3</sup> found in this study. Previously, these authors had also compared subsurface drip irrigation and furrow irrigation, reporting WUE values of 2.9 kg m<sup>-3</sup> with drip tape buried at 0.25, 0.35 and 0.45 m, and of 2.0 kg m<sup>-3</sup> with furrow irrigation (28). Statistically, no significant differences were found among the three drip tape depths, though substantial differences were observed between subsurface drip irrigation and furrow irrigation. Lamm and Trooien (2003) found that WUE, in individual years, was not significantly affected by lateral depth, but when analyzed during the four-year test, lines buried at 0.51 and 0.61 m used less water. According to Payero *et al.* (2008), researchers may generally mention "increasing WUE" as a desirable objective. In some cases, they refer to WP, in others to WUE or other water use indicators, such as yield/total water (rain + irrigation + variations in soil water storage).

Increasing field WP or WUE must follow both biophysical crop response, and economic factors. Even though this study did not evidence emergence effects on yield and WUE caused by inadequate irrigation, this might easily occur. According to Pablo *et al.* (2007), corn WUE was higher with drip lines buried at 15 cm than at 20 - 30 cm given better soil wetting during pre-emergence growth stages. Dripline depth will depend on the crop and the sowing/transplant method. Thus, laterals buried at 20 cm may suffice to irrigate transplanted tomatoes but not for crop sowing (34).



**CONCLUSION**

Germination percentage was not affected by lateral depth (between the surface and a depth of 40 cm). No significant differences were found in green matter between treatments in either crop cycle. Significant differences were found for dry matter. Both SDI treatments had the highest yields when compared to DI treatments. Dry matter represented 21% and 14% of green matter in the first and second sowing dates, respectively. Even though no significant differences were found in WUE (with and without rainfall) or WP indicators, high crop water use was achieved regarding green and dry matter. WUE values were between 12 and 41 % higher than those cited. Although results about subsurface drip irrigation in agricultural plots under integrated irrigation are encouraging, it should be borne in mind that they are contingent upon soil type and crop. It should also be noted that these irrigation practices involve deep plowing, only possible between buried laterals. Otherwise, they should be avoided altogether, no plowing at all, or else applying the concept of direct sowing in intensive agriculture.

**REFERENCES**

- Allen, R.; Pereira, L.; Raes, D.; Smith, D. 2006. Evapotranspiración del cultivo. Guías para la determinación de los requerimientos de agua de cultivos. FAO. Riego y Drenaje N° 56. Rome-Italy.
- Andreau, R.; Etchevers, P.; Chale, W.; Génova, L. 2012. Riego por goteo superficial y subterráneo de tomate cultivado bajo cubierta: distribución de la humedad edáfica y rendimiento cualicuantitativo. VI Jornadas de Actualización en Riego y Fertirriego. <https://www.ina.gov.ar/cra/riego/fertirriego/pdf/Andreau.pdf>
- APHA-AWWA-WPCF. 1992. Métodos normalizados para el análisis de agua potables y residuales. Ediciones Días de Santos. SA. XVII edición.
- Avellaneda, M.; Bermejillo, A.; Mastrantonio, L. 2004. Aguas de riego: calidad y evaluación de su factibilidad de uso. EDIUNC. Mendoza. Argentina.
- Ayars, J.; Evans, R. 2015. Subsurface Drainage - What's Next? <https://doi.org/10.1002/ird.1893>
- Blake, G. R.; Hartge, K. 1986. Bulk Density. In: A. Klute (Ed.) Methods of soil analysis. Part 1. Physical and Mineralogical Methods. ASA and SSSA. p. 363-375.
- Bolsa de Comercio de Rosario. 2020. Estimaciones nacionales de Producción. Consultado en línea el 6 de julio del 2020. <https://www.bcr.com.ar/es/mercados/gea/estimaciones-nacionales-de-produccion/estimaciones>
- Bordovsky, J. P.; Porter, D. 2003. Cotton response to pre-plant irrigation level and irrigation capacity using spray, LEPA, and subsurface drip irrigation. ASAE Paper N° 032008. p. 27-30.
- Bouyoucos, G. 1962. Hydrometer method improved for making particle size analysis of soils. Agron. J. 54: 464-465.
- Bozkurt, Y.; Yazar, A.; Gencel, B.; Semih, M. 2006. Optimum lateral spacing for drip-irrigated corn in the Mediterranean Region of Turkey. Agricultural Water Management. 113-120.
- Burt, C. 2004. Rapid field evaluation of drip and microspray distribution uniformity. Irrigation and Drainage Systems. 18: 275-297.
- Burt, C.; Styles, S. W. 1999. Drip and micro irrigation for trees, vines, and row crops: Design and management (with special sections on SDI). Irrigation Training and Research Center. Bioresource and Agricultural Engineering Department. California Polytechnic State University.
- Camp, C. R. 1998. Subsurface drip irrigation: A Review. America Society of Agricultural Engineers. 41: 1353-1367.
- Di Rienzo, J. S.; Casanoves, F.; Balzarini, M. G.; González, L.; Tablada, M. C. 2016. InfoStat versión 2017. FCA. Universidad Nacional de Córdoba. Argentina. <http://www.infostat.com.ar>
- FAO. 2013. Afrontar la escasez de agua (Un marco de acción para la agricultura y la seguridad alimentaria). FAO. <http://www.fao.org/3/a-i3015s.pdf>
- FAO. 2015. Estudio del potencial de ampliación del riego en Argentina. Roma. Italia. <http://www.fao.org/3/a-i5183s.pdf>
- Fernández, R.; Ávila R.; López, M.; Gavilán, P.; Oyonarte, N. 2010. Manual de riego para agricultores: módulo 1. Fundamentos del riego: manual y ejercicios. Sevilla: Consejería de Agricultura y Pesca, Servicio de Publicaciones y Divulgación. 104 p.
- Fontela, C.; Morábito, J.; Maffei, J.; Salatino, S.; Mirábile, C.; Mastrantonio, L. 2009. Riego por goteo en Mendoza, Argentina: Evaluación de la uniformidad del riego y del incremento de salinidad, sodicidad e iones cloruro en el suelo. Revista de la Facultad de Ciencias Agrarias. Universidad Nacional de Cuyo. Mendoza. Argentina. 41(1): 153-154.
- Grassi, C. J. 1998. Fundamentos del riego. Centro interamericano de desarrollo e investigación ambiental y territorial CIDIAT. Serie Riego y Drenaje RD-36. Venezuela.

20. Hanson, B.; May, D. 2011. Drip irrigation salinity management for row crop. Publication 8447. <http://anrcatalog.ucdavis.edu>.
21. Ibarguren, L.; Reborá, C.; Bertona, A.; Antonini, C. 2020. Sorghum silage production in the northern oasis of Mendoza, Argentina. *Revista de la Facultad de Ciencias Agrarias. Universidad Nacional de Cuyo. Mendoza. Argentina.* 52(1): 121-127.
22. Lamm, F.; Spurgeon W.; Manges, H. 1992. Drip irrigation for corn: A promising prospect. *Irrig. J.* 3: 12-16.
23. Lamm, F.; Stone, L.; Manges, H.; O'Brien, D. 1997. Optimum lateral spacing for subsurface drip irrigated corn. *American Society of Agricultural Engineers.* 40: 102-1027.
24. Lamm, F. R.; Trooien, T. P. 2003. Effect of dripline on field corn production in Kansas. In *Proc. Irrigation Assn. Int'l. Irrigation Technical Conf. CA.* Available from Irrigation Assn., Falls Church, VA.
25. Lamm, F. R.; Trooien, T. P. 2005. Dripline depth effects on corn production when crop establishment is nonlimiting. *American Society of Agricultural Engineers.* 21: 835-840.
26. Lara-Viveros, F. M.; Landero-Valenzuela, N.; Aguado-Rodríguez, G. J.; Bautista-Rodríguez, E. I.; Martínez-Acosta, E.; Callejas-Hernández, J. 2020. Effects of hydropriming on maize seeds (*Zea mays* L) and the growth, development, and yield of crops. *Revista de la Facultad de Ciencias Agrarias. Universidad Nacional de Cuyo. Mendoza. Argentina.* 52(1): 72-86.
27. Los Andes. 2017. Maíz forrajero: crece la superficie cultivada en Mendoza. (18 de Febrero de 2017). Los Andes. Recuperado de <https://www.losandes.com.ar/maiz-forrajero-crece-lasuperficie-cultivada-en-mendoza/>
28. Montemayor, J.; Gómez, O.; Monsiváis, J.; Ramírez, O.; Zermeño, A.; Ruiz, E.; Fortis, M.; Salazar, E.; Aldaco R. 2006. Efecto de tres profundidades de cinta de riego por goteo en la eficiencia de uso de agua y en el rendimiento de maíz forrajero. *TEC Pecu Méx.* 44(3): 359-364.
29. Montemayor, J.; Olague J.; Fortis, M.; Bravo, R.; Leos, J.; Salazar, E.; Castruita, J.; Rodríguez, J.; Chavarría J. 2007. Consumo de agua en maíz forrajero con riego subsuperficial. *Terra Latinoamericana.* 25(2): 163-168.
30. Montemayor, A.; Lara, I.; Woo, I.; Munguía, J.; Riverá, M.; Trucíos, M. 2012. Producción de maíz forrajero (*Zea mays* l.) en tres sistemas de irrigación en la comarca lagunera de Coahuila y Durango, México. *Agrociencia.* 46: 267-278.
31. Morábito, J.; Mirábito, C.; Salatino, S. 2007. Eficiencia de riego superficial, actual y potencial en el área de regadío del río Mendoza (Argentina). *Revista Ingeniería del Agua de la Universidad de Córdoba, España.* 14(3): 199-213.
32. Morábito, J.; Schilardi, C.; Martín, L.; Salatino, S. 2012. El desempeño del uso agrícola del agua en los oasis de los ríos Mendoza y Tunuyán a través de nuevos indicadores. [http://www.riegoyfertilriego.com.ar/VI\\_Jornadas/VI\\_JARF\\_TrabajosCompleto/Morabito%20\\_46\\_.pdf](http://www.riegoyfertilriego.com.ar/VI_Jornadas/VI_JARF_TrabajosCompleto/Morabito%20_46_.pdf)
33. Morábito, J.; Rearte, E.; Schilardi, C.; Martín, L.; Salatino, S. 2015. Desempeño del riego de equipos de pivote central en la provincia de Mendoza, Argentina. Instituto Nacional del Agua. [https://www.ina.gov.ar/pdf/Cra\\_1\\_Pivotes.pdf](https://www.ina.gov.ar/pdf/Cra_1_Pivotes.pdf).
34. Marouelli, W. A.; Silva, W. L. C. 2002. Drip line placement depth for processing tomatoes crop. *Hortic. Bras.* 20: 206-210.
35. Nelson, G.; Rosegrant, M.; Koo, J.; Robertson, R.; Sulser, T.; Zhu, T.; Ringler, C.; Msangi, S.; Palazzo, A.; Batka, M.; Magalhaes, M.; Valmonte-Santos, R.; Ewing, M.; Lee, L. 2009. Cambio climático: Impacto en la agricultura y los costos de Adaptación. [http://www.fao.org/fileadmin/user\\_upload/AGRO\\_Noticias/docs/costo%20adaptacion.pdf](http://www.fao.org/fileadmin/user_upload/AGRO_Noticias/docs/costo%20adaptacion.pdf)
36. Neufeld, J.; Davison, J.; Stevenson, T. 2004. Subsurface drip irrigation. <https://www.unce.unr.edu/publications/files/ag/other/fs9713.pdf>
37. Nijensohn, L.; Pilasi, H. 1962. Correlaciones entre contenido de agua, volumen de sedimentación y porcentaje de arcilla. *Actas de la 2° R.A.C.S. y 1° C.L.C.S.*
38. OCDE/FAO. 2017. *Perspectivas Agrícolas 2017-2026.* Éditions OCDE. París. [http://dx.doi.org/10.1787/agr\\_outlook-2017-es](http://dx.doi.org/10.1787/agr_outlook-2017-es)
39. Oktem, A.; Simsek, M.; Gulgun-Oktem, A. 2003. Deficit irrigation effects on sweet corn with drip irrigation system in a semi-arid region. I Water-yield relationship. *Agricultural Water Management.* 61: 63-74.
40. Pablo, R.; O'Neil, B.; McCaslin, B.; Remmenga, M.; Keenan, J.; Onken, B. 2007. Evaluation of corn grain yield and water use efficiency using subsurface drip irrigation. *Journal of Sustainable Agriculture.* 30(1): 153-172. DOI: 10.1300/J064v30n01\_10
41. Patel, N.; Rajput, T. 2007. Efecto de la profundidad de colocación de la cinta de goteo y el nivel de riego en el rendimiento de la papa. *Agricultural Water Management.* 88(1-3): 209-223. <https://doi.org/10.1016/j.agwat.2006.10.017>
42. Payero, J.; Tarkalson, D.; Irmak, S.; Davison, D.; Petersen, J. 2008. Effect of irrigation amounts applied with subsurface drip irrigation on corn evapotranspiration, yield, water use efficiency and dry matter production in a semiarid climate. *Agricultural Water Management.* 895-908.
43. Rébora, C.; Ibarguren, I.; Barros, A.; Antonini, C.; Arenas, F.; Calderón, M.; Guerrero, D. 2018. Producción de maíces sileros en el oasis norte Mendoza, Argentina. *Revista de la Facultad de Ciencias Agrarias. Universidad Nacional de Cuyo.* 50(2): 369-375.

44. Schilardi, C.; Martín L.; Rearte, E.; Morábito, J. 2017. Desempeño actual y potencial de diferentes métodos de riego en Mendoza. Recomendaciones para Mejorar el aprovechamiento del agua de riego. Agua y Sociedad.
45. Severina, I.; Boccardo, M.; Aimar, F.; Giubergia, J.; Haro, J.; Salinas, A. 2016. Distanciamiento entre laterales de riego por goteo subterráneo: Efectos sobre el crecimiento del cultivo de trigo en la región centro de Córdoba. 5° Reunión Internacional de Riego: Uso eficiente del agua para riego. Ediciones INTA.
46. Steduto, P. 1996. Water use efficiency. In: Pereira L. S., Feddes R. A., Gilley J. R., Lesaffre B. (eds). Sustainability of irrigated agriculture. Series E: Applied Sciences. vol 312.
47. Steven, R.; Troy, R.; Howell, T. 2006. Controlling water use efficiency with irrigation automation: Cases from drip and center pivot irrigation of corn and soybean. Southern Conservation Systems Conference. Texas. p. 57-66.
48. Swennenhuis, J. 2006. CROPWAT 8.0. Roma. Italia. [http:// www.fao.org/nr/water/infores\\_databases\\_cropwat.html](http://www.fao.org/nr/water/infores_databases_cropwat.html).
49. Van Halsema, G. E.; Vincent, L. 2011. Efficiency and productivity terms for water management: a matter of contextual relativism *versus* general absolutism. Agricultural Water Management. 108: 9-15.
50. Wainstein, P. 1969. Clasificación de las aguas de riego de Mendoza. Informe Científico N° 15. Instituto de Suelo y Riego. Facultad de Ciencias Agrarias. Universidad Nacional de Cuyo. Mendoza. Argentina.
51. Winpenny, J.; Heinz, I.; Koo-Oshima, S. 2009. Reutilización del agua en la agricultura: ¿Beneficios para todos? Italia. FAO. <http://www.fao.org/docrep/017/i1629s/i1629s.pdf>
52. Yescas, C.; Segura, M.; Martínez, L.; Álvarez, V.; Montemayor, J.; Orozco, J.; Frías, J. 2015. Rendimiento y calidad de maíz forrajero (*Zea mays* L.) con diferentes niveles de riego por goteo subsuperficial y densidad de plantas. Revista internacional de Botánica experimental. Phytón. 84: 272-279.