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RESEARCH ARTICLE

The Response of Two Drip-Irrigated Sweet Corn Varieties to the Twin-Row Production System in the Dry Mediterranean Region

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Abstract:

Introduction:

Minimizing production costs for drip-irrigated crops by reducing the number of driplines per unit-area is an urgent need to address the sustainability of the present production system.

Materials and Methods:

A two-year field experiment (2017 and 2018) was carried out to assess the effects of twin-row crop production system on two sweet corn varieties (*Zea mays* L.: an introduced variety “Silver Queen” and a local variety “White Kokab”) grown in a clay loam soil in the dry Mediterranean region. Three-row crop/dripline spacing configurations for each variety with three replicates were tested as: (i) single-row system at 75-cm crop row spacing with 75-cm dripline spacing (a dripline for each crop row), (ii) single-row system at 75-cm crop row spacing with 150-cm dripline spacing (a dripline for two crop rows), and (iii) twin-row system, 37.5 cm apart, on 150-cm centers, with 150-cm dripline spacing (a dripline for each twin-rows).

Results and Conclusion:

The local variety was better than the introduced variety in husked cop yield (13.93 t ha^{-1}) and irrigation water use efficiency (IWUE, 1.92 kg m^{-3}). Results also showed that the twin-row system with 150-cm dripline spacing provided similar husked cop yield and IWUE as the conventional 75-cm dripline spacing due to the more favourable rootzone soil water status; and both were higher in the two attributes than the single-row 150-cm dripline spacing. With 50% less unit-area driplines, twin-rows with 150-cm dripline spacing was considered to be more productive, economical and environmentally friendly.

Keywords: Clay loam soil, Husked cop yield, Irrigation water use efficiency, Single-row system, Sweet corn, Twin-row system.

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1. INTRODUCTION

Sweet corn (*Zea mays* L.) is a popular crop in many countries. Fresh consumption by boiling or grilling is quickly increasing worldwide. Large husked cops of sweet corn are preferred in the market. Furthermore, vegetative parts (stalks and leaves) are used to feed animals. Its growing popularity increases local and international demand. Due to its high profitability, sweet corn represents one of the most economical crops for the local farmers. However, fficient water use represents an urgent need to meet the sustainability of corn productivity due to the water shortage in the dry Mediterranean area.

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Drip irrigation is an efficient method to save water, enhance yield, and yield quality, compared with sprinkle and surface irrigation methods [1, 2]. Unfortunately, its high initial costs represent one of the biggest constraints to the widespread adoption of drip irrigation.

The cost of driplines (laterals) is a large fraction of initial investment costs. According to Bozkurt *et al*. [3], it represents about 45% of the total costs. In this situation, using one dripline for two crop rows instead of for one row would half the number of driplines per unit-area, and consequently, would decrease the initial costs [3 - 9]. However, increasing the distance between driplines may need excessive preplant irrigation or using another system for proper seed germination [4, 10, 11]. Moreover, mean crop yield may reduce as dripline spacings increase due to low yields of plant rows located away from driplines [3, 12 - 14]. This could be worse in soils in which gravity forces control soil water distribution more than capillary forces, as in coarser soils [15], or large-crack soils as in high clay-content soils [10].

Twin-row production systems (paired-rows) have been adopted as a means to increase yields compared to single-row system [16 - 19]. Twin-rows would be one of the most significant factors in controlling the yield reduction when using wider lateral spacing. Considering this fact, it is necessary to provide supportive data for the adoption of twin-row production system, especially in the dry Eastern Mediterranean region where water is very scarce and valuable.

In this context, this study aimed to compare the effects of both single- and twin-row production systems with two different dripline spacings (75 and 150 cm) on two drip-irrigated corn varieties grown in clay loam soil under the dry Mediterranean climatic conditions. Cop characteristics, yields, and irrigation water use efficiency were evaluated and discussed. Practical alternatives could be introduced based on the obtained results in order to make twin-row production system familiar for most farmers and to stimulate them to adopt it in their fields, to sustain corn productivity and to meet water shortage in the dry Mediterranean region.

2. MATERIALS AND METHODS

A two-year field experiment (2017 and 2018) was carried out at the Agricultural Experiment Station, Damascus, Syria (36°26′ E, 33°20′ N, altitude 600 m). The study area is dominated by a dry Mediterranean climate type with an average precipitation of about 120 mm year^{-1} and reference evapotranspiration (ET) as calculated by FAO Penman-Monteith equation exceeds 2000 mm year^{-1}. The meteorological data of the study site, collected during both growing seasons could be summarized overall as being near the 20-year average, as can be seen in Table **1**.

The soil texture was clay loam with 29.5% clay, 42.7% silt, and 27.8% sand. Before sowing, topsoil characterstics were: bulk density of 1.35 g cm^{-3}, pH of 8.0, EC of 0.6 dS m^{-1}, <1% of organic matter, available P of 22.0 ppm, NH_4^+ of 14.7 ppm, and NO_3^- of 21.1 ppm.

Field experiment composed of two sweet corn varieties: Silver Queen (var.1) and a local variety "White Kokab" (var.2). Under each variety, two different dripline spacings (75 and 150 cm) with two different crop row production systems with the same plant density (about 67,000 plants ha^{-1}) were studied. Experiments were arranged in a split-plot design involving two corn varieties (var.1 and var.2) as main-plot treatments and three combinations of crop row and dripline spacings, with three replicates. The main-plot size was 34×12 m^2, while the size of the sub-plot differed according to the tested dripline spacing. As can be seen in Fig. (**1**), combinations were composed of:

- S-75: A single-row production system was used with 75-cm crop rows (*i.e.*, 75 cm between crop rows). One dripline was used for each crop row. Therefore, the dripline spacing was 75 cm.

- S-150: A single-row production system was used with 75-cm crop rows (*i.e.*, 75 cm between crop rows). One dripline was used for two crop rows. Therefore, the dripline spacing was 150 cm.

- TS-150: A twin-row production system was used. Corn was planted in paired rows, 37.5 cm apart, on 150 cm centers. Each strip of twin-rows was served by one dripline. Therefore, the dripline spacing was 150 cm.

In both S-75 and S-150, a single-row production system was used, *i.e.*, conventional plant row widths, in which corn was sown with a regular row spacing of 75 cm and spaced 20 cm apart within row. While in TS-150, a twin-row production system was used, so that crop rows were brought closer (37.5 cm) and grouped into strips (ranges or bands) with twin-rows. Thus, the plant density and the number of crop rows in unit-area were maintained equal in the three treatments.

Before sowing day, field soil was disked and ploughed to a depth of about 35 cm. A sufficient interdistance (about 2 m) was maintained between experimental plots. Corn was sown on 18thApril 2017 and 3rd April 2018. Due to the lack of precipitation during the early stages in both cropping seasons, another lateral move irrigation system, available on the station, was utilized two times to apply 100 mm in order to properly germinate the seeds and to well establish plants. After that, the drip irrigation treatments were started on one month after sowing as planned, using dripline tubes of 16-mm diameter with built-in emitters spaced at 40 cm with a nominal flow rate of 4 litre hr^{-1} (*i.e.*, 10 litre hr^{-1} m^{-1}). For each growing season, a quantity of 46.0 kg ha^{-1} of P_2O_5 as triple superphosphate was added to the study field in early winter. Moreover, urea (N: 46%) was used as a source of N-fertilizer. A quantity of 150 kg N ha^{-1} was applied in two equally split applications: at sowing and about two weeks later. Thus, all crop rows received the same quantities of fertilizers.

The durations of growth stages, *i.e.*, the initial development, mid-season and late-season growth stages were 20, 30, 40, and 10 days long, respectively. Related crop coefficient values (Kc) for sweet corn crop were 0.3, 1.15, and 1.05 for initial, mid-season and late-season growth stages, respectively, as acquired from FAO databases [20]. Daily crop water requirement (daily crop evapotranspiration, ETc), was estimated as the product of multiplying the daily ET by Kc. Weekly crop water requirement, *i.e.*, the weekly sum of daily ETc values was used to adjust the schedule for the following week. Water depth applied in each irrigation event was equal for all treatments. However, treatments differed in terms of irrigation durations, due to the different dripline spacings. Thus, the amount of irrigation water per unit-area was equal among treatments. Each treatment was given about 753 and 700 mm in 2017 and 2018, respectively, as a total irrigation water depth. The drip irrigation durations applied to S-75, S-150, and TS-150 were 49, 98, and 98 hr in 2017, and 45, 90, and 90 hr in 2018, respectively.

Using *in-situ*-calibrated neutron probe technique (NP), rootzone soil humidity was measured on a weekly basis in plots of "Silver Queen" variety each cropping season. The measurements were conducted about 72 hr after each drip irrigation event. Neutron probe access tubes were inserted into rootzone under plant stems. As can be seen in Fig. (**1**), one soil profile was probed in each treatment. The total amount of water which is stored in the rootzone soil profile represents the total soil water storage (SWS), as can be estimated by the following equation:

$$SWS = \int_{0}^{Zm} \theta(z)\ dz \qquad \textbf{(1)}$$

where z is the soil depth (m), Zm is the root zone depth (=1.2 m), and θ is the soil water content (cm^3 cm^{-3}).

Variations in time of soil water storages for the three irrigation treatments were jointly plotted as can be seen in Fig. (**2**). The water stress response function as described by Feddes *et al.* [21] was used in order to determine if the rootzone was exposed to water stress or not. Water uptake is considered maximum when soil pressure head (h) ranged between two values h_2 and h_3. However, it decreases when h ranged between h_3 and h_4. Water uptake becomes zero when $h<h_4$ (the wilting point pressure head). For sweet corn grown in clay loam soil, soil water content (θ) which corresponded to h_2, h_3, and h_4 were 44.5, 23.2, and 13.6 cm^3 cm^{-3}, respectively, according to Feddes *et al.* [21]. Soil water storages at these root water uptake parameters were also plotted (Fig. **2**).

For fresh marketable products, the harvest was conducted at the milky stage when the water content of seeds was 70-75%. This was after 100 days after sowing for both tested varieties and both growing seasons. A 2m row length, *i.e.*, 10 plants from the center of each plot were selected. Corn cobs from selected plants were hand harvested and husked. Well-filled cobs were considered a marketable product, according to the familiar corn-farming practices in the study area. Weight, length, and diameter of husked cobs were measured. To determine dry matter yield, aboveground vegetative parts of selected plants were also collected and oven-dried at 70°C until constant weight. Cob yield and dry matter were expressed into unit-area yields as t ha^{-1}. Irrigation water use efficiency (IWUE, kg m^{-3}) was estimated by dividing yield by the water volume of irrigation (m^3). Both values of IWUE for husked cob yield (IWUE$_{hc}$) and dry matter (IWUE$_{dm}$) were estimated.

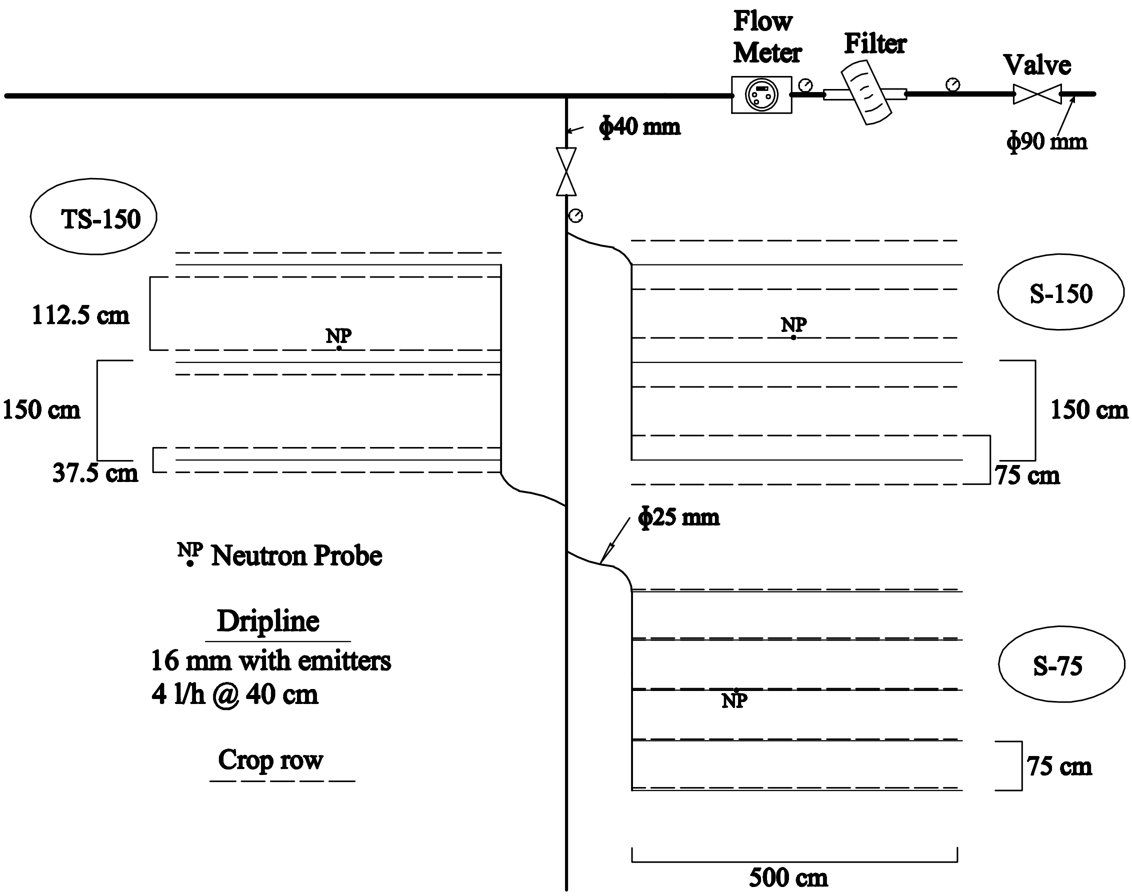

Fig. (1). Outline of a replicate according to crop row/dripline spacing configurations.

Table 1. Some meteorological variables for the study station during both growing seasons (2017 and 2018), and the average of last twenty years.

Climate Parameter	Year/Month	Apr.	May	Jun.	Jul.
Minimum temperature (C)	**2017**	9.7	14.4	17.2	20.6
	2018	10.0	15.6	18.2	19.8
	20-year average	10.1	14.1	17.6	19.3
Maximum temperature (C)	**2017**	26.2	31.6	35.7	40.6
	2018	27.2	31.5	34.6	36.9
	20-year average	25.3	30.4	35.0	37.4
Mean temperature (C)	**2017**	19.2	24.9	28.4	31.1
	2018	19.9	25.7	27.7	28.8
	20-year average	18.1	23.6	27.7	29.4
Relative air humidity (%)	**2017**	63.1	57.9	56.3	56.0
	2018	54.8	51.5	59.6	55.6
	20-year average	60.9	56.5	56.3	60.7
Reference evapotranspiration, ET (mm)	**2017**	5.7	7.6	9.0	10.3
	2018	6.8	7.8	8.8	10.3
	20-year average	5.6	7.5	9.4	10.4
Precipitation (mm)	**2017**	0.0	0.0	0.0	0.0
	2018	14	0.0	0.0	0.0
	20-year average	5.9	4.2	0.0	0.0

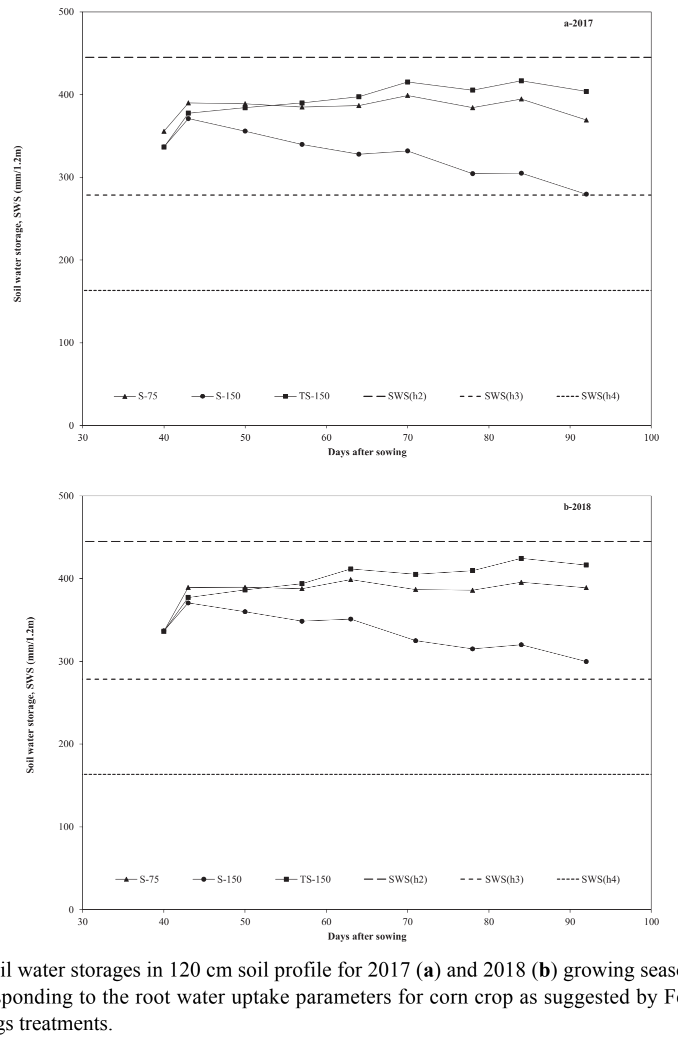

Fig. (2). Changes over time in soil water storages in 120 cm soil profile for 2017 (**a**) and 2018 (**b**) growing seasons. Dashed lines represent soil water storages at h2, h3, and h4 corresponding to the root water uptake parameters for corn crop as suggested by Feddes *et al*. (1978). S-75, S-150, and TS-150 represent dripline spacings treatments.

Table 2. Mean comparisons of crop responses as influenced by crop row/dripline spacing and corn variety.

Tested Factor	Husked cob Length (cm)	Husked cob Diameter (cm)	Husked cob Weight (g)	Dry Matter Yield (t ha^{-1})	Husked cob Yield (t ha^{-1})	IWUE$_{dm}$ (kg m^{-3})	IWUE$_{hc}$ (kg m^{-3})
Crop row/ dripline spacing							
S-75 (1:1)	18.8 a	4.8 a	251.0 a	8.28 a	14.31 a	1.14 a	1.97 a
S-150 (1:2)	17.5 b	4.8 a	209.6 b	8.09 a	11.95 b	1.11 a	1.65 b
TS-150 (1:2)	18.7 a	4.9 a	247.2 a	8.95 a	14.09 a	1.23 a	1.94 a
LSD$_{0.05}$	0.8	0.2	19.2	0.95	1.09	0.13	0.15
Variety							
Var. 1	18.3 a	4.9 a	227.6 b	8.31 a	12.97 b	1.15 a	1.79 b
Var. 2	18.4 a	4.8 a	244.3 a	8.56 a	13.93 a	1.18 a	1.92 a
LSD$_{0.05}$	0.7	0.2	15.7	0.77	0.89	0.11	0.12

In each column and each tested factor, means followed by different letters are significantly different according to LSD test at 5% level.
IWUE$_{dm}$ = irrigation water use efficiency for dry matter, and IWUE$_{hc}$ = irrigation water use efficiency for husked cob yield.

The measured traits were submitted to the Analysis of Variance (ANOVA) using the DSAASTAT add-in version 2011 [22]. According to Gomez and Gomez [23], a combined analysis of data over both growing seasons was performed to identify treatment whose mean effect over the years is stable and high. A comparison of treatment means was conducted using the LSD-test (Least Significant Difference Test) at the 5% level of significance.

3. RESULTS AND DISCUSSION

3.1. Husked Cop Characteristics

No significant interactions between year and treatment, nor between variety and crop row/dripline spacings were detected by ANOVA (p>0.05). Thus, the effects of studied factors on the measured features were displayed as the averages of both tested growing seasons (Table **2**).

Regarding husked cob size, the S-75 treatment produced cobs significantly longer by about 8% than those in S-150. The length of the husked cob was enhanced when using the twin-row system with 150-cm dripline spacing so that no significant difference was recorded between S-75 and TS-150 (Table **2**). The mean values of husked cob diameter ranged from 4.8 to 4.9 cm, with no significant differences among treatments (Table **2**). However, the local variety “White Kokab” produced cobs significantly heavier (244.3 g cob^{-1}) than the introduced variety “Silver Queen” (227.6 g cob^{-1}). Also, the S-75 treatment produced cobs significantly heavier by about 20% than those of S-150. When using 150-cm dripline spacing under twin-rows, the mean weight of the husked cob was augmented. No significant difference was observed between S-75 and TS-150 (Table **2**). Similar findings were reported by previous studies. Bozkurt *et al.* [3] found no significant impacts of different dripline spacings on cob length. Al-hurmuzi and Topak [9] found no significant difference between two dripline spacings of 70 and 140 cm in terms of husked cob weight and length. However, they found that 70cm spacing produced larger cobs in terms of husked cob diameter relative to the 140cm spacing, even under a twin-row cropping system.

3.2. Yields And Irrigation Water Use Efficiency

Regarding dry matter yield, no significant differences were found between both varieties, nor between dripline spacings, at the 5% level. Although nonsignificant, the 150cm dripline spacing under the twin-row system produced dry matter yields about 10% more than the other irrigation treatments (Table **2**).

As well, mean husked cop yields were found to be changed significantly among treatments (Table **2**). The highest yield was found under the White Kokab variety (13.93 t ha^{-1}) compared with the Silver Queen variety (12.97 t ha^{-1}), whatever the crop row/dripline spacings. On the other hand, the mean value of yield in S-150 was reduced by about 16% compared with that from the conventional 75cm spacing (Table **2**). This indicated that yield significantly decreased as dripline spacing increased under the single-row production system. However, results showed that the yield of S-75 treatment (14.31 t ha^{-1}) did not significantly differ from that of TS-150 (14.09 t ha^{-1}). Thus, the yield was considerably enhanced when changing to twin-row systems with 150cm dripline spacing. This is in agreement with the results of Al-hurmuzi and Topak [9] who recorded significant differences between 70 and 140cm dripline spacings. They found that the highest fresh cob yield (19.64 t ha^{-1}) was obtained from the 70cm spacing. However, no significant differences in fresh cob yields of single-row and twin-row systems were found under the 140cm dripline spacing.

As mentioned above, all treatments received the same irrigation water depth and varied in terms of irrigation duration. For Irrigation Water Use Efficiency for dry matter (IWUE$_{dm}$), no significant differences were recorded between both varieties, nor between crop row/dripline spacings (Table **2**). While irrigation water use efficiency for economic yield (IWUE$_{hc}$) significantly decreased as dripline spacing increased under single-rows. The highest value was observed under S-75 (1.97 kg m^{-3}). However, IWUE$_{hc}$ under 150-cm spacing with crop rows being brought closer in twin-rows (TS-150) was comparable to that of S-75 (Table **2**).

In both growing seasons, Soil Water Storages (SWS) varied over time but remained within the range of optimal root water uptake, *i.e.*, between SWS(h_2) and SWS(h_3) (Fig. **2**). This signified that corn crop was not subjected to water stress throughout the whole cropping season. However, increasing dripline spacing to 150 cm under single-rows (S-150) resulted in a somewhat heavy depletion of soil water storages in both years. The mean over time in soil water storage decreased by about 20% by S-150 treatment relative to that of S-75. While using 150cm spacing under twin-rows (TS-150) maintained SWS at a high and fairly steady level, as well as the conventional 75cm dripline spacing (Fig. **2**).

The improvements in both yield and $IWUE_{hc}$ obtained with the twin-row system may be explained by the enhancements in root zone water status. Relative to the location of dripline, crop rows were placed at 37.5 under single-rows in S-150 and at 18.75 cm under twin-rows in TS-150. The closer proximity of the crop row to the dripline could be more important in stimulating root growth than wider spacing [24]. Besides, the use of twin-rows accelerated the canopy closure, reducing weeds, and therefore, the competition during the earlier stages, mitigating the severity of the wetting-drying cycle between two consecutive irrigations and losing less water through evaporation. Moreover, this more favorable soil water condition under twin-row design may stimulate plants to consume more nutrients. In addition, light interception increased when plants were brought closer than wide-row spacing, resulting in additional increases in yields. These findings are in agreement with previous studies [25 - 28]. Our results showed no yield advantage to twin-row design over the traditional 75cm spacing. This agreed well with other published findings. During a 3-year study, Buehring *et al.* [29] did not find any corn yield advantage in twin-rows grown on about 96cm centers over single-rows. Nafziger [30] found that twin-row design had higher light interception than 75cm row system during vegetative growth, but by an early reproductive stage light interception in the 75cm rows had caught up; and reported that the early advantage did not outcome in an increased light interception during grain fill or, consequently, higher yield. However, Ebelhar and Clark [31] found that twin-row yields on 100cm centers were more positive.

3.3. Economic And Environmental Considerations

A partial budget analysis should have been carried out to compare the studied treatments economically. Unfortunately, there is no accurate data on product prices in the local market due to the huge daily fluctuation of the exchange rate, because of the predominant conditions in Syria. However, a limited data could be provided based on the prices of today (Dec. 2019). The local price of sweet corn is about 100 USD per tonne. The cost of dripline plus the cost of its laying out on the field is about 0.15 USD per meter. The 75cm spacing provided about 2.36 t ha^{-1} more than the 150cm spacing under single-rows. This means an additional profit of 236 USD per hectare. However, the 150-cm spacing provided 50% less driplines, saving about 1000 USD per hectare. Hence, the reduction in crop yield did not justify the extra cost of a closer dripline spacing. This in agreement with other published findings [5, 9, 13, 16, 32, 33].

For environmental considerations, only 3-5% of irrigation water amounts were percolated under a soil depth of 150 cm, according to a simulation study using Hydrus2D program conducted on tested irrigation treatments (data not shown). Moreover, reducing the quantity of needed driplines by two times leads to a decrease in the number of related plastic fittings and the main pipeline size. This could reflect the number of whole plastic materials used per hectare to be also reduced by about two times, and thus reducing the harmful environmental effects resulting from damaged plastic network components. With no significant differences in yields and $IWUE_{hc}$ between S-75 and TS-150, using 150-cm dripline spacing under twin-rows is appropriate for the environmental protection, and brings a cost advantage, and therefore, beneficial for corn crop production.

CONCLUSION

The local variety “White Kokab” was better than the introduced variety in husked crop yield and Irrigation Water Use Efficiency (IWUE). The new twin-row system 150-cm dripline spacing gave similar cop yield and IWUE as the conventional 75cm dripline spacing, and both were higher in the two traits than the single-row 150cm dripline spacing. With 50% less cost per unit-area on dripline, the twin-row 150cm dripline spacing is more economical as well as environmentally friendly.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

HUMAN AND ANIMAL RIGHTS

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

The data supporting the findings of the article is available from author upon request.

FUNDING

None.

CONFLICT OF INTEREST

The author declares no conflict of interest, financial or otherwise.

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REFERENCES

[1] Clemmens AJ. Measuring and improving irrigation performance at the field level. Trans ASAE 2002; 22(8): 89-96.

[2] Tiercelin JR. Traité d’irrigation. Lavoisier Tec & Doc Edition 2007; p. 1266.

[3] Bozkurt Y, Yazar A, Gencel B, Sezen MS. Optimum lateral spacing for drip-irrigated corn in the Mediterranean Region of Turkey. Agric Water Manage 2006; 85: 113-20. [http://dx.doi.org/10.1016/j.agwat.2006.03.019]

[4] Henggeler JC. A history of drip-irrigated cotton in Texas. In: Lamm F R, Ed. Proc 5th International Microirrigation Congress. 669-74.

[5] Camp CR, Bauer PJ, Hunt PG. Subsurface drip irrigation lateral spacing and management for cotton in the southeastern Coastal Plain. Trans ASAE 1997; 40(4): 993-9. [http://dx.doi.org/10.13031/2013.21351]

[6] Camp CR. Subsurface drip irrigation: A review. Trans ASAE 1998; 41(5): 1353-67. [http://dx.doi.org/10.13031/2013.17309]

[7] Lamm FR, Trooien TP. Subsurface drip irrigation for corn production: A review of 10 years of research in Kansas. Irrig Sci 2003; 22(3-4): 195-200. [http://dx.doi.org/10.1007/s00271-003-0085-3]

[8] Zhou LF, Feng H, Zhao Y, *et al.* Drip irrigation lateral spacing and mulching affects the wetting pattern, shoot-root regulation, and yield of maize in a sand-layered soil. Agric Water Manage 2017; 184: 114-23. [http://dx.doi.org/10.1016/j.agwat.2017.01.008]

[9] Al-hurmuzi JOH, Topak R. Lateral spacing affect on yield and quality attributes of drip-irrigated sweet corn. Selcuk J Agr Food Sci 2018; 32(1): 55-9.

[10] Howell TA, Schneider AD, Evett SD. Subsurface and surface microirrigation of corn-Southern High Plains. Trans ASAE 1997; 40(3): 635-41. [http://dx.doi.org/10.13031/2013.21322]

[11] Bordovsky JP, Porter D. Cotton response to preplant irrigation level and irrigation capacity using spray, LEPA, and subsurface drip irrigation. ASAE Paper No. 032008. St. Joseph, Mich. 2003.

[12] Kruse EG, Israeli I. Evaluation of a subsurface drip irrigation system. Presented at the 1987 Summer Meeting of the American Society of Agricultural Engineers. 21.

[13] Lamm FR, Stone LR, Manges HL, O'Brien DM. Optimum lateral spacing for subsurface drip-irrigated corn. Trans ASAE 1997; 40(4): 1021-7. [http://dx.doi.org/10.13031/2013.21354]

[14] Bosch DJ, Powell NL, Wright FS. Investment returns from three subsurface microirrigation tubing spacings. J Prod Agric 1998; 11(3): 371-6. [http://dx.doi.org/10.2134/jpa1998.0371]

[15] Thorburn PJ, Cook FJ, Bristow KL. Soil-dependent wetting from trickle emitters: implications for trickle design and management. Irrig Sci 2003; 22: 121-7. [http://dx.doi.org/10.1007/s00271-003-0077-3]

[16] Camp CR, Sadler EJ, Busscher WJ. Subsurface and alternate-middle microirrigation for the southeastern Coastal Plain. Trans ASAE 1989; 32(2): 451-6. [http://dx.doi.org/10.13031/2013.31025]

[17] Frederick JR, Bauer PJ, Busscher WJ, McCutcheon GS. Tillage management for double cropped soybean grown in narrow and wide row width culture. Crop Sci 1998; 38(3): 755-62. [http://dx.doi.org/10.2135/cropsci1998.0011183X003800030023x]

[18] Bauer PJ, Frederick JR, Busscher WJ. Tillage effect on nutrient stratification in narrow- and wide-row cropping systems. Soil Tillage Res 2002; 66(2): 175-82. [http://dx.doi.org/10.1016/S0167-1987(02)00025-9]

[19] Stone KC, Bauer PJ, Busscher WJ, Millen JA. Narrow row corn production with subsurface drip irrigation. Appl Eng Agric 2008; 24(4): 455-64. [http://dx.doi.org/10.13031/2013.25146]

[20] FAO. Crop evapotranspiration: Guidelines for computing crop requirements, Irrigation and Drainage Papers, No 56 Roma, . 1998.

[21] Feddes RA, Kowalik PJ, Zaradny H. Simulation of field water use and crop yield. New York: Wiley 1978; p. 189.

[22] Onofri A. Routine statistical analyses of field experiments by using an Excel extension. National Conference Italian Biometric Society Proc 6th (Pisa) In: "La statistica nelle scienze della vita e dell'ambiente";. 20-22: 93-6.

[23] Gomez KA, Gomez AA. Statistical procedures for agricultural research. 2nd ed. New York, NY: John Wiley & Sons 1984; p. 680.

[24] Cetin O, Uygan D. The effect of drip line spacing, irrigation regimes and planting geometries of tomato on yield, irrigation water use efficiency and net return. Agric Water Manage 2008; 95: 949-58. [http://dx.doi.org/10.1016/j.agwat.2008.03.002]

[25] Olson RA, Sander DJ. Corn Production.Corn and corn production. Madison, WI: ASA, CSSA, and SSSA 1988.

[26] Board JE, Kamal M, Harville BG. Temporal importance of greater light interception to increased yield in narrow-row soybean. Agron J 1992; 84: 575-9. [http://dx.doi.org/10.2134/agronj1992.00021962008400040006x]

[27] Dalley CB, Kells JJ, Renner KA. Effect of glyphosate application timing and row spacing on weed growth in corn (*Zea mays*) and soybean (*Glycine max*). Weed Technol 2004; 18: 177-82. [http://dx.doi.org/10.1614/02-150B]

[28] Bradley KW. A review of the effects of row spacing on weed management in corn and soybean. Crop Manage 2006. [http://dx.doi.org/10.1094/CM-2006-0227-02-RV]

[29] Buehring NW, Harrison MP, Dobbs RR. Corn response to twin and narrow rows with selected seeding rates. Annual Report 2002 of the North Mississippi Research and Extension Center. Mississippi Agricultural & Forestry Experiment Station Information Bulletin 2003; 398: 43-9.

[30] Nafziger ED. Inter- and intraplant competition in corn. Crop Manage 2006. [http://dx.doi.org/10.1094/CM-2006-0227-05-RV]

[31] Ebelhar MW, Clark DR. Nitrogen management and seeding rates for twin-row and single-row Corn production. Proc Am Soc Agron 2010; pp. 105-11.

[32] Spurgeon WE, Manges HL. Drip line spacing and plant population for corn. Proceeding of the Third National Irrigation Symposium. Phoenix, Arizona. October 28-November 1, 1990; 217-22.

[33] Powell NL, Wright FS. Grain yield of subsurface microirrigated corn as affected by irrigation line spacing. Agron J 1993; 85(6): 1164-9. [http://dx.doi.org/10.2134/agronj1993.00021962008500060014x]