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Water use Efficiency in Surface and Subsurface Drip Irrigation in *Zea mays* L.

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Abstract

In food production, water is a limiting factor; therefore, it is necessary to achieve maximum efficiency in the use of this resource in agricultural systems. The efficiency of the water use of surface and subsurface drip irrigation in the *Zea mays* L. crop was evaluated. 1,600 m^2 of hard hybrid corn were cultivated, with four treatments: superficial drip irrigation (T1, control) and subsurface at 10 (T2), 20 (T3) and 30 (T4) cm deep and four repetitions. In a randomized block design, each experimental unit was 100 m^2 (10 m x 10 m). The yield, water use efficiency (WUE), frequency, time and irrigation sheet, diameter of the wetted bulb were measured. There were statistical differences for all the variables evaluated (p<0.01), except for the sheet of water per irrigation due to the effect of the treatments. Yield (10,263 kg/ha), WUE (7.92 kg/m^3), diameter wet bulb (0.145 m) were higher in T3 and T4; the frequency of irrigation (3.6 days) and the total sheet of water was lower in T3 and T4 (129 mm); the total irrigation time was shorter in T4 (34.08 h). Subsurface drip irrigation at 20 and 30 cm depth showed the highest efficiency.

Keywords: agricultural systems; maize; water scarcity; yield; irrigation time.

Eficiencia de Uso del Agua en Riego por Goteo Superficial y Subsuperficial en *Zea mays* L.

Resumen

En la producción de alimentos el agua constituye un factor limitante; por ello, es preciso alcanzar la máxima eficiencia del uso de este recurso en los sistemas agrícolas. Se evaluó la eficiencia del uso de agua del riego por goteo superficial y subsuperficial en el cultivo de *Zea mays* L. Se cultivaron 1.600 m^2 de maíz híbrido duro, con cuatro tratamientos: riego por goteo superficial (T1, testigo) y subsuperficial a 10 (T2), 20 (T3) y 30 (T4) cm de profundidad, con cuatro repeticiones. En un diseño en bloques completamentes al azar, cada unidad experimental tuvo 100 m^2 (10 m x 10 m). Se realizó un análisis de varianza y comparación de medias mediante la prueba de Tukey. Se evaluó el rendimiento, eficiencia del uso del agua (EUA), frecuencia, tiempo y lámina de riego, y diámetro del bulbo humedecido. Hubo diferencias estadísticas para todas las variables evaluadas (p<0,01), excepto para la lámina de agua por riego por efecto de los tratamientos. El rendimiento (10.263 kg/ha), EUA (7,92 kg/m^3) y diámetro (0,145 m) del bulbo húmedo fueron mayores en T3 y T4; la frecuencia de riego (3,6 días) y la lámina total de agua fue menor en T3 y T4 (129 mm); el tiempo total de riego fue menor en T4 (34,08 h). El riego por goteo subsuperficial a 20 y 30 cm de profundidad presentó la mayor eficiencia.

Palabras clave: sistemas agrícolas; maiz; escasez de agua; rendimiento; tiempo de riego.

Introduction

World demand for water related to population growth, economic development and changes in consumption patterns, among other factors, has increased 1% annually (United Nations World Water Assessment Programme (WWAP), 2018). According to de Miguel and Tavares (2015), the environmental challenge regarding water management requires reaching a balance, prioritizing between economic growth, poverty reduction, water conservation and climate change; however, theirs and the ecosystem management still are independent; therefore, an integrated approach is required, emphasizing the importance of water in ecosystems and the relationship of its management and operation, within a comprehensive perspective.

Shortages of hydric resource in many regions of the world, especially in arid and semiarid areas, the high cost of use and demand for agricultural foodstuff required by a growing population, it makes worth the search for alternatives to improve use efficiency or productivity of water, especially in agriculture, because this sector consumes large volumes of the liquid, compounded by the fact that a high percentage of this resource represents consumptive use for the plant (runoff, deep percolation, direct soil evaporation and evapotranspiration, among others) (Gomes *et al.*, 2011; Nieto *et al.*, 2018; Papanatsiou *et al.*, 2019). For which Sanchez and Rivera (2018) indicated that it is necessary to use and implement new forms of applications for irrigation, which are known as efficient, to optimize water resources and to obtain greater productivity and crop yield.

According to the Food and Agriculture Organization of the United Nations (FAO, 2019), the cause of the shortage of this precious liquid is mainly agriculture; essential for food security, and which represents 70% of this resource extraction, reaching up to 95% in some developing countries. The expansion of this shortage poses a challenge for sustainable development. Freshwater resources are alarmingly diminishing, which suggests that two thirds of the world population by 2025 could be living in water-stressed countries, if current patterns of consumption continue.

In Ecuador, and particularly in the southern region of the country, there are areas where rainfall ranges between 200 and 600 mm/year (Development Plan and Territorial Order of El Oro Province, 2015), being evident the scarcity of water; and turning its availability in the main limit for agricultural production.

The evaluation of different alternatives or methods of irrigation are necessary for maximum efficiency in water use. All the classic irrigation alternatives apply large amounts of water to meet their need in the crops, due to their high consumption, especially by evaporation. The subsurface drip irrigation can avoid the excessive water consumption by reducing application losses (evaporation) (Ayars *et al.*, 2015; Eranki *et al.*, 2017; Sinha *et al.*, 2017; Bringas-Burgos *et al.*, 2020), since it is supplied to the depth where the root system of the crop develops, forming the wet bulb in the soil subsurface part, avoiding being in direct contact with solar radiation (Lucero-Vega *et al.*, 2017). Al-Ghobari and Dewidar (2018) indicated that with this irrigation system, water requirements of the plants were reduced between 20 and 40%, and the water applications were uniform.

In subsurface drip irrigation, the main advantage is that the soil moisture content is conserved, using low volumes with high frequencies, thus allowing optimal plant growth, a relevant aspect because the greatest limitation for agricultural production in arid and semi-arid zones is the availability of water (Montemayor *et al.*, 2006).

Corn as grain and forage constitutes one of the most important cereals for human and animal consumption, in pharmaceuticals and in industrial production. In Ecuador, maize corresponds to one of the main short-cycle crops; it grows in different altitude regions, hence it adapts to different environments. The Ecuadorian National Institute of Statistics and Censuses (INEC, 2019), indicated that the sown area with hard dry maize, nationwide in 2018 was 383,399 ha; where production was concentrated in Los Ríos province (45.4%) with 602,000 metric tonnes.

Because maize is a C4 crop, its water use efficiency is high; this is due to the high photosynthesis rate, with a minimal contribution from the slightly restricted transpiration rate (Steduto *et al.*, 2007). It also highlights that under irrigation conditions and high soil fertility it reached yields between 11,000 and 14,000 kg/ha (Hsiao and Fereres, 2012).

It is clear that water is a factor of productive development, where the interests of experts in planning and management of water resources for irrigation purposes, users of water for irrigation, government officials, water administrators and society in general should converge; and find the means for this resource generates the greatest economic and social benefit.

Water use in agriculture must be done in an efficient, productive, equitable and respectful of the environment way. It is about producing more food using less water, increasing the resilience of farming communities to cope with floods and droughts, and applying clean technologies that protect the environment. The problem of water scarcity is a fundamental aspect of sustainable development.

Howell (2001) pointed out that evaporation, runoff and percolation losses were minimized through micro-irrigation; in addition, this technique make irrigation more efficient by making short and frequent applications; thus taking advantage of fert-irrigation to provide the crop nutrients requirements and increase production.

With basis in these reasons above, the present work objective was to evaluate water use efficiency applied through surface and subsurface drip irrigation in the hard seed hybrid maize.

Experimental

The trials were carried out in the experimental area of Santa Inés farm, Faculty of Agricultural Sciences, Technical University of Machala, located at km 5 1/2 via Pasaje, El Oro province, planning zone 7, Ecuador; between coordinates 620,000 W and 9,638,000 S and 620,200 W and 9,637,800 S, geographical zone 17 S, in Universal Transverse Mercator (UTM) system, where the Jubones river floodplain basin ends.

The climate is tropical megathermic semihumid, with an altitude of 5 masl, average temperature of 25°C, while the average yearly rainfall registers 600 mm, with two well marked seasons, the rainy one that usually begins in January and ends in April, and the dry one that goes from May to December. The reference evapotranspiration in this area is 1,300 to 1,500 mm, the annual water deficit ranges between 225 and 925 mm (Development Plan and Territorial Ordering of El Oro Province, 2015). The soil is loamy-silty in the first 30 cm depth.

The genetic material used was hard seed hybrid maize (PIONEER® 30K75), seeded at a distance of 80 cm between rows and 40 cm between plants, with two seeds per point. As for the vegetative characteristics of the simple hybrid class, it has semi-erect leaves, it reaches medium height, about 2.50 m, it shows semi-late vegetative phase 125-135 days, its ear position is 1.30 m, and a grain/cob shelling ratio 85/15.

The experiment design was of random full blocks, with four treatments and four replications. The trials were established on a total maize acreage of 1,600 m^2, containing 16 experimental units of 100 m^2 (10 m long x 10 m wide). The treatments were: surface drip irrigation (T1, control), subsurface drip irrigation to 10 (T2), 20 (T3) and 30 (T4) cm depth. The trenches for the installation of the irrigation system were made manually.

Irrigation scheduling was done in order to respond adequately to when watering and how much is the water contribution. The irrigation system was independent for each treatment, controlled by a gate valve. The water layer was controlled through volumetric precision valves, the irrigation frequency and times were performed according to the readings of soil sensors installed in field for each treatment, the instruments were properly calibrated before being installed.

The drippers nominal flow was 1.65 l/h ± 5%, given by the manufacturer (*Hydrodrip Super Flat Integral Dripline*, PLASTRO), whose working pressure was 10 m H_2O. They were installed 80 cm between side irrigation and 50 cm between drippers, to moisten a continuous horizontal strip. The irrigation laterals were polyethylene of 16 mm in diameter, the secondary pipe was polyethylene of 32 mm in diameter, the main pipe was PVC of 40 mm in diameter, the energy or pressure supplied to the system was 12 m H_2O at the irrigation discharge head, through a motor-driven equipment, fed by an underground well.

The crop yield was determined by recording the dry grain biomass of 40 plants per treatment, within a total of 160 plants per treatment; water use efficiency (WUE) of irrigation, also known as water productivity, was defined as function of yield in kg of dry corn grain product per m^3 of water used. The following equation was applied:

$$\text{Water Use Efficiency (WUE)} = \frac{\text{Production (kg)}}{\text{Water Used (m}^3\text{)}} \tag{1}$$

To determine the optimum soil moisture content for the plant, 16 sensors (Irrometer®) were installed in each of the blocks and treatments, previously calibrated at the trial site. For this process the sensor was installed in soil whose moisture content was at field capacity, and for each reading of the instrument, soil moisture was also determined in weight basis through the gravimetric method (Figure 1). When the curve becomes horizontal, the soil moisture sensor readings (cbar) indicates the plant needs irrigation; principle that was used for its application, whose readings also indicated the matrix potential of the soil or the strength for the soil to retain water droplets; this device, according to Ferreyra *et al.* (2006) and Girona *et al.* (2006), allowed to control the magnitude of water stress, either due to excess or deficit of water.

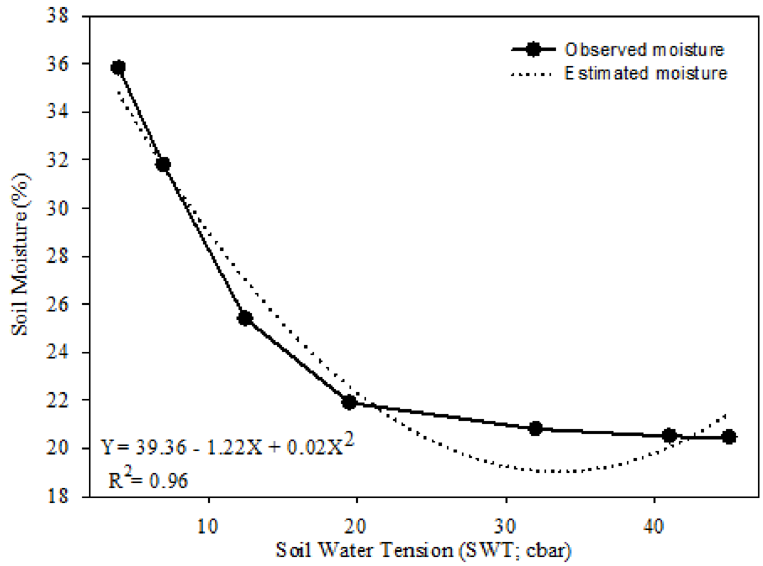

Figure 1. Soil moisture retention curve for UTMACH experimental farm.

The sensors were installed at 20 cm depth inside the soil wet bulb; because the root system's highest percentage of roots is found at that depth. Irrigation was provided when the reading indicates 45 cbar, and was stopped when this mark was 10 cbar, which indicated that the moisture content was at field capacity.

To determine the soil wet bulb diameter of the emitters installed on and under surface (10, 20 and 30 cm depth), an excavation was made, and a tape measure was used to measure it. Those measures were taken from the central axis, starting from this, was measured at different depths towards the ends, and the mean from the different wet bulb diameters calculated, process which was carried out after completion of the agricultural cycle, in order to not interfere with the plant normal root and leaf development.

To determine the diameter of the wet bulb of the emitters installed superficially and subsurface (10, 20 and 30 cm deep), it was excavated, and a tape measure was used to measure it. The as measures were taken from the central axis, starting from this, was measured at different depths towards the ends, and the mean obtained from the different diameter moistened obtained, process after completion of the cycle of culturing was carried out, in order not to interfere with the root and normal leaf development of the plant.

A Fisher test (F-test) analysis of variance (ANOVA) was performed on each variable, to identify statistically significant differences in the effects of treatments. To determine the best treatment (or treatments), they were subjected to Tukey's multiple comparison test ($p \leq 0.05$). Statistical analyzes were carried out using the statistical software suit SAS®, version 15.1 (Statistical Analysis System, 2020).

Results and discussion

Statistically significant differences were found in the effects of treatments for the variables Yield (kg/ha; $p<0.024$) and water use efficiency (WUE) (kg/m3; $p<0.002$). Regarding the crop yield response to the effect of treatments, two treatments groups were generated without statistically significant differences within ($p>0.05$), but with statistically significant differences between groups ($p<0.01$). One group was constituted by treatment of subsurface drip irrigation at 20 and 30 cm depth, while the other group comprised treatments irrigation systems surface and subsurface drip 10 cm depth (Table 1).

Table 1. Crop Yield for maize dry grain (*Z. mays* L.) in kg/ha and Water Use Efficiency (WUE) in kg/m^3 by the application of surface and subsurface drip irrigation at 10, 20 y 30 cm depth.

Treatments	Yield (kg/ha)	Water Use Efficiency (kg/m^3)
Subsurface drip irrigation at 20 cm depth (T3)	10,337.5^a	7.95^a
Subsurface drip irrigation at 30 cm depth (T4)	10,189.1^a	7.89^a
Surface drip irrigation (T1)	9,259.4^b	6.10^b
Subsurface drip irrigation at 10 cm depth (T2)	9,232.8^b	6.63^b

The same superscript (a,b) in the column, do not show honestly significant difference (HSD) ($p\leq0.05$), according to Tukey's test due to the applied treatments.

The highest yield was showed by subsurface drip irrigation at 20 (T3) and at 30 (T4) cm depth treatments, with an mean (group average) of 10,263.3 kg/ha, followed by surface and subsurface drip 10 cm depth treatments (9,246.1 kg/ha), the first group being superior with a difference a little more than 1.000 kg/ha; that is, 1.11 times higher in Group 1 compared to Group 2 (Table 1). Regarding to this variable, experimental performance of the best treatments were compared with regional crop yields, taking as reference the official yield reports for El Oro province in 2019, which mean was 5,207.57 kg/ha (INEC, 2020). Estimated crop yields in this study almost double those obtained for regional yield reported. This was 1.77 and 1.99 times higher for subsurface drip irrigation treatments at 10 and 20 cm depth, respectively.

According to Zamora-Salgado *et al.* (2011), a crop yield performance between 6 and 9 metric t/ha under irrigation conditions, it could be acceptable as commercial production, with a corn moisture content between 10 and 13%, which is in agreement with the results obtained in this investigation, where the moisture content of the grain was 13%.

The water use efficiency (WUE) or water productivity supplied through irrigation drip, both surface and subsurface (10, 20 and 30 cm depth) was 6.10, 6.63, 7.95 and 7.89 kg/m^3, respectively (Table 1). Subsurface drip irrigation treatments at 20 (T3) and 30 (T4) cm depth did not show statistical differences between them ($p>0.05$), but they were different when compared with drip irrigation at surface (T1) and 10 (T2) cm depth, showing no differences between the latter two either ($p>0.05$; Table 1). However, subsurface drip irrigation to 20 cm depth (T3), showed the highest values of WUE in the crop.

In this investigation, the yield in subsurface irrigation at 20 cm depth was 1.43 times greater than subsurface irrigation at 30 cm depth; 10.43% greater than the surface drip irrigation and 10.69% greater than subsurface 10 cm depth, which was the one with the smallest production. Likewise, the maximum water productivity was 7.95 kg/m^3 in subsurface irrigation at 20 cm depth, which corresponded to 0.75, 16.60 and 23.27% of water savings, when compared with subsurface drip irrigation at 30 and 10 cm depth, and surface drip irrigation.

Zamora *et al.* (2007) and Zamora-Salgado *et al.* (2011) report water use efficiency for a drip irrigation system into a hybrid maize crop of 2.53 kg/m^3, while Salomó *et al.* (2019) obtained an average WUE value for three years of evaluation of 2.81 and 2.5 kg/m^3 for subsurface drip irrigation at 25 and 35 cm depth; respectively, while for flood irrigation it was 2.45 kg/m^3; contrasting widely with the results obtained in this investigation, where the values obtained were 2.76 times higher.

There were no statistically significant differences ($p>0.05$) for the water layer applied though irrigation (mm) due to treatments effect, while for the other variables: irrigation frequency (days), mean time per irrigation (hours), total irrigation time (hours), total applied water layer (mm) and wet bulb diameter (m), significant differences were detected due to treatment effect ($p<0.05$). Irrigation frequency comprise two groups, one constituted by the subsurface drip irrigation to 20 (T3) and 30 (T4) cm depth, with no difference between them, but statistically different of the second, constituted by irrigation drip surface (T1) and subsurface 10 cm depth (T2). There it can be noted that the irrigation frequency vary between 3.0 days (second group) and 3.6 days (first group) (Table 2).

Table 2. Frequency, time, water layer and wet bulb diameter due to the effect of surface and subsurface irrigation at 10, 20 y 30 cm depth.

	Drip Irrigation			
Depth	**Surface**	**Subsurface**		
	0 cm	**10 cm**	**20 cm**	**30 cm**
Irrigation frequency (days)	3.00^{b}	3.00^{b}	3.60^{a}	3.60^{a}
Mean time per irrigation (hours)	1.20^{a}	1.11^{b}	1.24^{a}	1.21^{a}
Total irrigation time (hours)	40.20^{a}	36.48^{ab}	34.78^{ab}	34.08^{b}
Water layer applied per irrigation (mm)	4.6^{a}	4.2^{a}	4.7^{a}	4.6^{a}
Total applied water layer (mm)	152^{a}	139^{ab}	130^{b}	129^{b}
Wet bulb diameter (m)	0.412^{b}	0.420^{b}	0.442^{a}	0.447^{a}

Different superscripts in each row (a,b,ab) show a honestly significant difference (HSD) ($p<0.05$), according to Tukey's comparison test due to the applied treatments.

The applied water is related to the crop phenological stage and its physiological response to the production and quality of the expected harvest. This implies, less amount of water in some periods of development of the plant, which allows predicting when and how much to water. In general, plants respond to the water potential in the soil and not directly to the frequency of irrigation, which makes it increasingly important to determine soil moisture (water content), the plant water status and soil-plant-atmosphere continuum water balance.

The mean time per irrigation was between 1.1 and 1.24 h; where the subsurface drip irrigation to 20 and 30 cm depth and the surface drip irrigation , show no significantly differences ($p>0.05$) between them, but the comparison with the subsurface drip irrigation at 10 cm depth, shows they were statistically different ($p<0.01$). In this sense, the mean time per irrigation in subsurface drip at 20 cm depth was 2.42, 3.23 and 10.48% greater than the subsurface irrigation drip at 30 cm depth, the surface drip and the subsurface drip to 10 cm depth, respectively (Table 2).

There were statistically significant differences ($p<0.01$) for the total irrigation time between subsurface drip irrigation at 30 cm depth and surface drip irrigation, while subsurface drip irrigation at 10 and 20 cm depth, were similar and no statistical difference between them were found; the total irrigation time vary between 40.2 and 34.08 h (Table 2). It should be noted that surface drip irrigation required 9.25, 13.48 and 15.22% more irrigation time, which represented 3.72, 5.42 and 6.12 h in excess, compared to subsurface drip irrigation to 10, 20 and 30 cm deep in that order. This suggests a shorter time of the pumping equipment use, and less water and electricity consumption, to fulfill this task in the crop by using subsurface irrigation.

The water layer applied per irrigation varies between 4.2 and 4.7 mm. However, the total water layer applied to the maize crop 100 days after sowing, through surface and subsurface drip irrigation at 10, 20, and 30 cm depth, were 152, 139, 130 and 129 mm, respectively (Table 2), which corresponded to a difference of 8.55, 14.47 and 15.13% lower, comparing with the surface drip irrigation, which provided the largest water layer of all the treatments. This represented a difference of 13, 22 and 23 mm of water, maintaining the same comparison between the surface drip irrigation, with respect to subsurface drip irrigation to 10, 20 and 30 cm depth, in the order given.

It has been pointed out that, when comparing underground drip irrigation with traditional irrigation (gravity), the irrigation water used for the cultivation of corn was reduced from 35 to 55% (Lamm and Trooienm, 2003), while Montemayor *et al.* (2007) indicated that in forage corn, when comparing subsurface drip irrigation with surface irrigation, there was a water saving of 27.4%; the authors agreeing that in gravity irrigation there was a greater loss of water.

It also highlights that, with the implementation of the surface and subsurface irrigation system at 10 cm depth, the soil surface was kept relatively dry, while at 20 and 30 cm depth, it was observed totally dry. In this regard, Thompson *et al.* (2009) indicated that there was a significant control of the weeds, the leaching of NO_3- was decreased and the yields were higher when compared to surface irrigation; attributing this to the fact that water and nutrients reached the most active part of the roots.

Regarding the wet bulb diameter, it varied between 0.412 and 0.447 m; in this variable, the indicated values corresponded to surface drip irrigation and subsurface drip irrigation at 30 cm depth, respectively. On the soil surface where the superficial and subsurface drip irrigation 10 cm depth treatments were located, the wetting of the bulb was observed, while with the subsurface irrigation at a greater depth (20 and 30 cm depth), this was not possible, which was in agreement with the indicated by Bonachela (2001), who noted that while the wet bulb was in contact with direct solar radiation, evaporation was longer, adding a consumption not demanded by the plants, estimated as up to 43% for young crops.

Conclusions

When evaluating surface and subsurface irrigation systems, the results indicate that subsurface drip irrigation installed at 20 cm depth results in a significant reduction in the use of water resources, with a positive effect on all the variables evaluated, in addition to being the most water use efficient for irrigation.

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