POLISH JOURNAL OF NATURAL SCIENCES
Abbrev.: Pol. J. Natur. Sc., Vol 34(2): 175–184, Y. 2019

SWEET MAIZE YIELD STRUCTURE DEPENDING ON CULTIVATION TECHNOLOGY UNDER THE DRIP-IRRIGATED CONDITIONS

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Key words: mineral fertilization, irrigation, plant density, ploughing, productivity.

Abstract

The results of the study devoted to cultivation technology effects on the indices of yield structure of sweet maize are presented. Field trials with the crop were carried out during 2014–2016 at the dark-chestnut slightly saline drip-irrigated soil by using the randomized split plot design method in four replications. Three factors were studied in the trials: depth of mouldboard ploughing (20–22, 28–30 cm), nutritive background (no fertilizers, $N_{60}P_{60}$, $N_{120}P_{120}$), plant density (35 000, 50 000, 65 000, 80 000 plants ha^{-1}). Increase in the depth of ploughing and plant density to 80 000 plants ha^{-1} leads to considerable decrease of the structural indices and yields. The best yield structure was obtained under the mouldboard ploughing at the depth of 20–22 cm, nutritive background $N_{120}P_{120}$ and plant density of 35 000 plants ha^{-1}. The highest yields of sweet maize ears with husks (14.00 t ha^{-1}) were achieved under the higher plant density of 65 000 plants ha^{-1}.

Introduction

Sweet maize is a valuable vegetable crop that has high nutritive and dietary value. It is widely cultivated all over the world (EFTHIMIADOU et al. 2009). Most cultivation areas are situated in the USA where sweet maize is a national product. Hungary is the European top producer of high-quality sweet maize (SZYMANEK et al. 2006). Sweet maize becomes more and more popular in Europe from year to year. Demand for fresh and processed sweet maize products increases, and satisfaction of the growing demand requires significant increase in produced gross volumes of the

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crop. Thereby, scientific researches in the field of sweet maize cultivation technology are on the table for modern agricultural science. Previously conducted studies proved that sweet maize yields and their structure depends on a number of natural and anthropogenic factors, viz.: genetic features of the cultivated hybrids (LAZCANO et al. 2011), phytosanitary status of the cultivation area (TURSUN et al. 2016), environmental and weather conditions (GARCIA y GARCIA et al. 2009), water and nutrients availability (MAHARJAN et al. 2016), general peculiarities of cultivation technology (KWABIAH 2004, SAHOO and MAHAPATRA 2004), etc. Special attention in the researches has to be paid to the peculiarities of yield structure formation, because yield structure determines not only yield levels, but qualitative parameters of the obtained yield, such as size and mass of the marketable ears, and these parameters are very important for fresh market realization. The aim of our investigations was to determine effects of some cultivation technology treatments (depth of ploughing, nutritive background, plants density) on the sweet maize yields and their structure under the drip-irrigated conditions of the South of Ukraine.

Materials and Methods

The field experiments were carried out by using the randomized split plot design method in four replications during the period from 2014 to 2016 at the irrigated lands of the Agricultural Cooperative Farm "Radianska Zemlia" (Kherson region, Ukraine). Geographical coordinates of the experimental field are: latitude 46°43′42″N, longitude 32°17′38″E, altitude 42 m. The study envisaged research of the following treatments:

– factor *A* – primary soil tillage (mouldboard ploughing at the depth of 20–22 and 28–30 cm);

– factor *B* – nutritive background (no mineral fertilizers applied; mineral fertilizers applied at rates of $N_{60}P_{60}$ and $N_{120}P_{120}$);

– factor *C* – plants density (35 000, 50 000, 65 000 and 80 000 plants ha^{-1}).

The soil in the field experiments was represented by the dark-chestnut slightly saline soil. The humus content in the arable soil layer was 2.5%. The bulk density of the 0–100 cm soil layer was 1.35 t m^{-3}. The content of the lightly-hydrolyzed Nitrogen was 35 mg kg^{-1}, the mobile Phosphorus content was 32 mg kg^{-1}, the exchangeable Potassium content was 430 mg kg^{-1} in the arable soil layer. The weather conditions during the period of the experiments are presented in the Table 1. The hydrothermal coefficient (HTC) was calculated as a relation of the sum of precipitation to the sum of positive temperatures above 10°C (USHKARENKO et al. 2014).

Table 1

Weather conditions in the field experiments with sweet maize

Month	Decade	Air temperature [ºC]	Relative air humidity [%]	Precipitation amounts [mm]	HTC [units]
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 data (for the period from 1986 until 2005)					
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

We used the variety Brusnytsia (standard sweet – *su,* with duration of vegetation period of 77–79 days) in the field experiments. Sweet maize cultivation technology was based on the common recommendations for cultivation of the crop under the irrigated conditions of the South of Ukraine. The previous crop was winter wheat. Stubbling at the depth of 10–12 cm followed by the mouldboard ploughing was conducted after the harvesting of the previous crop. Mineral fertilizers (ammonium nitrate and superphosphate) were applied with accordance to the experimental design in pre-ploughing period by the means of a seed drill. Soil cultivations at the depth of 8–10, and further at the depth of 5–6 cm were carried out in the spring period. Sweet corn was sown at the depth of 5–6 cm with an inter-row spacing of 70 cm. The time of sowing was: 1st of May in 2014, 22nd of May in 2015 and 21st of May in 2016, respectively. Herbicide Harnes (a.s. – acetochlor, 900 g dm^{-3}) was applied in pre-sowing period in the dose of 2.0 dm^3 ha^{-1}. Karate Zeon insecticide (a.s. – lambda-cyhalothrin, 50 g dm^{-3}) was applied at the stage of 3–5 leaves of the crop in the dose of 0.2 dm^3 ha^{-1}. Master Power herbicide (a.s. – foramsulfuron, 31.5 g dm^{-3}, iodosulfuron, 1.0 g dm^{-3}, tienecarbazon-methyl, 10 g dm^{-3}, cyprosulfamide (antidote), 15 g dm^{-3}) was applied at the stage of 7–8 leaves of the crop in the dose of 1.25 dm^3 ha^{-1}. Koragen insecticide (a.s. – chlorantraniliprole, 200 g dm^{-3}) was applied at the beginning of the flowering stage in the dose of 0.1 dm^3 ha^{-1}. Soil moisture during the crop vegetation was maintained at the level of 80% of the field water-holding capacity by the means of drip irrigation. We applied irrigation water 10 times at the rate of 5 mm before the stage of 7–8 leaves of the sweet maize, and then 12 times at the rate of 10 mm in the further period of the crop vegetation in 2014. In 2015 and 2016 we applied irrigation water in the above-mentioned volumes, but fewer times: 6 and 9 in 2015, 8 and 12 in 2016, respectively. The total volume of the irrigation water applied at the field was 170 mm in 2014, 120 mm in 2015, and 160 mm in 2016.

Sweet maize yields at the technical ripeness stage were hand-harvested and weighed on the digital weighs. Time of harvesting depended on the cultivation technology treatments, and it is given in the Table 2. The number of marketable ears per plant was counted in the pre-harvesting period. Physical sizes (such as diameter and length) of the marketable ears were assessed by the means of calliper.

The experimental data were processed by the means of the multi-factor analysis of variance (ANOVA). The least significant difference (LSD) was estimated at the reliability level of 95%. We used AgroStat add-on for the Microsoft Office Excel as a tool for the statistical evaluation of the experimental data (USHKARENKO et al. 2014).

Table 2

Time of harvesting of sweet maize ears depending on the cultivation technology

Cultivation technology treatments			Years of study		
Mouldboard ploughing depth	nutritive background	plant density [plants ha^{-1}]	2014	2015	2016
20–22 cm	no fertilizers	35 000	15.VII	31.VII	1.VIII
		50 000	15.VII	1.VIII	2.VIII
		65 000	17.VII	1.VIII	2.VIII
		80 000	18.VII	3.VIII	3.VIII
	$N_{60}P_{60}$	35 000	19.VII	3.VIII	4.VIII
		50 000	20.VII	4.VIII	4.VIII
		65 000	22.VII	7.VIII	4.VIII
		80 000	23.VII	8.VIII	4.VIII
	$N_{120}P_{120}$	35 000	21.VII	5.VIII	4.VIII
		50 000	22.VII	7.VIII	4.VIII
		65 000	23.VII	8.VIII	4.VIII
		80 000	25.VII	10.VIII	5.VIII
28–30 cm	no fertilizers	35 000	15.VII	31.VII	4.VIII
		50 000	15.VII	1.VIII	4.VIII
		65 000	17.VII	1.VIII	4.VIII
		80 000	18.VII	3.VIII	4.VIII
	$N_{60}P_{60}$	35 000	19.VII	3.VIII	5.VIII
		50 000	20.VII	4.VIII	5.VIII
		65 000	22.VII	7.VIII	5.VIII
		80 000	23.VII	8.VIII	6.VIII
	$N_{120}P_{120}$	35 000	21.VII	5.VIII	6.VIII
		50 000	22.VII	7.VIII	6.VIII
		65 000	23.VII	8.VIII	7.VIII
		80 000	25.VII	10.VIII	7.VIII

Results and Discussion

The most important yield structure indices for sweet maize are: number of rows per ear, number of kernels per row, length and diameter of ear, ear mass, quantity of marketable ears per 100 plants (Table 3).

All the studied treatments had significant effect on the yield structure indices of sweet maize. We determined that mouldboard ploughing at the depth of 28–30 cm does not have positive effect on the yield structure, unless the crop is cultivated without fertilization (Table 4). This fact could be explained by the peculiarities of nutrition absorption by plants from

Table 3

Sweet maize yield structure depending on the cultivation technology (average for 2014–2016)

Mouldboard ploughing depth	Nutritive background	Plant density [plants ha^{-1}]	Number of				Physical sizes of the marketable ears		
			rows	kernels in a row	kernels per ear	marketable ears per 100 plants	length [cm]	diameter [cm]	mass [g]
20–22 cm	no fertilizers	35 000	14.1	25.5	358	55	16.2	4.3	187
		50 000	13.8	25.2	346	42	16.0	4.2	182
		65 000	13.7	24.7	339	35	15.9	4.2	178
		80 000	13.5	24.3	327	30	15.7	4.1	166
	$N_{60}P_{60}$	35 000	14.4	28.1	405	100	16.9	4.5	203
		50 000	14.2	27.5	388	85	16.6	4.4	192
		65 000	14.1	26.9	378	82	16.4	4.4	188
		80 000	13.9	26.7	371	61	16.3	4.3	181
	$N_{120}P_{120}$	35 000	14.8	30.1	445	120	17.6	4.8	229
		50 000	14.6	28.6	419	102	17.4	4.7	218
		65 000	14.5	28.4	412	100	17.2	4.6	215
		80 000	14.2	27.3	387	75	16.6	4.4	205
28–30 cm	no fertilizers	35 000	14.1	25.5	361	61	16.3	4.3	190
		50 000	14.0	25.2	354	49	16.2	4.3	183
		65 000	13.8	24.9	345	41	16.0	4.2	179
		80 000	13.7	24.5	336	34	15.8	4.1	167
	$N_{60}P_{60}$	35 000	14.3	27.5	394	93	16.5	4.4	193
		50 000	14.1	27.2	383	78	16.3	4.3	186
		65 000	14.0	26.9	376	69	16.1	4.2	183
		80 000	13.7	26.5	363	54	15.9	4.1	169
	$N_{120}P_{120}$	35 000	14.6	28.9	421	105	17.1	4.5	222
		50 000	14.3	28.6	408	88	16.9	4.5	215
		65 000	14.2	28.2	402	80	16.6	4.4	213
		80 000	13.9	27.7	386	60	16.5	4.3	200
LSD (at $p < 0.05$)		*A*	N/*A*		9.63	1.7	0.15	0.08	1.57
		B			12.95	1.2	0.12	0.08	0.78
		C			10.84	2.1	0.19	0.14	2.46
		ABC			30.08	5.4	0.49	0.37	6.14

the soil and mineral fertilizers (USHKARENKO 1994). If we do not provide the crop with additional nutrition in the form of fertilizers it needs to develop more roots and go deeper into the soil profile to find the necessary elements for growth and development. Therefore, sweet maize cultivated with no fertilization shows better performance in yields and their structure at the deeper ploughing, which makes easier for the roots to penetrate down into the soil profile. However, if we give the crop additional artificial nutrition, there is no need to go deeper to find nutrition. In this case, the crop has an opportunity to find all the necessary elements for growth and development in the upper layers. And deep ploughing under the condition of artificial humidification just leads to migration of mineral fertilizers down by the soil profile and makes them less usable for the crops. Increasing crop density is also unreasonable, because it leads to significant decrease of all the studied structural indices because of increasing intro-specie competition and more plants per the same unit of life factors (light, air, nutrition, etc.). Application of mineral fertilizers is a factor of the greatest improvement in the studied parameters of sweet maize yields.

Table 4

Sweet maize yields depending on the cultivation technology [t ha^{-1}] (average for 2014–2016)

Mouldboard ploughing depth	Plant density [plants ha^{-1}]	Nutritive background		
		no fertilizers	$N_{60}P_{60}$	$N_{120}P_{120}$
20–22 cm	35 000	3.60	7.09	9.62
	50 000	3.82	8.14	11.14
	65 000	4.05	10.03	14.00
	80 000	3.99	8.82	12.32
28–30 cm	35 000	4.06	6.29	8.15
	50 000	4.49	7.24	9.45
	65 000	4.78	8.20	11.07
	80 000	4.54	7.30	9.62
LSD (at $p < 0.05$)			*A*	0.07
			B	0.15
			C	0.18
			ABC	0.47

And this fact is not surprising: the better you feed plants, the better productivity they usually show. The highest outlet of the marketable ears with the best visual parameters (sizes and mass) was achieved under the combination of treatments: mouldboard ploughing at the depth of 20–22 cm, plant density 35 000 plants ha^{-1}, nutritive background $N_{120}P_{120}$. The results of our study are in agreement with ones obtained by the foreign scientists in this field. So, we proved that the higher nutritive background is, the better sweet maize yield structure is. And the structural parameters become worse under the higher plant densities (OKTEM and OKTEM 2005). Also, we were not the first who mentioned that maize yields increase due to the better structural parameters under the tillage minimization (TORBERT et al. 2001).

We established that all the studied factors significantly affected the yields of the crop according to the ANOVA results. Previous scientific investigations discovered that better sweet maize yields could be obtained under the conventional tillage system than under the conservation tillage (EDGELL et al. 2015). However, it was defined that increased depth of mouldboard ploughing led to considerable decrease in yields on the fertilized experimental treatments in our study. On average, deep ploughing decreased sweet maize yields by 13.4–14.1%. The best performance of the deep ploughing was established on the non-fertilized variants (sweet maize yields increased by 15.7%), while fertilization levelled the advantages of the deep soil loosening. It is interesting that the results of some other studies report that the best sweet maize yields could be obtained not under the mouldboard, but under the disk ploughing (SHAMS et al. 2015, SHAMSABADI et al. 2017). These differences in the crop productivity could be put on the differences in the conditions of sweet maize cultivation, and differences in used machinery and varieties. Increasing sweet maize plant density from 35 000 to 65 000 plants ha^{-1} is an effective way of productivity increase – in average, it raised by 33.9%. Of course, the ears picked from he plots with plants density of 35 000 plants ha^{-1} were larger than the ones picked from the plots with higher crop density. But a significant increase in the number of ears per area unit provided a bigger increase in total mass of ears than a decrease in the mass of every single ear. However, enormously dense crops cause a negative effect and lead to significant losses of the yields (in average by 11.4%). The same results presenting that too dense crops have lower productivity were obtained earlier (BHATT 2012). We think that this phenomenon is connected with drastically increase of intro-species competition within the crops that fatigue plants, which is reached at the certain point of plants per area unit. And this point of curve will be different for different varieties cultivated under the different environmental and technological conditions. Some researches pointed out that sweet maize yields at different plants densities depend on the genotype features of the cultivated hybrids of the crop (AL-NAGGAR et al. 2015). However, if we discuss green mass yields they are considerably higher under the higher plants density (RAGHAVENDRA et al. 2016). All in all, nutrient management and mineral fertilization seem to be the most important factor of sweet maize productivity (WADILE et al. 2016). Higher fertilization rates significantly increased crop yields: application of mineral fertilizers at rates of $N_{60}P_{60}$ – by to 96.1%, and $N_{120}P_{120}$ – by 168.4% in comparison with non-fertilized treatments. The similar results were earlier obtained by some other scientific groups (AKPAN and UDOH 2017, RIVERA-HERNÁNDEZ et al. 2010). It was determined that sweet maize yields increased by 34%, 44%, 52%, and 54%, respectively, under the application of Nitrogen mineral fertilizers in the doses of 30, 60, 90, and 120 kg ha^{-1} (KHAN et al. 2018). As we see, the question is not of “do we need to fertilize sweet maize”, the question is “how much fertilizers should be applied in this concrete conditions”. However, cultivation technology of sweet maize is a complex system and needs a complex investigation approach. So, our study has a number of limitations and the question of sweet maize agrotechnology remains actual and needs further researches.

Conclusions

1. The results of the investigations showed that the yield and yield structure of sweet maize were significantly affected by the studied factors. However, the strength of the effect was uneven. The highest effect on the studied parameters of the crop productivity had mineral fertilizers, and the least – the depth of mouldboard ploughing.
2. The best parameters of the sweet maize yield structure were provided by the mouldboard ploughing at the depth of 20–22 cm, nutritive background of $N_{120}P_{120}$ and plants density of 35 000 plants ha^{-1} as follows: marketable ears length was 17.6 cm, diameter – 4.8 cm, ears mass in husks – 229.0 g, marketable ears per 100 plants – 119.8.
3. The maximum yield of marketable sweet maize ears with husks was observed under the mouldboard ploughing at the depth of 20–22 cm, nutritive background of $N_{120}P_{120}$ and plants density of 65 000 plants ha^{-1}.
4. There is an obvious tendency of significant increase in sweet maize yields and yield structure with increase of the mineral fertilizers application rate. However, increase of the depth of ploughing considerably decreased the above-mentioned parameters of the crop productivity. Regulation of the plants density is a flexible instrument of adjusting the yields and their parameters for the actual market demands.

Accepted for print 26.11.2018

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