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DRIP-IRRIGATED SWEET CORN WATER USE DEPENDING ON THE DEPTH OF PLOWING, MINERAL FERTILIZATION RATES AND CROPS DENSITY

Raisa VOZHEHOVA[1], Pavlo LYKHOVYD[1], Viktor USHKARENKO[2], Sergiy LAVRENKO[2]

[1]Institute of Irrigated Agriculture of NAAS, Naddniprianske, Kherson, Ukraine, 73483, Phone: 0552361196, E-mail: izz.ua@ukr.net
[2]Kherson State Agrarian and Economic University, 23 Stritenska Street, Kherson, Ukraine, 73006, Phone: 0552 417865, E-mail: office@ksau.kherson.ua

Corresponding author email: pavel.likhovid@gmail.com

Abstract

The effect of plowing depth (20-22; 28-30 cm), mineral fertilization rates (N-P: 0-0, 60-60, 120-120 kg ha^{-1}), and crops density (35,000, 50,000, 65,000, 80,000 plants ha^{-1}) on the yield, and water use efficiency (WUE) of drip-irrigated sweet corn were studied. The field experiment was conducted in the semi-arid climatic conditions of the South of Ukraine (Kherson oblast) at the dark-chestnut middle-loamy soil. The trials were conducted using split-plot design in four replications. Irrigation scheduling and rates were set by the field water balance method considering the amounts of available soil moisture and precipitation. Manual harvesting of the crop ears was conducted at R3 phenological stage. WUE was calculated as the ratio of the ears' yield to the gross water use of the crop. Statistical evaluation was performed by analysis of variance (ANOVA) and regression analysis at the probability level of 95%. The studied factors and their interaction had a significant effect on sweet corn productivity and WUE. The best crop productivity along with the best WUE was provided by plowing on 20-22 cm, fertilization rates of 120-120 kg ha^{-1}, and crops density of 65,000 plants ha^{-1}.

Key words: *Zea mays L., water management, crop productivity, cultivation technology.*

INTRODUCTION

Sweet corn (*Zea mays* L. ssp. *saccharata* Sturt.) is an annual crop, which belongs to *Poacea* family (Tracy, 2000). It is the only *Poacea* crop, which is a vegetable crop, which is primarily used for food (Leath et al., 1982). Sweet corn, both of *su*, se and sh_2 genotype, is a mutant form of corn, which derives due to the recessive genes that suppress the transformation of sugars into starch in the kernels while their ripening (Ferguson et al., 1978; Tracy et al., 2006). Thanks to this feature it received its high organoleptic qualities.

Each year sweet corn grows more and more important due to its high nutritional and dietary value accompanied by incredible taste and flavor (Szymanek et al., 2005). The demand for sweet corn is increasing. Most sweet corn is produced for fresh market, and partially it is proceeded for frozen products, cannery, pickles, etc. Most sweet corn is produced in the USA with the total fresh market production of nearly 1.49 million tons in 2013 (NASS, 2013). Sweet corn production in the countries of the Euro Union is constantly growing. The crop is mostly cultivated in Western Europe (France - 26,000 ha, Italy - 3,800 ha), Hungary - 39,000 ha, and Israel - 3,500 ha. In the recent years, areas under sweet corn in Poland increased to 3,000 ha, in Ukraine - to 6,000 ha, respectively. Annual consumption of sweet corn in Western Europe and the USA is about 10-15 kg per capita, while in Eastern Europe it is still very low (Szymanek et al., 2005).

Sweet corn in Ukraine remains a destiny of small farm-holders, and it is mostly cultivated on the plots of 0.5-1.5 ha with only few farms, which dare to grow sweet corn by the conveyor method on the areas of about 50 ha. However, we believe that Ukraine has a great potential for becoming one of the major European sweet corn producers because of favorable soil-climatic conditions of the country, especially, its Southern regions. The main reason of low interest of Ukrainian agricultural producers in sweet corn cultivation we see in the absence of adequate scientifically based recommendations for its agrotechnology. Modern scientific literature has lots of information related to sweet corn cultivation technology, however, the results of different studies are quite different because of a few reasons, including different growth conditions, hybrids used, soil peculiarities, agricultural machines, etc.

So, researchers studied the effect of tillage system and fertilization on sweet corn productivity at the research station of the Institute of Plant Breeding of the Philippines in 2016 showed that conventional tillage, which provided 46.4 t ha^{-1} of ears, is more advantageous than no-till, while the studied fertilization options did not cause any significant effect on the crop growth and productivity (Canatoy, 2018). The field trials conducted in 2008 at sandy clay loam soil in the humid climate of the research farm of University Putra Malaysia proved that significantly higher yield of sweet corn ears was provided by tillage system with disk plowing followed by harrowing (10.55 t ha^{-1}), while rotary cultivator tillage and moldboard plowing systems were considerably worse with yields of 8.88 and 9.58 t ha^{-1}, respectively. Besides, the study showed that the maximum sweet corn productivity was achieved on the crops with the highest density of plants (seed spacing of 20 cm) - 12.52 t ha^{-1}, while seed spacing of 30 and 40 cm resulted in the significant yield losses of 3.22 and 5.31 t ha^{-1}, respectively (Hosseinali et al., 2017). Sweet corn reaction on tillage was studied in 1994 at the silt loam soil of Weslaco where the best option was proved to be a ridge tillage, which provided 0.16-1.19 t ha^{-1} more ears yield than conventional and no-till systems (Makus, 2000).

There are also several scientific reports related to the effect of mineral fertilization on sweet corn yield. The trials conducted at the Tirhut College of Agriculture (India) during the Rabi season in 2014-2015 revealed that the highest seed yield of sweet corn (16.87 t ha^{-1}) were provided by the fertilization system with NPK rates of 120:60:45 at the crops spacing of 45×20 cm under the flat bed planting thereafter further strengthening of the crop nutrition led to slight decrease in the yield (Kumar & Narayan, 2018). The results of the study conducted at the irrigated lands of Guaira, Brazil in 2013 on the acric and eutrophic Latosol soil showed that sweet corn yields increased in response to the increase of Nitrogen fertilization from 0 to 300 kg ha^{-1} - from 6.747 to 9.666 t ha^{-1} of marketable ears (Cruz et al., 2015). In the field experiments conducted at the plain field sand of the University of Illinois River Valley Sand Field in 1990 with different sh_2 sweet corn hybrids the most yield of kernels was obtained at the highest Nitrogen rate of 310 kg ha^{-1} - 6.7-7.2 t ha^{-1} (Wang et al., 1995). The study conducted at the Highland Rim Experiment Station in Springfield during 1993-1995 with three sweet corn hybrids showed that the highest ears yield of 3.7 t acre^{-1} was obtained under the most quantity of Nitrogen fertilizers used (168 kg ha^{-1}). However, Nitrogen rate of 112 kg ha^{-1} provided just slightly worse crop productivity of 3.6 t acre^{-1} (Mullins et al., 1999). So, the results of most studies allow us to suggest that usually the more fertilizers are applied, the more yield can be potentially got. However, this hypothesis requires examination.

There are different opinions on the optimal plant density of sweet corn for better crop productivity. The highest average yield of sweet corn obtained in the field experiments at northeastern US in 1996-1997 was 4.26 t acre^{-1} (in dry matter) at the plant density of 28,000 plants acre^{-1} (Morris et al., 2000). By the results of the experiment conducted at the plain of Isparta, Turkey, in 1997-1998 the highest yield of marketable sweet corn ears was obtained on the variants with plant density of 5.7 plants m^{-2} - 9.3-11.1 t ha^{-1} in comparison to 9.0-10.2 and 8.9-10.5 t ha^{-1} on the variants with plant density of 4.1 and 9.5, respectively (Akman, 2002). Shin et al. (2014) reported about no significant changes in sweet corn marketable ears yield related to plant density. As it is obvious, the optimum plant density of sweet corn crops differs depending on the peculiarities of the crop cultivation, hybrids' genotypes, and environmental conditions. That is why it is important to study the effects of certain aggrotechnological elements in the concrete agro-environmental conditions. The goal of our study was to determine the effect of the depth of moldboard plowing, nitrogen-phosphorus fertilization rates and plant density on sweet corn productivity at the drip-irrigated conditions of the semi-arid zone of Eastern Europe.

Besides high productivity and economic efficiency, modern cultivation technology should guarantee the most efficient use both of renewable and non-renewable natural resources (especially, water), material resources and labor (Aldrich et al., 1975). That is why the second important goal of our study was to determine the water use efficiency of sweet corn under the impact of different cultivation options. Sweet corn has comparatively high irrigation water requirements, which are fluctuating within 142-361 mm per growing cycle depending on the length of vegetative period, weather conditions, hybrid genotype, irrigation method, etc. (Wendt et al., 1977) Therefore, water limitation is the main factor of sweet corn yield decrease in the arid and semi-arid regions of our planet, which suffer from insufficient amounts of precipitation (Garcia y Garcia et al., 2009). The best way of improving the crop growth conditions in this case is artificial application of water - irrigation. And the only way of getting the best payout of the applied irrigation water is an introduction of rational cultivation technology, which can drastically improve water use efficiency of the crop (Phene & Beale, 1976). The study devoted to investigation of how tillage system effects sweet corn water use revealed that the most water use of the crop was provided by no-till (446 mm), while the lowest value of the index (424 mm) was guaranteed by conduction of conventional tillage (Petersen et al., 1985). Better nutrition results in the increase of the crop productivity, and, in its turn, in higher water use efficiency under the same irrigation schedule. For example, the results of the study conducted by Souza et al. (2016) in Brazil report about the increase of sweet corn water use efficiency with enough nitrogen fertilization. Water use efficiency and productivity of sweet corn is also affected by planting techniques, weed management (Zystro et al., 2012), inter-row pacing and peculiarities of placement of drip tape under the drip-irrigated conditions (Al-Hurmuzi & Topak, 2018), irrigation scheduling and irrigation water quality (Stone et al., 2001; Lykhovyd et al., 2019), genotype, soil, and weather conditions (Garcia y Garcia et al., 2009). Therefore, we found it reasonable to conduct the study of sweet corn water use efficiency depending on the peculiarities of the crop cultivation technology, namely: moldboard plowing depth, nitrogen-phosphorus fertilization rates and plants density at the drip-irrigated conditions of the semi-arid region of Eastern Europe.

MATERIALS AND METHODS

The field experiment was carried out within the period of three years (2014-2016) at the irrigated lands of the Cooperative Farm «Radianska Zemlia» (latitude 46°43′N and longitude 32°17′E; altitude 42 m). The experimental field was situated in Southern part of Kherson oblast in Ukraine, and its area belongs to the semi-arid cold steppe zone (BSc) by the classification of Koppen-Geiger climate map (Beck et al., 2018) with the value of the coefficient of humidity of 0.5-0.6 (Angström, 1936). The climate of the zone is characterized as moderately dry and warm, with an average annual air temperature of 9.8ºC, total solar radiation of 4613 MJ m^{-2} per year, photosynthetic insolation during the vegetative period (with the air temperatures above 5ºC) of 2100 MJ m^{-2}, sum of the effective temperatures above 10 ºC of 3800-4000 ºC, average annual precipitation amounts of 399 mm (by the data provided by Kherson State Hydrometeorological Center). A soil of the experimental field was represented by dark-chestnut slightly solonets middle-loamy soil. The physical characteristics of the soil are represented in the Table 1. The depth of humus profile is 45-55 cm with the content of humus in the arable (0-30 cm) layer of 2.5%. The content of main nutritive elements in the arable layer of the soil was: 35 mg kg^{-1} for hydrolyzed Nitrogen, 32 mg kg^{-1} for mobile Phosphorus, and 430 mg kg^{-1} for exchangeable Potassium. Groundwater is located 3-5 m deep and does not affect crop production and hydrological regime of the experimental field.

The field experiment was conducted during 2014-2016. The experimental design covered investigation of three agrotechnological elements on the yield, water use and water use efficiency of sweet corn in the drip-irrigated conditions, viz. depth of moldboard plowing, nitrogen-phosphorus application rates, plants density (Table 2).

Table 1. Physical characteristics of the dark-chestnut solonets middle-loamy soil at the Cooperative Farm «Radianska Zemlia», Kherson oblast, Ukraine

Soil layer (cm)	Bulk density (g cm^{-3})	Solid particles density (g cm^{-3})	Field capacity (%)	Wilting point (%)	Porosity (%)
0-10	1.14	2.62	22.0	7.2	56.9
10-20	1.25	2.63	20.8	7.0	52.8
20-30	1.28	2.64	20.6	7.1	51.4
30-40	1.38	2.65	20.5	6.9	48.0
40-50	1.38	2.67	19.9	7.0	48.2
50-60	1.39	2.68	19.5	7.1	47.9
60-70	1.42	2.68	19.4	7.2	47.0
70-80	1.43	2.69	19.0	7.3	46.8
80-90	1.42	2.70	18.7	7.4	47.4
90-100	1.42	2.68	18.5	7.3	47.0
0-30	1.22	2.63	20.5	7.1	53.7
040	1.26	2.63	20.5	7.1	52.3
0-50	1.29	2.64	20.8	7.0	51.5
0-100	1.35	2.66	19.9	7.2	49.3

Table 2. The design of the field experiments conducted at the Cooperative Farm «Radianska Zemlia», Kherson oblast, Ukraine

Depth of moldboard plowing (cm) (Factor A)	Nitrogen-phosphorus application rates (kg ha^{-1}) (Factor B)	Plants density (plants ha^{-1}) (Factor C)
A1: 20-22	B1: 0-0	C1: 35,000
		C2: 50,000
		C3: 65,000
		C4: 80,000
	B2: 60-60	C1: 35,000
		C2: 50,000
		C3: 65,000
		C4: 80,000
	B3: 120-120	C1: 35,000
		C2: 50,000
		C3: 65,000
		C4: 80,000
A2: 28-30	B1: 0-0	C1: 35,000
		C2: 50,000
		C3: 65,000
		C4: 80,000
	B2: 60-60	C1: 35,000
		C2: 50,000
		C3: 65,000
		C4: 80,000
	B3: 120-120	C1: 35,000
		C2: 50,000
		C3: 65,000
		C4: 80,000

The crop was sown each year using a split plot partially randomized design in four replications. The length of the accounting area of the experimental plot was 10.8 m, the width - 2.8 m. A middle-ripening sweet corn variety Brusnytsia of *su* type was used in the field experiment. Sowing was conducted on different days each year depending on the weather and soil conditions: on May 1 in 2014, on May 22 in 2015, and on May 21 in 2016. After harvesting of the previous crop, which was represented by winter wheat, the soil was cultivated and fertilized with accordance to the design of the study. We used *ammonium nitrate* and *super phosphate* fertilizers, which were applied in pre-plowing period. The herbicide *acetochlor* in the dose of 2.0 l ha^{-1} was used under pre-sowing cultivator tillage on the depth of 5-6 cm. Sweet corn was sown using a pneumatic seed drill on the depth of 5-6 cm with an inter-row spacing of 70 cm with different sowing rates according to the design of the study. Further the crops were manually thinned at the stage of 3-5 leaves (V3) (Ritchie et al., 1993) to desirable densities of 3.5, 5.0, 6.5 and 8.0 plants m^{-2}. At V3 stage an insecticide *lambda cyhalothrin* in the dose of 0.2 l ha^{-1} was applied. At V6 stage the herbicide with a combined active substance of *foramsulfuron, iodosulfuron, thiencarbazone-methyl* was applied in the dose of 1.25 l ha^{-1}. At the beginning of VT (tasseling) stage an insecticide *chloranthraniliprole* in the dose of 0.1 l ha^{-1} was applied.

Weather conditions during the study were quite contrast each year, being highly different from the long-term means (Table 3).

The total precipitation amounts during the vegetative period of sweet corn in 2014 were 14 mm less than the long-term mean amounts. The most drought was observed in the 2nd and 3rd ten-day periods of May, and in the 1st ten-day period of July. At the same time, 2015 was a very humid year, with the total precipitation amounts during the vegetative period of sweet corn 99.6 mm higher than the long-term mean amounts. However, the precipitation was distributed highly unequally with 72% of the total amount fell on the 3rd ten-day period of May and 1st ten-day period of July, while the rest of the period suffered from drought. The next year, 2016, is characterized as the most moderate among the years of the study with an equal distribution of precipitation and low (3.4 mm) difference of its amount with the long-term means for the period.

The most period of the crop vegetation (from the 3rd ten-day period of May until harvesting) in 2014 was characterized as air drought by the index of relative air humidity. Sweet corn vegetative period was quite humid in 2015, and air drought was observed in the end of the crop vegetation in 2016.

The entire vegetative period of sweet corn was sufficiently supplied with heat in all the years of the study. The sum of the effective temperatures above 10ºC for the period of the crop growth was 1960.1ºC in 2014, 1799.6ºC in 2015, and 1882.5ºC in 2016.

Table 3. Weather conditions during the vegetative period of sweet corn in the field experiments conducted in 2014-2016 at the Cooperative Farm «Radianska Zemlia», Kherson oblast, Ukraine

Month	Ten-day period	Air temperature (ºC)	Relative air humidity (%)	Precipitation amount (mm)	Coefficient of humidity (pts)
2014					
May	I	13.7	75	33.0	2.4
	II	17.8	75	5.2	0.3
	III	22.2	61	0.0	0.0
June	I	22.4	64	13.3	0.6
	II	20.0	58	28.6	1.4
	III	20.0	64	22.5	1.1
July	I	23.5	53	0.0	0.0
	II	25.5	56	9.4	0.4
	III	26.1	49	10.0	0.3
2015					
May	III	19.6	69	70.7	3.3
June	I	21.3	61	7.1	0.3
	II	21.3	67	3.4	0.2
	III	20.0	73	27.8	1.4
July	I	22.8	74	84.9	3.7
	II	21.0	66	19.7	0.9
	III	26.0	67	0.0	0.0
August	I	26.0	49	0.0	0.0
2016					
May	III	18.5	77	20.7	1.0
June	I	17.8	70	16.2	0.9
	II	21.9	75	12.8	0.6
	III	26.5	62	14.0	0.5
July	I	22.4	61	21.6	1.0
	II	25.8	59	0.0	0.0
	III	25.0	54	24.7	0.9
August	I	26.0	55	0.6	0.0
Long-term means (1986-2005) according to Kherson Hydrometeorological Station					
May	I	14.1	63	15.0	1.1
	II	16.6	62	14.0	0.8
	III	17.4	66	13.0	0.7
June	I	19.2	68	13.0	0.7
	II	19.5	65	18.0	0.9
	III	21.2	67	14.0	0.7
July	I	21.3	62	22.0	1.0
	II	22.3	61	14.0	0.6
	III	22.1	61	13.0	0.5
August	I	22.4	61	7.0	0.3

Sweet corn was drip-irrigated. A drip tape Eurodrip CLS 5 mil with 20 cm emitter spacing was placed in each row to supply the crop with irrigation water. The irrigation-maintained soil moisture at the level of 80% of the field capacity in the active root-filled layer of 0-30 cm until V6 stage, and in the root-filled layer of 0–50 cm from V6 stage to harvesting. The irrigation water requirements and irrigation schedule were determined by the field water balance with considering available soil moisture and precipitation amounts, which were measured by using rain gauge installed nearby the experimental field (Brouwer & Heibloem, 1986). Soil moisture of every experimental plot was measured by using the gravimetric method in the samples collected by the means of a soil auger in the morning from the soil layers of 0-10, 10-20, 20-30, 30-40, and 40-50 cm (Reynolds, 1970). The amounts of irrigation water fed to the field at one application were 5 mm until V6 stage, and 10 mm from V6 stage to harvesting. The irrigation scheduling of the crop in the experiment is presented in the Table 4. Total amount of irrigation water supplied to the experimental field was 170 mm in 2014, 120 mm in 2015, and 160 mm in 2016. The average amount of irrigation water applied in 2014-2016 during the crop vegetative period in the experiments was 150 mm.

Table 4. The irrigation scheduling of sweet corn in the field experiments conducted in 2014-2016 at the Cooperative Farm «Radianska Zemlia», Kherson oblast, Ukraine

Year of the study	Number of irrigation water applications per stages of the crop growth	
	V0–V6 (irrigation with 5 mm per application)	V6–R3 (irrigation with 10 mm per application)
2014	10	12
2015	6	9
2016	8	12

Sweet corn in Ukraine is mainly cultivated for fresh market needs. Therefore, we have studied the effect of cultivation technology on fresh corn ears yield. The ears were harvested manually from the entire area of each experimental plot in four replications at R3 stage (milk ripeness of kernel) early in the morning. The moisture of the kernel was about 70%. The ears were divided into marketable and unmarketable with accordance to the requirements of State Standard GOST 55910-2013. The ears with the length, which is less than 150 mm, damaged by the insects or diseases, with unfilled top-end, missing kernels in the rows of the middle part of the ear were sorted out as unmarketable together with other non-typical ears, and were not accounted when the yield of the crop was estimated. The yield of sweet corn ears was determined both with and without husks.

The gross water use (*WU*) of sweet corn crops was calculated by the formula 1 (Kostyakov, 1960).

$$WU = ASWU + EPA + IWA \quad (1)$$

where: *WU* is the gross water use of the crop, mm; *ASWU* is the amount of soil water used by the crop during the vegetative period, mm; *EPA* is the amount of effective precipitation during the crop vegetation, mm; *IWA* is the amount of irrigation water applied to the field, mm.

The *ASWU* was determined by the formula 2 as a difference between the soil water content in the 0-100 cm layer at the beginning of sweet corn vegetation, and in the end of it.

$$ASWU = SWCB - SWCE \quad (2)$$

where: *ASWU* is the amount of soil water used by the crop during the vegetative period, mm; *SWCB* is the amount of soil water in the 0–100 cm layer at the beginning of sweet corn vegetation, mm; *SWCE* is the amount of soil water in the 0-100 cm layer in the end of sweet corn vegetation (before harvesting), mm.

The effective precipitation amounts were calculated by using the coefficient of 0.6 (Kostyakov, 1960) for the total amount of precipitation during the crop vegetation by the formula 3.

$$EPA = TPA \times 0.6 \quad (3)$$

where: *EPA* is the amount of effective precipitation during the crop vegetation, mm; *TPA* is the total amount of precipitation during the crop vegetation, mm.

Drip irrigation did not cause runoff, so this parameter was not considered as well as groundwater, which did not take part in the crop water supply.

The water use efficiency (*WUE*) was estimated as a ratio of the ears yield to the water use of the crop by the formula 4 (Garcia y Garcia et al., 2009).

$$WUE = CY / WU \quad (4)$$

where: WUE is the water use efficiency of the crop, kg mm^{-1}; CY is the yield of sweet corn ears, kg ha^{-1}; WU is the water use of the crop, mm.

WUE was determined both for sweet corn ears with and without husks in four replications.

Analysis of variance (*ANOVA*) was performed for the *WU*, yields and *WUE* of sweet corn by the means of Microsoft Excel software (Carlberg, 2017). The relationship between *WUE* and the crop yield were determined by standard procedure of linear regression analysis within Microsoft Excel software (Carlberg, 2016). All the differences between the studied variants were evaluated by the value of the least significant difference at the probability level of 95% ($p < 0.05$).

RESULTS AND DISCUSSIONS

Water use of sweet corn is highly dependent on fertilization management, irrigation treatments, weather, and climatic conditions, etc. (Garcia y Garcia et al., 2009; Gunes et al., 2016; Waite, 2016; Greaves & Wang, 2017; Wang et al., 2017). Water use of sweet corn in the field experiments averaged to 258.3-278.6 mm in dependence on the cultivation treatments (Table 5). The main regularities of the crop water use, which were determined through the analysis of the obtained experimental data, are:

1. The increase of moldboard plowing depth from 20-22 to 28-30 cm caused the marginal increase of *WU* (in average by 0.7 mm) mainly at the expense of more soil water used by the crop at deeper plowing. This result agrees with some previously conducted studies related to the effect of different tillage practices and depths on winter wheat *WU* (Guan et al., 2015), row crops *WU* (Norwood, 1999). In contrary, Lamm et al. (2009) reported about considerable increase of corn *WU* under the conventional tillage option in comparison to no-till. These differences in scientific results put us on the track that the effect of tillage depth on corn *WU* depends on the method of tillage used and environmental conditions of the study conduction.
2. Application of nitrogen-phosphorus mineral fertilizers with higher rates distinctly increased *WU* of sweet corn in average from 263.5 mm at the unfertilized variants to 269.3 mm at fertilization rate of 60-60, and to 273.5 mm at the rate of 120-120. However, Bakelana et al. (1986) reported that nitrogen application did not cause any remarkable effect on corn *WU*. Therefore, the issue is quite debatable.
3. Increasing the density of sweet corn crops led to the gradual increase of *WU* by 4.1, 4.5, and 1.6 mm with the gradual increase of plants density by every 15,000 of plants ha^{-1}. This agrees with some other studies, which discovered the impact of crops thickness on corn *WU* (Bakelana et al., 1986; Karasahin, 2014). Schlegel et al. (2012) proved that corn seeding rate and plant density should be adjusted with accordance to soil water availability and irrigation water supply capacities.
4. The main share of more than 50% in the structure of *WU* pertained to the irrigation water applied to the field regardless of the treatment options.

WUE of any crop can only be assessed in a direct connection with productivity of the crop. Therefore, sweet corn ear yield with and without husks was previously determined to evaluate the crop *WUE*.

The highest statistically reliable ear yield both with and without husks was provided by the cultivation technology with moldboard plowing on the depth of 20-22 cm, nitrogen-phosphorus application rate of 120-120, and plant density of 65,000 plants ha^{-1}. The above-mentioned agrotechnology in the drip-irrigated conditions allowed obtaining of 14,000 kg ha^{-1} of marketable ears with husks, and 10,930 kg ha^{-1} of marketable ears without husks, respectively (Table 6).

Tillage is an important factor of crop productivity, which has a significant effect on the field management, including weed management, nutrients uptake, water use, root development, etc. (Cline & Silvernail, 2002). Different tillage practices and depths can lead to improvement or, in contrary, decrease of the crop yield (Barber, 1971; Adeoye, 1982). Deeper plowing caused general decrease of sweet corn yield. However, it performed better under the non-fertilized conditions where the crop suffered from the lack of nutrition.

Proper fertilization management can significantly improve sweet corn productivity

(Efthimiadou et al., 2010; Uwah et al., 2011). This statement was proved by the results of our study. The increase of fertilizers application rates drastically increased sweet corn productivity. Application of fertilizers at the rate of 60-60 kg ha^{-1} improved the crop's yield by 89.36 and 96.51% for ears with and without husks, respectively. While application of them at the rate of 120-120 kg ha^{-1} caused the productivity increase of 156.14 and 168.86% for ears with and without husks, respectively, in comparison to zero mineral fertilizers application rate. However, it should be mentioned that according to some scientific studies the increase in sweet corn yield cannot be infinitive with the raise of fertilization rates. At some point, it reaches the value when further improvement of yield cannot be achieved by extra-nutrition (He et al., 2012).

The optimum plant population was achieved at the density of 65,000 plants ha^{-1} that is proved by the highest sweet corn productivity, which averaged to 8,688 and 6,670 kg ha^{-1} for ear with and without husks, respectively. Further thickening of the crop to 80,000 plants ha^{-1} had negative effect on the productivity as well as thinned crops with the densities of 35,000 and 50,000 plants ha^{-1}. At the same time, the research conducted in Malaysia showed that sweet corn ear yields gradually increased with the increase of plant density and reached its maximum of 12,520 kg ha^{-1} at the highest thickness of the crop (Hosseinali et al., 2017). However, we see that in the conditions of our trials this statement is not quite fair: the increase in the crop yield can be achieved only until its thickening to the certain quantity of plants per area. Williams II (2012) reported that the highest economic efficiency of sweet corn production for different hybrids studied in the conditions of Northern America was provided by the crops' density of 56,000 plants ha^{-1}. He also stated that the optimum plant population strongly depends on the hybrid.

As for the *WUE* of sweet corn in the experiments, it reached the maximum of 50.52 and 39.44 kg mm^{-1} for ear with and without husks, respectively, under the variant of the highest productivity of the crop with plowing depth of 20-22 cm, nitrogen-phosphorus application rate of 120-120, and plant density of 65,000 plants ha^{-1}. Very high and close correlation between the indexes of the crop yield and *WUE* were determined with a coefficient of correlation R of 0.9993, and coefficient of determination R^2 of 0.9986.

Lamm et al. (2009) reported about the increase of *WUE* of corn crop with the plant density increase. Ogola et al. (2005) also mentioned about corn *WUE* increase by 24% due to the increase in crops density from 66,667 to 133,333 plants ha^{-1} in the irrigated conditions. The results of our study agree with the above-mentioned statements. However, too much increased plant density of 80,000 plants ha^{-1} had negative effect on the index. In contrary, El-Hendawy et al. (2008) proved that *WUE* of corn increased under the decreasing plant densities from 95,000 to 48,000 plants ha^{-1} that is in some discrepancy with our results. The best *WUE* of corn was achieved at the sandy loam soil of Great Plains on the treatments with 140-250 kg ha^{-1} of nitrogen applied under the plant density of 57,000-69,000 plants ha^{-1} (Al-Kaisi & Yin, 2003), which is quite close to the results of our study. *WUE* of corn grown in the Northern Great Plains was also affected by tillage options. Higher *WUE* of 13.1 kg mm^{-1} in comparison to 10.9 kg mm^{-1} was obtained under the no-till option, which provided significantly better results than conventional tillage (Lenssen et al., 2018). The results of our experimental research also showed that there is no need to increase depth of plowing to 28–30 cm because the best crop productivity and *WUE* were obtained under the plowing on the less depth of 20-22 cm. Rational fertilization can also improve *WUE* of the crop. This statement was proved not only by the results of our research where the increase of *WUE* with the increase of fertilizers application rates reached the values of 85.07-92.22% for the rate of 60-60 kg ha^{-1}, and 146.49-158.94% for the fertilizers rate of 120-120 kg ha^{-1} comparatively to non-fertilized option. The results of the studies conducted at the Agronomic Research Farm of the University of Agriculture in Pakistan also revealed that the increase in Nitrogen supply from 0 to 250 kg ha^{-1} resulted in significant corn *WUE* increase (Ashraf et al., 2016).

Table 5. Mean values with standard errors of sweet corn water use (*WU*) in the field experiments conducted in 2014-2016 at the Cooperative Farm «Radianska Zemlia», Kherson oblast, Ukraine

Treatment	Soil water content and use from 0–100 cm layer (mm)			Vegetation period (days)	Precipitation (mm)		*IWA* (mm)	*WU* (mm)
	ASWB	*ASWE*	*ASWU*		*TPA*	*EPA*		
A1 B1 C1	232.9	206.7	26.2	72	136.7	82.0	150.0	258.3 ± 2.0
A1 B1 C2	232.9	203.3	29.6	73	136.7	82.0	150.0	261.6 ± 2.0
A1 B1 C3	232.9	199.2	33.7	74	136.7	82.0	150.0	265.7 ± 2.7
A1 B1 C4	232.9	198.2	34.7	75	136.7	82.0	150.0	266.8 ± 3.0
A1 B2 C1	232.9	202.6	30.3	75	136.7	82.0	150.0	262.4 ± 2.6
A1 B2 C2	232.9	198.4	34.5	76	139.5	83.7	150.0	268.1 ± 3.9
A1 B2 C3	232.9	195.2	37.7	78	139.5	83.7	150.0	271.4 ± 4.2
A1 B2 C4	232.9	194.6	38.3	79	142.8	85.7	150.0	274.0 ± 6.3
A1 B3 C1	232.9	199.5	33.4	77	139.5	83.7	150.0	267.1 ± 3.7
A1 B3 C2	232.9	195.8	37.1	78	139.5	83.7	150.0	270.7 ± 3.6
A1 B3 C3	232.9	191.5	41.4	79	142.8	85.7	150.0	277.1 ± 5.3
A1 B3 C4	232.9	191.0	41.9	80	142.8	85.7	150.0	277.6 ± 5.2
A2 B1 C1	238.2	210.7	27.5	73	136.7	82.0	150.0	259.5 ± 1.8
A2 B1 C2	238.2	208.0	30.2	74	136.7	82.0	150.0	262.3 ± 2.2
A2 B1 C3	238.2	204.0	34.2	74	136.7	82.0	150.0	266.2 ± 3.0
A2 B1 C4	238.2	202.7	35.5	75	136.7	82.0	150.0	267.5 ± 3.1
A2 B2 C1	238.2	207.0	31.2	75	136.7	82.0	150.0	263.3 ± 2.1
A2 B2 C2	238.2	203.3	34.9	77	139.5	83.7	150.0	268.6 ± 2.5
A2 B2 C3	238.2	200.2	38.0	78	139.5	83.7	150.0	271.7 ± 2.5
A2 B2 C4	238.2	199.0	39.2	79	142.8	85.7	150.0	274.8 ± 4.3
A2 B3 C1	238.2	204.2	34.0	78	139.5	83.7	150.0	267.6 ± 3.2
A2 B3 C2	238.2	200.5	37.7	78	139.5	83.7	150.0	271.4 ± 3.1
A2 B3 C3	238.2	196.4	41.8	80	142.8	85.7	150.0	277.5 ± 4.3
A2 B3 C4	238.2	195.3	42.9	81	142.8	85.7	150.0	278.6 ± 4.2
LSD_{05}								4.3

Table 6. Mean values and standard errors of sweet corn ear yield and water use efficiency (WUE) in the field experiments conducted in 2014-2016 at the Cooperative Farm «Radianska Zemlia», Kherson oblast, Ukraine

Treatments	Sweet corn ear yield (kg ha^{-1})		*WUE* (kg mm^{-1})	
	With husks	Without husks	With husks	Without husks
A1 B1 C1	3,600 ± 113	2,670 ± 106	13.94 ± 0.97	10.34 ± 0.73
A1 B1 C2	3,820 ± 126	2,850 ± 81	14.60 ± 0.85	10.89 ± 0.66
A1 B1 C3	4,050 ± 130	3,010 ± 103	15.24 ± 0.93	11.33 ± 0.74
A1 B1 C4	3,990 ± 142	2,960 ± 106	14.96 ± 1.02	11.09 ± 0.75
A1 B2 C1	7,090 ± 190	5,560 ± 158	27.02 ± 1.09	21.19 ± 0.79
A1 B2 C2	8,140 ± 342	6,310 ± 275	30.36 ± 1.11	23.54 ± 0.84
A1 B2 C3	10,030 ± 408	7,670 ± 220	36.96 ± 1.22	28.26 ± 0.91
A1 B2 C4	8,820 ± 395	6,800 ± 301	32.19 ± 1.05	24.82 ± 0.80
A1 B3 C1	9,620 ± 309	7,530 ± 229	36.02 ± 1.37	28.19 ± 1.30
A1 B3 C2	11,140 ± 393	8,810 ± 343	41.15 ± 2.88	32.55 ± 2.37
A1 B3 C3	14,000 ± 437	10,930 ± 348	50.52 ± 2.14	39.44 ± 1.59
A1 B3 C4	12,320 ± 368	9,580 ± 299	44.38 ± 2.84	34.51 ± 2.32
A2 B1 C1	4,060 ± 137	3,000 ± 94	15.65 ± 1.74	11.56 ± 1.34
A2 B1 C2	4,490 ± 154	3,340 ± 138	17.12 ± 1.67	12.73 ± 1.24
A2 B1 C3	4,780 ± 160	3,570 ± 134	17.96 ± 2.01	13.41 ± 1.50
A2 B1 C4	4,540 ± 143	3,370 ± 117	16.97 ± 1.57	12.60 ± 1.31
A2 B2 C1	6,290 ± 219	4,890 ± 175	23.89 ± 2.71	18.57 ± 2.04
A2 B2 C2	7,240 ± 209	5,550 ± 152	26.95 ± 3.38	20.66 ± 2.91
A2 B2 C3	8,200 ± 244	6,250 ± 193	30.18 ± 3.57	23.00 ± 2.76
A2 B2 C4	7,300 ± 206	5,640 ± 162	26.56 ± 2.75	20.52 ± 2.05
A2 B3 C1	8,150 ± 335	6,230 ± 226	30.46 ± 2.99	23.28 ± 1.99
A2 B3 C2	9,450 ± 318	7,360 ± 223	34.82 ± 2.58	27.12 ± 1.89
A2 B3 C3	11,070 ± 367	8,590 ± 262	39.89 ± 2.91	30.95 ± 2.15
A2 B3 C4	9,620 ± 315	7,560 ± 240	34.53 ± 2.43	27.14 ± 1.92
LSD_{05}	470	320	2.68	2.10

CONCLUSIONS

Both sweet corn productivity and *WUE* were significantly affected by all the studied elements of the crop cultivation technology. The results of our study showed that the best sweet corn productivity and the most *WUE* were provided by the cultivation technology with moldboard plowing on the depth of 20-22 cm, nitrogen-phosphorus application rate of 120-120 kg ha^{-1}, and plants density of 65,000 plants ha^{-1} that resulted in the yield of ear with and without husks of 14,000 and 10,930 kg ha^{-1}, and *WUE* of the crop averaged to 50.52 kg

mm^{-1} and 39.44 kg mm^{-1}, respectively. The increase of the moldboard plowing depth to 28-30 cm, thinned or thickened crops, poor nutrition resulted in the significant decrease both yield and *WUE* of the crop. However, deeper plowing provided significantly better productivity of the crop and *WUE* at the unfertilized variants of the experiment. The lowest productivity of sweet corn (3,600 and 2,670 kg ha^{-1} of marketable ears with and without husks, respectively) accompanied by the worst WUE indexes of 13.94 and 10.34 kg mm^{-1} was obtained under the crop cultivation with moldboard plowing on the depth of 20-22 cm with the density of 35,000 plants ha^{-1} and no fertilizers applied. Strong close correlation between *WUE* and yield of the crop was determined with the R^2 value of 0.9986. The fact is that the higher crop productivity is, the higher *WUE* is.

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