Growth and yield of corn under surface and subsurface drip irrigation

Crecimiento y rendimiento de maíz bajo riego por goteo superficial y subsuperficial

Crescimento e produtividade do milho sob irrigacão por gotejamento superficial e subsuperficial

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Crop production

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Abstract

To evaluate the effect of surface and subsurface drip irrigation on the growth and yield of corn, a trial was carried out at the Technical University of Machala-Ecuador, 1,600 m^2 of hybrid corn (PIONEER 30K75) were cultivated to apply the treatments: irrigation by surface and subsurface drip at 10, 20 and 30 cm depth. The seed was sown in August 2019 at 80 cm between rows and 40 cm between plants, two seeds per point, with a plant density of 62,500 plants.ha^{-1}. The experimental design was randomized blocks with four treatments and four repetitions. Plant height, fresh and dry biomass of leaves, stalks, and roots, biomass of 100 dry kernels, and yield of dry kernel were evaluated. The highest plant height and biomass of 100 dry kernels was 2.79 m, and 39.08 g, which corresponded to the subsurface drip irrigation treatment at a depth of 30 cm; the highest fresh and dry biomass of leaves, 13,631.3 kg.ha^{-1} and 3,800 kg.ha^{-1} respectively, as well as the highest yield of dry kernel 10,337.5 kg.ha^{-1} was for the subsurface drip irrigation treatment at 20 cm depth. The highest fresh and dry biomass of stalks 32,768.8 kg.ha^{-1} and 10,381.3 kg.ha^{-1}, and the fresh and dry biomass of roots of 6,381.3 kg.ha^{-1} and 2,150 kg.ha^{-1}, corresponded to the superficial drip irrigation treatment. With drip irrigation, at 20 and 30 cm depth, higher growth and yield were obtained.

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Resumen

Para evaluar el efecto del riego por goteo superficial y subsuperficial en el crecimiento y rendimiento del maíz, se efectuó un ensayo en la Universidad Técnica de Machala-Ecuador, se cultivaron 1.600 m^2 de maíz híbrido (PIONEER 30K75) para aplicar los tratamientos: riego por goteo superficial y subsuperficial a 10, 20 y 30 cm de profundidad. La semilla fue sembrada en agosto del 2019 a 80 cm entre surcos y 40 cm entre plantas, dos semillas por punto, con una densidad de siembra de 62.500 plantas.ha^{-1}. El diseño experimental fue bloques al azar, con cuatro tratamientos y cuatro repeticiones. Se evaluó altura de planta, biomasa fresca y seca de hojas, tallo y raíces, biomasa de 100 granos secos y rendimiento en grano seco. La mayor altura de planta y biomasa de 100 granos secos, fue de 2,79 m y 39,08 g que correspondió al tratamiento riego por goteo subsuperficial a 30 cm de profundidad; la mayor biomasa fresca y seca de hojas, 13.631,3 kg.ha^{-1} y 3.800 kg.ha^{-1} respectivamente así como el mayor rendimiento de grano seco 10.337,5 kg.ha^{-1} fue para el tratamiento riego por goteo subsuperficial a 20 cm de profundidad. La mayor biomasa fresca y seca de tallos 32.768,8 kg·ha^{-1} y 10.381,3 kg.ha^{-1} y la biomasa fresca y seca de raíces de 6.381,3 kg.ha^{-1} y 2.150 kg.ha^{-1}, correspondió al tratamiento riego por goteo superficial. Con el riego por goteo, a 20 y 30 cm de profundidad se obtuvo mayor crecimiento y rendimiento.

Palabras clave: biomasa del maíz, riego por goteo, riego subsuperficial, rendimiento del maíz.

Resumo

Para avaliar o efeito da irrigação por gotejamento superficial e subsuperficial no crescimento e produção de milho, foi realizado um experimento na Universidade Técnica de Machala – Equador, 1,600 m^2 de milho híbrido (PIONEER 30K75) foram cultivados para aplicar os tratamentos: irrigação por gotejamento superficial e subsuperficial a 10, 20 e 30 cm de profundidade. A semente foi semeada em agosto de 2019 a 80 cm entre linhas e 40 cm entre plantas, duas sementes por ponto, com densidade de plantio de 62.500 plantas.ha^{-1}. O delineamento experimental foi em blocos ao acaso, com quatro tratamentos e quatro repetições. Foram avaliadas a altura da planta, biomassa fresca e seca de folhas, caule e raízes, biomassa de 100 grãos secos e rendimento de grãos secos. A maior altura de planta e biomassa de 100 grãos secos foi de 2,79 m e 39,08 g, que correspondeu ao tratamento de irrigação por gotejamento subsuperficial na profundidade de 30 cm; a maior biomassa de folhas frescas e secas, 13.631,3 kg.ha^{-1} e 3.800 kg.ha^{-1} respectivamente, assim como a maior produtividade de grãos secos 10.337,5 kg.ha^{-1} foi para o tratamento de irrigação por gotejamento subsuperficial a 20 cm de profundidade. A maior biomassa fresca e seca de caules 32.768,8 kg·ha^{-1} e 10.381,3 kg.ha^{-1} e a biomassa fresca e seca de raízes de 6.381,3 kg.ha^{-1} e 2.150 kg.ha^{-1}, corresponderam ao gotejamento superficial tratamento. Com irrigação por gotejamento, a 20 e 30 cm de profundidade, obteve-se maior crescimento e produtividade.

Palavras-chave: Biomassa de milho, irrigação por gotejamento, irrigação subsuperficial, produtividade de milho.

Introduction

Corn is one of the most important cereals in the world, due to its use in human food, animal feed, and as a raw material for industry (Coral *et al*., 2019). Corn yields have increased over time, thus in 2012 it was reported 886 million tons grown on 171.5 million hectares, and in 2017 it was 1.1 billion tons grown on 195 million hectares (FAOSTAT, 2018). According to OECD-FAO (2019), by 2028, world corn production will be 1,311 million tons, due to high planting density, technified irrigation supply, improved fertilization, and planting of improved seeds.

The country with the largest corn production is the United States of America, with approximately 32.4 % (392.45 million tons), China ranks second with 22.7 % (257.17 million tons), Brazil ranks third with 8.1 % (82.29 million tons), Argentina fourth with 4.8 % (43.46 million tons), and Ukraine fifth with 3.1 % (35.8 million tons) of global production (OECD-FAO, 2019).

In general, corn production in South America has increased with much variability in terms of yields achieved, which can be higher than 10 t.ha^{-1}, or lower than 2.12 t.ha^{-1} (Carvajal and Cepeda, 2019).

One of the countries where the crop has experienced a significant rise has been Ecuador, registering in 2020 a harvested area of 365,334 ha, yields of 4,580 kg.ha^{-1}, and a production of 1,479,700 t (FAOSTAT, 2021). It has spread throughout the territory, with hard yellow corn predominating on the coast and soft white corn in the Andean Region. Total production of hard corn was 1,304,884 t, harvested on 341,301 ha (ESPAC, 2020); production is concentrated in the coastal provinces of Los Ríos, Manabí, and Guayas with a production of 643,000, 281,000, and 248,000 t, respectively, representing 40.31 %, 28.64 %, and 16.10 % of the total cultivated area. In the province of Loja located in the Andean Region, the cultivated area represents 5.9 % (INEC, 2021; ESPAC, 2020).

There are multiple factors that have a direct and indirect influence on the morphophysiological and productive behavior of the corn crop (Bonilla and Singaña, 2019). It has been established that sustainability of production is possible with the efficient application of agricultural practices such as irrigation, without underestimating the effect of elements such as planting material, climate, soil, water, and population density, among others (Moran *et al*. (2020).

The search for alternatives that help reduce water consumption in corn production is currently having a great impact. Within these actions, localized drip irrigation becomes a viable alternative since it reduces water doses, with significant savings, while achieving greater utilization by the plant (Wittling *et al*., 2019). It has been determined that with drip irrigation, water is saved in a range of 70 % to 90 % in corn production (Bahena-Delgado *et al*. 2017). However, it has been shown that when the crop's water requirement is reduced, it can affect both the vegetative and reproductive stages, impacting morphophysiological parameters such as plant height, stalk diameter, and ear of corn insertion, as well as yield variables (Tapia *et al*., 2021).

In the previous research, with the application of 120 % of the total gross irrigation lamina calculated, equivalent to 376.31 mm, the highest yield was achieved with 13.49 t.ha^{-1}, with a water use efficiency of 8.98 kg.m^{-3} of dry corn; while when 80 % of the total gross lamina was applied, the yield decreased significantly, achieving 4.25 t.ha^{-1}, and a water use efficiency of 3.88 kg.m^{-3}, showing that a reduction in the water requirement of the corn hybrid (PIONEER 4039) can significantly reduce crop yield. The results showed that yields without water deficiency were between 13.5 and 15.3 t.ha^{-1}

approximately. Water deficiencies during the critical period of the crop produced yield losses of approximately 50 % of the potential.

Water stress at kernel filling caused yield decreases of about 30 %, and deficiencies in the vegetative stage and the critical period caused a yield decrease of 56 % (Giménez, 2012). With this background, the objective of the research was to evaluate the effect of surface and subsurface drip irrigation on growth and yield of corn.

Materials and methods

The trial was developed in the experimental field of the Santa Inés farm, Faculty of Agricultural Sciences, Technical University of Machala, located at km 5 1/2 Pasaje road, belonging to the province of El Oro, Planning Zone 7, Ecuador; between coordinates 620,000 W and 963,800 S, Geographic Zone 17 S, Universal Transverse Mercator Projection, where the alluvial plain of the Jubones river watershed ends. The climate is tropical megathermal semi-humid, at an altitude of 5 meters above sea level; the average multiannual temperature oscillates around 25 °C, while the average multiannual precipitation is around 600 mm, with two well-marked pluviometric periods, the rainy period from January to April, and the dry period from May to December. The reference potential evapotranspiration is 1,300 to 1,500 mm; the annual water deficit ranges from 225 to 925 mm (Development and Land Management Plan for the Province of El Oro, 2015). The soil texture in the first 30 cm of depth is silt loam, with a pH of 6.5 and a bulk density of 1.47 $gr.cm^{-3}$.

The plant material used was hybrid corn (PIONEER 30K75) sown in August 2019 at 80 cm between rows and 40 cm between plants, with two seeds per point, with a plant density of 62,500 plants. ha^{-1}. The last irrigation was provided at 100 days after sowing (DAS), and the analysis of the variables was performed until 110 (DAS). The experimental design was totally randomized blocks, with four treatments: 1) surface drip irrigation, 2) subsurface drip irrigation at 10 cm, 3) subsurface drip irrigation at 20 cm and 4) subsurface drip irrigation at 30 cm depth. Four replications were used. The experimental unit was a 100 m^2 plot planted with hybrid corn, totaling 16 experimental units, giving a total corn cultivated area of 1600 m^2.

Irrigation was planned to respond adequately to the water requirements of the crop. The irrigation system was designed with a 40 mm diameter PVC main pipe and a 32 mm diameter polyethylene secondary pipe. The irrigation laterals were 16 mm diameter irrigation tape with self-compensating drippers inserted at 50 cm (Hydrodrip Super Flat Integral Dripline, PLASTRO) with a flow rate of 1.65 $L.h^{-1}$ and a working pressure of 10 meters of the water column. The design flow rate was 1.76 $L.s^{-1}$. The energy provided for the operation of the irrigation systems was through an electric motor pump supplied from an underground well.

The irrigation supply was independent for each treatment, through control valves; the volume supplied was recorded by volumetric valves; the frequencies and times of irrigation were determined by the reading of the tensiometers installed at a depth of 20 cm since the greatest volume of roots is found at this depth. To evaluate the growth and yield variables, 10 plants were selected per experimental unit (40 plants per treatment), for a total of 160 plants. The variables were: 1) plant height (m), 2) fresh and dry biomass of leaves, stalks and roots, 3) biomass of 100 dry kernels, and 4) dry kernel yield.

For plant height, recording began 30 days after sowing with an interval of 10 days until 100 days after sowing. To determine the fresh biomass of leaves, stalks, and roots, a precision balance (Memmert, Model: V-10801065-800699) was used; subsequently, they were placed in an oven at 60 °C for 72 hours; after 12 days of drying, the dry biomass of each selected plant was recorded. For the dry kernel biomass, the selected ears were collected, whose moisture content was approximately 25 %, then they were dried in the oven at 60 °C for 72 hours; subsequently, the shelling was performed manually and taken to the laboratory to determine the moisture content at 13 %, and record the biomass of the dry kernels. The dry kernel yield at 13 % moisture was estimated through the biomass of the dry kernel per plant.

Results and discussion

From 30 to 100 DAS plant height was affected by irrigation treatments, with significant statistical differences ($p < 0.002$). Drip irrigation at 20 and 30 cm depth was statistically different compared to surface and subsurface drip irrigation at 10 cm depth. When comparing the results of the subsurface drip irrigation treatments at 20 and 30 cm depth, there were no significant differences in terms of plant growth, as in the application of the irrigation lamina (Table 1).

The greatest length range was observed between 40 and 60 DAS in all treatments, stabilizing at 70 dds, when the plant stopped growing. The results indicated that the subsurface drip irrigation treatment at 30 cm depth recorded the greatest length (0.58 and 2.79 m at 30 and 70 DAS, respectively), where 129.2 mm of irrigation lamina was applied; while the surface drip irrigation treatment recorded the lowest height (0.52 and 2.66 m at 30 and 70 DAS, respectively), where 152 mm of irrigation lamina was applied (table 1).

Table 1. Plant height (m) and irrigation lamina applied (mm) in corn crop (*Zea mays* L.) irrigated with surface and subsurface drip irrigation at 10, 20, and 30 cm depth.

	Plant height (m)							
	Days after sowing							
Drip irrigation treatment	30	40	50	60	70	80	90	100
Surface	0.52 b	1.07 b	1.73 b	2.35 b	2.66 b	2.66 b	2.66 b	2.66 b
Subsurface 10 cm depth	0.57 a	1.07 b	1.73 b	2.34 b	2.70 b	2.70 b	2.70 b	2.70 b
Subsurface 20 cm depth	0.60 a	1.15 a	1.85 a	2.39 b	2.78 a	2.78 a	2.78 a	2.78 a
Subsurface 30 cm depth	0.58 a	1.16 a	1.87 a	2.56 a	2.79 a	2.79 a	2.79 a	2.79 a
	Accumulated applied irrigation lamina (mm)							
Surface	36.9 a	54.8 a	75.4 a	97.3 a	113.5 a	123.7 a	138.8 a	152.0 a
Subsurface 20 cm depth	39.2 a	52.9 b	68.1 b	83.2 b	96.9 b	109.1 b	120.7 b	130.4 b
Subsurface 30 cm depth	38.1 a	51.0 b	66.4 b	82.2 b	95.1 b	105.9 b	117.6 b	129.2 b

Different letters within each column indicate that there were statistical differences according to Tukey's multiple means test ($p < 0.05$) due to the effect of the treatments applied.

Alvarez and Alvarez (2018), and Uzátegui (2019) in relation to the growth of corn plants, reported that these reached a maximum height of 2.59 m which was lower than that obtained in this research.

Likewise, Campuzano *et al*. (2014) indicated averages in eight hybrid varieties, whose values ranged between 1.85 and 2.01 m of plant height, which was also lower than those indicated in this study.

Likewise, Tapia *et al*. (2021), when evaluating the effect of different irrigation laminas and plant densities, determined significant differences between the variables evaluated. Plants that received 120 % of the gross lamina, reached an average height of 243.11 cm, lower than the one obtained in this study.

Rodriguez *et al.* (2016) indicated a maximum growth of 2.36 m at 60 DAS. In contrast, in this research the maximum height of the plants was presented at 70 dds; this suggests that at this stage, in which the development of the reproductive structures begins, the corn plant decreased or stopped its growth, to concentrate its photoassimilates to the production of its fruits.

While Hidalgo (2012) found a maximum plant height of hybrid corn of 2.68 m, planted at 90 x 40 cm, values closer to those obtained in this research.

Regarding the production of biomass of leaves, although no statistical differences were detected between treatments, the subsurface drip irrigation at 20 cm depth recorded the highest yield, corresponding to 218.1 $g.plant^{-1}$ (13,631 $kg.ha^{-1}$) of fresh biomass, equivalent to 1,362.8 $g.m^{-2}$; while the dry biomass was 60.8 $g.plant^{-1}$ (3,800 $t.ha^{-1}$), equivalent to 380 $g.m^{-2}$. The lowest yield was for the subsurface drip irrigation treatment at 10 cm depth, which reached 201.9 $g.plant^{-1}$ (12,619 $kg.ha^{-1}$ of fresh leaf) equivalent to 1,262 $g.m^{-2}$, while the dry biomass was 57.1 $g.plant^{-1}$ (3,569 $kg.ha^{-1}$) equivalent to 357 $g.m^{-2}$.

Regarding water use efficiency, it should be noted that subsurface drip irrigation can avoid excessive water consumption by reducing soil evaporation losses. The water that is found in the superficial part of the soil and that is evaporated by solar radiation has been called “non-beneficial consumption for the plant” (Ayars *et al*., 2015; Eranki *et al*., 2017; Sinha *et al*., 2017; Bringas *et al*., 2020).

The efficiency of water use in the biomass yield of leaves, the results show that the highest efficiency was for the subsurface drip irrigation treatment at 20 cm depth, with 10.5 $kg.m^{-3}$, being numerically equal to that achieved with irrigation at 30 cm; the lowest efficiency of water use was for the surface drip irrigation treatment with 8.8 $kg.m^{-3}$, showing no differences with subsurface irrigation at 10 cm (table 2).

The results obtained for dry biomass of leaves were much higher than those determined by Uzátegui (2019), who obtained yields of 50.3 $g.plant^{-1}$. Similarly, Rodríguez *et al.* (2016) reported fresh biomass yields of leaves between 150 and 206 $g.plant^{-1}$. While Espósito *et al* (2007) in dry-farmed corn, obtained dry biomass yields of leaves of 250.17 $g.m^{-2}$ with a plant density of 72,000 $seeds.ha^{-1}$.

The results corresponding to stalk biomass including ears, the surface drip irrigation treatment recorded the highest yield with 524.3 $g.plant^{-1}$ (32,768.8 $kg.ha^{-1}$) of fresh biomass, equivalent to 3,146 $g.m^{-2}$, with no statistical differences between treatments; while the dry biomass was 166.1 $g.plant^{-1}$ (10,381.3 $kg.ha^{-1}$), equivalent to 1,038 $g.m^{-2}$. The lowest value was for the subsurface drip irrigation treatment at 10 cm depth, which obtained 458.4 $g.plant^{-1}$ (28,650 $kg.ha^{-1}$) of fresh biomass, equivalent to 2,865 $g.m^{-2}$; dry biomass was 142.2 $g.plant^{-1}$ (8,887.5 $kg.ha^{-1}$), equivalent to 889 $g.m^{-2}$ (table 3).

Table 2. Fresh and dry biomass of leaves, volume of water applied, and water use efficiency in corn crop (*Zea mays* L.) irrigated with surface and subsurface drip irrigation at 10, 20, and 30 cm depth.

Drip irrigation treatment	Fresh biomass of leaves ($kg.ha^{-1}$)	Dry biomass of leaves ($kg.ha^{-1}$)	Volume of water applied ($m^3.ha^{-1}$)	Water use efficiency (fresh biomass $kg.m^{-3}$)	Water use efficiency (Dry biomass $kg.m^{-3}$)
Surface	13,431.3 a	3,606.3 a	1,519.3 a	8.8 b	2.4 b
Subsurface 10 cm depth	12,618.8 a	3,568.8 a	1,392.3 b	9.1 b	2.6 b
Subsurface 20 cm depth	13,631.3 a	3,800.0 a	1,303.5 b	10.5 a	2.9 a
Subsurface 30 cm depth	13,568.8 a	3,787.5 a	1,291.8 b	10.5 a	2.9 a

Different letters within each column indicate that there were statistical differences according to Tukey’s multiple means test ($p < 0.05$) due to the effect of the treatments applied.

Table 3. Fresh and dry biomass of stalks, volume of water applied, and water use efficiency in corn crop (*Zea mays* L.) irrigated with surface and subsurface drip irrigation at 10, 20, and 30 cm depth.

Drip irrigation system	Fresh biomass of stalks ($kg.ha^{-1}$)	Dry biomass of stalks ($kg.ha^{-1}$)	Volume of water applied ($m^3.ha^{-1}$)	Water use efficiency (fresh biomass $kg.m^{-3}$)	Water use efficiency (dry biomass $kg.m^{-3}$)
Surface	32,768.8 a	10,381.3 a	1519.3 a	21.6 b	6.8 b
Subsurface 10 cm depth	28,650.0 a	8,887.5 a	1392.3 b	20.6 b	6.4 b
Subsurface 20 cm depth	31,775.0 a	10,018.8 a	1303.5 b	24.4 a	7.7 a
Subsurface 30 cm depth	30,162.5 a	9,356.25 a	1291.8 b	23.4 a	7.2 a

Different letters within each column indicate that there were statistical differences according to Tukey’s multiple means test ($p < 0.05$) due to the effect of the treatments applied.

Regarding water use efficiency in biomass yield of stalks, the results showed that the highest water use efficiency was for the subsurface drip irrigation treatment at 20 cm depth with 24.4 kg.m^{-3} for fresh biomass, and 7.7 kg.m^{-3} for dry biomass, with no differences with the subsurface treatment at 30 cm; the lowest water use efficiency was for the subsurface drip irrigation treatment at 10 cm depth with 20.6 kg.m^{-3} for fresh biomass and 6.4 kg.m^{-3} for dry biomass, not differing from the surface irrigation treatment (table 3).

These results were higher than those obtained by Uzátegui (2019), who reported values of 79.8 g.plant^{-1} of dry biomass of stalks. Likewise, in trials conducted in the province of Santa Elena-Ecuador by Tumbaco (2019), results of fresh biomass of stalks of 28,200 kg.ha^{-1} were obtained.

The results showed that the water use efficiency in the biomass yield of stalks and the subsurface drip irrigation treatment at 20 cm were the most efficient due to the lower water consumption.

Regarding root biomass, although there were no differences between treatments, the highest yield was for the surface drip irrigation treatment with 102.1 g.plant^{-1} (6,381 kg.ha^{-1}) of fresh biomass, representing 638 g.m^{-2}; while the dry biomass was 34.4 g-plant^{-1} (2,150 kg.ha^{-1}), equivalent to 215 g.m^{-2}. The lowest yield was for the subsurface drip irrigation treatment at 10 cm depth with 86.1 g.plant^{-1} (5,381.3 kg.ha^{-1}) of fresh mass, equivalent to 538 g.m^{-2}; while dry biomass was 27.5 g.plant^{-1} (1,718.8 kg.ha^{-1}), equivalent to 172 g.m^{-2} (table 4).

The highest efficiency was for the subsurface drip irrigation treatment at 30 cm depth, with 4.5 kg.m^{-3} for fresh biomass, and 1.6 kg.m^{-3} for dry biomass, showing no differences with subsurface irrigation at 20 cm and with surface irrigation; the lowest water use efficiency was for the subsurface drip irrigation treatment at 10 cm depth with 3.9 kg.m^{-3} for fresh biomass and 1.2 kg.m^{-3} for dry biomass (table 4).

In trials conducted by Delgado *et al.* (2008), values between 30 and 35 g.plant^{-1} of dry root biomass were obtained 75 days after sowing, resulting different from those obtained in this research. While for the variable biomass of 100 dry kernels, no statistical differences were generated between treatments, the highest yield was for the subsurface drip irrigation treatment at 30 cm depth with a value of 39.1 g.100 kernels^{-1}, and the lowest was for the subsurface drip irrigation treatment at 10 cm depth, whose yield was 37.2 g.100 kernels^{-1} (table 5).

Regarding yield of the dry kernel when comparing the results of the surface and subsurface drip irrigation treatments at 10 cm depth with the results of the subsurface drip irrigation treatments at 20 and 30 cm depth, significant differences were found. The subsurface drip irrigation treatment at 20 cm depth obtained the highest yield 165.4 g.plant^{-1} (10,337.5 kg.ha^{-1}) not differing from the treatment at 30 cm depth; the lowest yield was for the subsurface drip irrigation treatment at 10 cm depth of 147.7 g.plant^{-1} (9,232.8 kg.ha^{-1}), showing no differences with surface irrigation (table 6).

Table 4. Fresh and dry root biomass, volume of water applied, and water use efficiency in corn crop (*Zea mays* L.) irrigated with surface and subsurface drip irrigation at 10, 20, and 30 cm depth.

Drip irrigation system	Fresh root biomass (kg.ha^{-1})	Dry root biomass (kg.ha^{-1})	Volume of water applied (m^3.ha^{-1})	Water use efficiency (fresh biomass kg.m^{-3})	Water use efficiency (dry biomass kg.m^{-3})
Surface	6.381,3 a	2.150,0 a	1.519,3 a	4.2 a	1.4 a
Subsurface 10 cm depth	5.381,3 a	1.718,8 a	1.392,3 b	3.9 b	1.2 a
Subsurface 20 cm depth	5.725,0 a	1.856,3 a	1.303,5 b	4.4 a	1.4 a
Subsurface 30 cm depth	5.781,3 a	2.025,0 a	1.291,8 b	4.5 a	1.6 a

Different letters within each column indicate that there were statistical differences according to Tukey's multiple means test ($p < 0.05$) due to the effect of the treatments applied.

Table 5. Biomass of 100 dry corn kernels.

Drip irrigation treatment	Weight of 100 dry kernels (g)
Surface	38.2 a
Subsurface at 10 cm depth	37.2 a
Subsurface at 20 cm depth	38.4 a
Subsurface at 30 cm depth	39.1 a

Table 6. Yield of dry corn kernel, volume of water applied, and water use efficiency.

Drip irrigation treatment	Yield (kg.ha^{-1})	Volume of water applied (m^3)	Water use efficiency (kg.m^{-3})
Surface	9,259.4 b	1519.25 a	6.10 b
Subsurface 10 cm depth	9,232.8 b	1392.25 b	6.63 b
Subsurface 20 cm depth	10,337.5 a	1303.5 b	7.95 a
Subsurface 30 cm depth	10,189.1 a	1291.75 b	7.89 a

Regarding water use efficiency in yield of the dry kernel, the highest efficiency corresponded to the subsurface drip irrigation treatment at 20 cm depth with 7.95 $kg.m^{-3}$, but did not differ from irrigation at 30 cm depth; the lowest water use efficiency was for the surface drip irrigation treatment at 10 cm depth with 6.10 $kg\text{-}m^{-3}$, showing no differences with surface irrigation (Table 6).

The highest yield of the dry kernel and water use efficiency obtained with subsurface irrigation is explained by the lowest N loss due to evaporation and drainage compared to surface irrigation (Lamm *et al*., 2001).

With subsurface drip irrigation technology in Quevedo-Ecuador, yields of 10,720 $kg.ha^{-1}$ were obtained (Vásconez *et al*., 2010); also Álvarez and Álvarez (2018) reported yields of corn kernel of 7,050 $kg.ha^{-1}$ in the Joa valley, province of Manabí-Ecuador.

In the research carried out by Tapia *et al*. (2021) the yield variable presented a significant effect according to the percentages of the gross lamina evaluated; with the application of 120 % of the gross lamina, the highest yield was obtained with 10.44 $t.ha^{-1}$ with a difference of 4.81 $t.ha^{-1}$ compared when 80 % of the total lamina was applied.

Conclusions

When irrigation was delivered subsurface at 20 and 30 cm depth, greater plant growth and higher biomass yield of leaves, stalks, and kernel were obtained, while when irrigation was delivered superficially, greater root biomass was obtained. The efficiency in the use of water employed for irrigation in the corn crop for the production of leaves, stalks, and kernel, is greater when irrigation is supplied in the subsurface part of the soil, where the largest volume of roots of the plant is found, maximizing the water applied and consumed.

Recommendations

In the case of hybrid corn, drippers should be buried at 20 cm depth, at which in this work a better water use efficiency was found**.**

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