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Water productivity using furrow and drip irrigation in hybrid maize

Productividad del agua empleando riego por surcos y goteo en maíz híbrido

Produtividade de água usando Irrigação por sulco e gotejamento em milho híbrido

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Crop production

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Abstract

Agriculture is the economic sector that consumes around 70 % of the total water extracted globally, considering itself a victim of its own inefficiency. The present work was oriented to look for irrigation alternatives that allow a greater productivity of water. The trial was carried out at the Faculty of Agricultural Sciences, Technical University of Machala, Ecuador. The amount of water applied to the corn crop through furrow and drip irrigation was evaluated. The treatments were: furrow irrigation, superficial drip irrigation and subsurface drip irrigation at 20 cm. The trial had a surface area of 450 m^2, in a completely randomized block experimental design with three treatments and three repetitions. The control of the irrigation regime was carried out through tensiometers installed for each treatment. The volume of water applied and the dry grain yield in irrigation by furrows was 3,484 $m^3.ha^{-1}$ and 9,175 $kg.ha^{-1}$, for surface drip irrigation of 1,452 $m^3.ha^{-1}$ and 10,200 $kg.ha^{-1}$, and for subsurface drip irrigation it was 1,237 $m^3.ha^{-1}$ and 10,181.2 $kg.ha^{-1}$. The water productivity for the furrow irrigation treatment was 2.63 $kg.m^{-3}$, for surface drip irrigation it was 7.02 $kg.m^{-3}$ and for subsurface drip irrigation at 20 cm it was 8.23 $kg.m^{-3}$ being the highest productivity.

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Resumen

La agricultura, es el sector económico que consume alrededor del 70 % del total de agua extraída en forma global, considerándose víctima de su propia ineficacia. El presente trabajo se orientó a buscar alternativas de riego que permitan una mayor productividad del agua. El ensayo se realizó en la Facultad de Ciencias Agropecuarias, Universidad Técnica de Machala, Ecuador. Se evaluó la cantidad de agua aplicada al cultivo de maíz a través del riego por surcos y goteo, Los tratamientos fueron: Riego por surcos, riego por goteo superficial y riego por goteo subsuperficial a 20 cm. El ensayo tuvo una superficie de 450 m^2, en un diseño experimental de bloques completamente al azar con tres tratamientos y tres repeticiones. El control del régimen de riego se realizó a través de tensiómetros instalados para cada tratamiento. El volumen de agua aplicado y el rendimiento en grano seco en el riego por surcos fue 3.484 $m^3.ha^{-1}$ y 9.175 $kg.ha^{-1}$, para el riego por goteo superficial de 1.452 $m^3.ha^{-1}$ y 10.200 $kg.ha^{-1}$, y para el riego por goteo subsuperficial fue 1.237 $m^3.ha^{-1}$ y 10.181,2 $kg.ha^{-1}$. La productividad del agua para el tratamiento riego por surcos fue 2,63 $kg.m^{-3}$, para el riego por goteo superficial fue de 7,02 $kg.m^{-3}$ y para el riego por goteo subsuperficial a 20 cm de 8,23 $kg.m^{-3}$ siendo la mayor productividad.

Palabras clave: caudal no erosivo, riego subsuperficial, escasez de agua, pendiente de los surcos

Resumo

A agricultura é o sector económico que consomé cerca de 70 % do total de agua extraída globalmente, considerando-se vítima de sua própria ineficiência. O presente trabalho foi orientado a buscar alterntivas de irrigação que permitam uma maior produtividade de água. O experimento foi realizado na Facultade de Ciências Agrárias. Universidade Ténica de Machala, Equador. Avaliou-se a quantidade de água aplicada na cultura domilho por meio de irrigação por sulco e gotejamento, sendo os tratamentos: irrigação por sulco, irrigação por gotejamento superficial e irrigação por gotejamento subsuperficial a 20 cm. O ensaio teve uma área de superficie de 450 m2, en delineamento experimental em blocos casualizados com três tratamentos e três repetições. O controle do regime de irrigação foi realizado por meio de tensiómetros instalados para cada tratamento. O volume de água aplicado e o rendimento de grãos secos na irrigação por sulcos foi de 3.484 $m^3.ha^{-1}$ e 9.175 $kg.ha^{-1}$, para gotejamento superficial de 1.452 $m^3.ha^{-1}$ e 10.200 $kg.ha^{-1}$, e para irrigação por gotejamento subsuperficiall foi de 1.237 $m^3.ha^{-1}$ e 10.181,2 $kg.ha^{-1}$. A produtividade de água para o tratamento de irrigação por sulco foi de 2,63 $kg.m^{-3}$, para irrigação por gotejamento superficial foi de 7,02 $kg.m^{-3}$ e para irrigação por gotejamento subsuperficial a 20 cm foi 8,23 $kg.m^{-3}$ sendo a maior produtividade.

Palavras-chave: fluxo não erosivo, Irrigação subsuperficial, falta de água, inclinação dos sulcos

Introduction

Water is the main element of all living organisms. In plants, it represents 80 to 90 % of the fresh weight in herbaceous plants and more than 50 % in woody plants (Alarcón, 2020), becoming the main means of transport of nutrients from the soil. Although water is the main element of the plant, the major consumption of this element is not in the formation of plant tissues, but in the process of evapotranspiration, considering that in most crops evapotranspiration represents more than 95 % of water consumption.

The water consumed by plants is that used during phenological phases, characterized by crop evapotranspiration (Siebert and Döll, 2010). Although agriculture consumes the largest amount of water withdrawn, however, 44 % of agricultural production is obtained in irrigated areas, representing only 18 % of the cultivated area (FAO, 2019). From an environmental point of view, the concept of water footprint is an established means of determining water consumption to obtain a given product, it is not effective in describing the impact of agricultural practices on water availability and scarcity in a particular region (Jeswani and Azapagic, 2011). Humanity must produce more food with less water, aiming to improve the efficiency of irrigation water use.

The optimization of water use, should be the main concern of those who plan its use for irrigation, water is an irreplaceable strategic resource that becomes the dynamizing axis of the agricultural sector through irrigation, in Ecuador irrigated production contributes 70 % of national agricultural production (SENAGUA, 2016). Efficient irrigation is water that properly moistens the root zone, therefore, the amount of water incorporated into the soil must correspond to the water consumed by the crop.

Irrigation has been applied by different methods and techniques, thus the most used by agricultural sectors is gravity or surface irrigation, which represents approximately 75 %, while sprinkler irrigation and high frequency localized irrigation (drip and micro-sprinkler) represent 25 % of the total irrigated area globally (FAO, 2019). In Ecuador, the area irrigated by gravity or surface is approximately 56 %, and for sprinkler, micro-sprinkler and drip irrigation it is 43 % of the total irrigated area (SENAGUA, 2019).

In gravity or surface irrigation, furrows and ridges have variable and decreasing flow rates due to the infiltration of water into the soil during its course, which supplies small flows from the highest to the lowest elevation, following the slope, preferably from 0.2 to 0.5 % (Fuentes, 2002). The length of the furrows is variable because it is a function of soil texture, slope, and soil depth. The soil is wetted by water infiltration through the wetted perimeter of small channels. Because they are spaced, the water partially covers the soil between furrows and is wetted by the effect of the advance of moisture in depth and laterally, the separation of the furrows ranges from 0.30 m to 1.20 m, depending especially on the texture and the crop.

The flow rate supplied to the furrows is a function of the furrow slope and soil texture and is called “maximum non-erosive flow rate” which is calculated with the following mathematical expression:

$$Qmax = \frac{C}{S(\%)}$$

Where: Qmax. Represents maximum non-erosive flow ($L.s^{-1}$); “S” the slope in percentage; C = 0.57 for sandy soils; C = 0.63 for loamy soils; and C = 0.96 for clay soils (Gurovich, 1985).

Drip irrigation is an alternative designed to improve water productivity in agriculture, in the case of surface drip irrigation water evaporation decreases significantly, because the wet surface of the soil is small, and in subsurface drip irrigation it is not in direct contact with solar radiation, reducing water losses by soil evaporation (Irmak *et al*., 2016). Most of the water applied through irrigation methods, both in surface irrigation systems (furrows, beds, flood) and sprinkling is lost by evaporation, considering that much of this water consumption is not useful for the plant (non-beneficial consumption).

Kafkafi and Tarchitzky (2012) state that drip irrigation allows direct delivery of water to the plant with minimal water losses by evaporation from the soil not covered by the plants. Martinez and Reca (2014) found a 20 % difference in favor of subsurface irrigation compared to surface irrigation; Lucero-Vega *et al*. (2017) determined that water loss by evaporation in subsurface irrigation was lower by 44 % with respect to surface drip irrigation.

The similarity between the furrow irrigation method and the drip irrigation method is that the crop takes the same amount of water for its physiological functioning irrigated with the two methods, and the difference is that different amounts of water are applied with particular characteristics of each irrigation method. The objective of this research was to evaluate the productivity of irrigation water applied by furrows, surface drip and subsurface drip in hybrid corn.

Materials and Methods

The research was carried out at the Facultad de Ciencias Agropecuarias, Universidad Técnica de Machala - Ecuador, whose geographical location is at coordinates 620000 W and 9638000 S and 620200 W and 9637800 S, geographical zone 17 S, universal transverse mercator projection.

The climate of the area where the project was developed is classified as tropical megathermal semi-humid, it is located at 5 masl, with an average temperature of 25 °C, the average rainfall is 600 mm with defined pluviometric periods, the rainy period usually begins in January and ends in April, the dry period begins in May and ends in December, the annual reference evapotranspiration is between 1300 to 1500 $mm.year^{-1}$, greater than rainfall, resulting in a significant water deficit (Plan de Desarrollo y Ordenamiento Territorial de la Provincia de El Oro, 2015). The soil is silt loam in the first 30 cm of depth, at greater depths the soils are generally sandy. The proportions of mineral material were: sand 34.24 %, silt 63.82 % and clay 1.94 % (Villaseñor *et al*., 2015).

The recording of the information began with the sowing of the seed on August 20, 2022, the corn seed used was DASS 3383 sown at 80 cm between rows and 40 cm between plants, with two seeds per hole, giving a planting density of 62,500 $plants.ha^{-1}$. The experiment was designed as a totally randomized block design with three treatments and three replications. The treatments were: furrow irrigation (T1), surface drip irrigation (T2), and subsurface drip irrigation at 20 cm (T3), with three replications. The experimental area was 450 m^2, the experimental unit was a 50 m^2 plot, and the last irrigation was applied after 100 days.

The irrigation system was designed so that each treatment is irrigated independently, with its respective piping system and control system (gate valves), installed before planting the seed. The accounting of the volume of water applied per irrigation and total accumulated during the crop cycle was done with precision volumetric valves. Regarding irrigation management, the frequencies or intervals of irrigation supply, as well as irrigation times were considered according to the readings of tensiometers (irrometer® model), which were installed at 20 cm depth, where the highest percentage of the plant's root mass is located. The discharge of the emitters (drippers) was 1.65 $L.h^{-1}$, with a variation of 5 % of the dripper discharge, the working pressure was 10 mH_2O (Hydrodrip Super Flat Integral Dripline, PLASTRO). The irrigation laterals were installed at 80 cm and 50 cm from the emitters (drippers) respectively. The irrigation laterals were 16 mm diameter hydrodrip tape, the secondary conduction was 32 mm polyethylene hose, while the main conduction was 40 mm external diameter PVC pipe. The furrows were 10 m long, with a slope of 0.5 % and the flow supplied was 1 $L.s^{-1}$. The energy source that fed the irrigation system was an electric pump supplied from a subway well located in the trial area.

To determine the optimum irrigation moment, previously calibrated tensiometers were installed in the area where the trial was developed, irrigation started when the tensiometers marked 45 cbar, in the tension-humidity curve it represented 20 % moisture, and irrigation was suspended at 10 cbar, in the tension-humidity curve it represented 32 % moisture content (water), indicating at that moment that the soil moisture was at field capacity, which is the optimum moisture point for the plants.

The dry grain yield of the crop was determined from 5 plants per experimental unit totaling 15 plants analyzed per treatment, whose values were processed through the Statistical Analysis System (SAS) software for their respective analysis. The irrigation efficiencies known for the different irrigation methods have been replaced by an indicator that expresses water productivity in terms of yield, proposed by Droogers and Kite (1999), which in this research was used to measure or determine the economic index of the water used for irrigation (irrigation water productivity), in a given crop, whose mathematical expression is as follows:

Results and discussion

The amount of water supplied is a function of the crop and the different methods of water application for irrigation, showing the results in terms of water productivity $kg.m^{-3}$ through furrow irrigation, surface drip irrigation and subsurface drip irrigation at 20 cm.

Regarding the number of irrigations, in the furrow irrigation treatment 17 irrigations were applied, for the surface drip irrigation treatment 30 were applied, and for subsurface drip irrigation 26 (figure 1, table 1), irrigation was applied up to 100 dap. It is worth mentioning that Guevara *et al*. (2005) applied 32 irrigations with subsurface drip irrigation buried 30 cm in corn. The furrow irrigation treatment registered a lower irrigation frequency of 6 days, while the surface drip irrigation treatment registered a higher irrigation frequency of 3 days, and the subsurface drip irrigation treatment of 4 days (table 1).

Although the furrow irrigation treatment registered less frequency and fewer irrigations, the volume applied was approximately 2.4 times and 2.8 times greater than the surface drip irrigation and subsurface drip irrigation treatments at 20 cm, respectively. This difference in volume of water applied means that the amount of water that is not beneficial to the plant is greater in the furrow irrigation than in the surface and subsurface drip irrigation. Emphasizing that the water lost by evaporation is non-beneficial consumption for the plant.

With regard to the amount of water applied, the results indicated significant statistical differences at ($p>0.05$) for the amount of water (mm) supplied by irrigation between the furrow irrigated treatment and those irrigated by surface drip and subsurface drip, by effect of the treatments; the amount of water supplied by irrigation was 20.5 $mm.irrigation^{-1}$ for furrow irrigation; 4.84 $mm.irrigation^{-1}$ for surface drip and 4.75 $mm.irrigation^{-1}$ for subsurface drip, respectively (table 2).

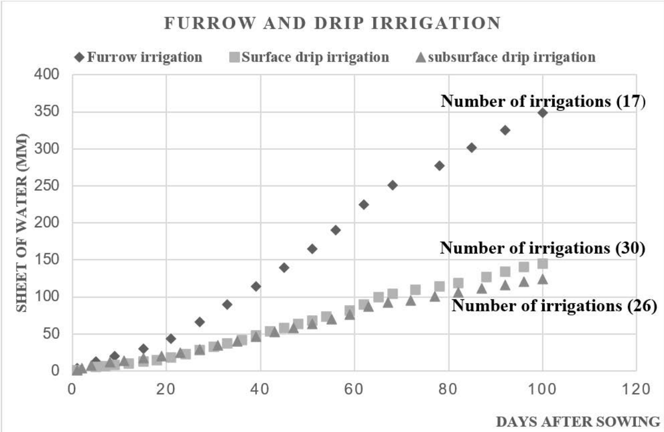

Figure 1. Water sheet and number of irrigations applied in hybrid maize: furrow irrigation (u), Surface drip irrigation (n) subsurface drip irrigation (p).

Table 1. Frequency and number of irrigations applied to maize (*Zea mays* L.).

	Furrow irrigation	Surface drip irrigation	Sub-surface drip irrigation (20 cm)
Frequency of irrigation (days)	6	3	4
Number of irrigations	17	30	26

The treatments irrigated by surface drip and subsurface drip irrigation did not show significant statistical differences, although the lowest amount of water applied was for the subsurface drip irrigation treatment at 20 cm, which was 4.75 mm.irrigation^{-1}.

Table 2. Applied water (mm) per irrigation and accumulated, through furrow irrigation, surface drip and subsurface drip, in corn (*Zea mays* L.).

Water sheet (mm)	Furrow irrigation	Surface drip irrigation	Sub-surface drip irrigation (20 cm)
By irrigation	20.5^{a}	4.84^{b}	4.75^{b}
Accumulated	348.5^{a}	145.2^{b}	123.7^{c}

$^{a, b, c}$Different letters in each row indicate significant statistical differences based on Tukey's multiple means test (p<0.05).

With respect to the total irrigation sheet, there were significant statistical differences (p<0.001) between the furrow irrigation treatment and the surface drip and subsurface drip irrigation treatments, where the furrow irrigation treatment applied a sheet of 348.4 mm, while the drip irrigation treatment applied a sheet of 145.2 mm and 123.7 mm for the subsurface drip irrigation at 20 cm. There were also statistical differences between surface drip irrigation and subsurface drip irrigation.

With subsurface drip irrigation at 20 cm, 36 % of the volume applied in the furrows was applied, and 85 % of the volume applied with surface drip irrigation. It is worth mentioning that research conducted by Al-Ghobari and Devidar (2018) determined that subsurface or subway irrigation systems can save water between 20 and 40 % with respect to surface irrigation systems.

In this study, the subsurface drip irrigation treatment at 20 cm was the one with the lowest water application, 123.7 mm of water. Research work developed by Lucero-Vega *et al*. (2017) determined that water loss by evaporation was lower in subsurface or subsurface irrigation with respect to surface drip by 44 %. This evaporative water loss in surface drip irrigation is considered non-beneficial consumption for the plant. Research work developed by Shen *et al*. (2020) found high moisture contents at depths of 0 to 40 cm, irrigated with subsurface drip with irrigation frequencies of 4 days.

Regarding dry grain yield at a moisture content of 13 %, there were statistical differences (p< 0.001) between the furrow irrigated treatment and the treatments irrigated by surface drip and subsurface drip. Dry grain yields for the furrow irrigated treatment were 146.8 g.plant^{-1} (9175 kg.ha^{-1}), while for the surface drip irrigation treatment the yield was 163.2 g.plant^{-1} (10200 kg.ha^{-1}), and for the subsurface drip irrigation at 20 cm, it was 162.9 g.plant^{-1} (10,181.2 kg.ha^{-1}) (table 3).

Dry grain yields for the surface drip irrigation and subsurface drip irrigation treatments at 20 cm showed no statistical differences (p<0.05) for treatment effects.

Table 3. Dry grain yield (kg.ha^{-1}), Volume of water applied (m^{3}.ha^{-1}), and Water productivity (kg.m^{-3}), applied in furrow irrigation, surface drip irrigation, and subsurface drip irrigation.

Treatment	Yield (kg.ha^{-1})	Volume of water applied (m^{3}.ha^{-1})	Water productivity (kg.m^{-3})
Furrow irrigation	175^{b}	3,484^{a}	2.63^{c}
Surface drip irrigation	10,200^{a}	1,452^{b}	7.02^{b}
Subsurface drip irrigation at 20 cm	10,181.2^{a}	1,237^{c}	8.23^{a}

$^{a, b, c}$Different letters in each row indicate significant statistical differences based on Tukey's multiple means test (p<0.05).

These results coincide with the research carried out by Martínez and Reca (2014) who obtained higher olive and oil yields with subsurface drip irrigation with respect to surface drip irrigation, stating that this is due to the better distribution of water in the wet bulb. The yields obtained in this research were lower than those obtained by Zhang *et al*., (2019) in Xinjian Northwest China who obtained yields of 19.1 and 21 t.ha^{-1}.

For the furrow irrigated treatment a volume of 3,484 m^{3}.ha^{-1} was applied, for surface drip irrigation the volume applied was 1,452 m^{3}.ha^{-1}, and for subsurface drip irrigation at 20 cm of 1,237 m^{3}.ha^{-1} (table 3).

Regarding the volume of water applied, there were statistical differences (p<0.001), between the treatment irrigated by furrows, surface drip and subsurface drip at 20 cm. Likewise, the treatments irrigated by surface drip and subsurface drip at 20 cm also presented statistical differences ($p<0.001$), with a difference of 15 % less water applied for the treatment irrigated by subsurface drip at 20 cm. Research conducted in China by Yan *et al*. (2016), applied water sheets in subsurface drip irrigation at 30 cm depth of 162 mm (1,620 $m^3.ha^{-1}$).

Referring to water productivity, they presented statistical differences ($p<0.003$) between the furrow irrigated treatment and those irrigated by surface drip and subsurface drip at 20 cm, for furrow irrigation a water productivity of 2.63 $kg.m^{-3}$ was obtained, for surface drip irrigation water productivity was 7.02 $kg.m^{-3}$, and for subsurface drip irrigation at 20 cm of 8.23 $kg.m^{-3}$. Research by Stanghellini (2010), found that the average water productivity in the 65-country drip-irrigated maize crop was 7.0 $kg.m^{-3}$.

Similarly, water productivity, the treatments irrigated by surface drip and subsurface drip at 20 cm, presented statistical differences ($p<0.003$) (table 3). Water productivity in the treatment irrigated by subsurface drip at 20 cm, in relation to water productivity in furrow irrigation was 3.1 times higher, and 1.2 times higher than water productivity in surface drip irrigation.

Conclusions

The management plan for furrow, surface drip and subsurface drip irrigation generates different strategies for its use and management, by having different frequencies and number of irrigations. Furrow irrigation required less frequency and fewer irrigations, in contrast to surface and subsurface drip irrigation at 20 cm, which were applied with a higher frequency and greater number of irrigations. The volume of water supplied by furrow irrigation was greater than the volume of water supplied by surface and subsurface drip irrigation systems. Water productivity was higher with subsurface drip irrigation at 20 cm.

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