Bulgarian Journal of Agricultural Science, 26 (No 4) 2020, 885–889

Energy efficiency of sweet corn cultivation at drip irrigation in dependence on depth of plowing, fertilization and plants density

Raisa Vozhehova[1], Viktor Ushkarenko[2], Serhii Kokovikhin[1], Iryna Biliaieva[1], Pavlo Lykhovyd[1*], Nataliia Lavrenko[2] and Ivan Mrynskyi[2]

[1]*Institute of Irrigated Agriculture of NAAS, Department of Scientific and Innovative Activities, Transfer of Technologies and Intellectual Property, Kherson, 73483, Ukraine*
[2]*Kherson State Agrarian University, Faculty of Agronomy, Kherson, 73006, Ukraine*
[*]*Corresponding author:* pavel.likhovid@gmail.com

Abstract

Vozhehova, R., Ushkarenko, V., Kokovikhin, S., Biliaieva, I., Lykhovyd, P., Lavrenko, N. & Mrynskyi, I. (2020). Energy efficiency of sweet corn cultivation at drip irrigation in dependence on depth of plowing, fertilization and plants density. *Bulg. J. Agric. Sci., 26 (4)*, 885–889

Modern cultivation technologies should provide resource and energy saving. There is an evident tendency to energy and climate smart agriculture strengthening because of the necessity of natural and energy resource saving. However, very little attention is paid to the questions of scientific substantiation of energy-saving in agriculture at the expense of crops cultivation technologies optimization. Therefore, we consider the subject of energy expenditures optimization at sweet corn production an actual one for modern Ukrainian and international agrarian science, especially because there is a lack of information in modern literature on this question. We studied different options of tillage depth, fertilization and plants density within for sweet corn grown in the drip-irrigated conditions of the semi-arid zone of the South of Ukraine. The study was performed during 2014–2016 in four replications, and provided for the following factors: plowing depth (20–22, 28–30 cm), fertilization doses (no fertilizers, NP 60 and NP 120 kg/ha of active substance applied), plants density (35, 50, 65, 80 thousands of plants/ha). The results of the study proved significant difference in the crop productivity and energy efficiency of the agrotechnology due to the changes in the studied parameters. The best productivity of 10.93 t/ha of marketable ears combined with the highest energy efficiency of the crop cultivation with the coefficient of energy efficiency of 2.44 were provided by the complex with plowing at the depth of 20–22 cm, fertilization dose of NP 120 kg/ha of active substance, 65 thousands of plants/ha.

Keywords: sweet corn; energy efficiency; drip irrigation; cultivation technology

Introduction

Modern agriculture is a great consumer of energy resources. For example, the US agriculture used 1.7 quadrillion Btu of energy in 2002 (Schnepf, 2004). However, it should be oriented to the resource and energy saving technologies, which are not only more environmentally friendly than most conventional cultivation practices but provide better economic efficiency of crop production (Kosinskii & Bondarev, 2014). Energy resources are an important part of agricultural production, and most of them are expensive, so, efficient use of energy is a precondition for efficient conduction of crop production (Crosson & Brubaker, 2016). Besides, efficient use of the energy contained in natural resources (water, solar energy, etc.) not only increases cultivation technology efficiency in general but provides a possibility of decreasing anthropogenic pressure on environment and will help in combating the negative processes, which take place in modern agriculture (soil fertility decrease, freshwater scarcity, warming of global climate, etc.). Thereby, modern agriculture is developing by the trend of "energy-smart" and "climate-smart" agriculture to provide sustainable development of the branch with the least harm to the natural ecosystems (Chen et al., 2008; Khatri-Chhetri et al., 2017). Energy and climate smart agriculture are closely interconnected. For example, modern climate-smart approach is directed on the reduction of greenhouse gas emission into the atmosphere. This might be achieved by a number of agricultural practices improvement, firstly, tillage. Nowadays the trend of tillage minimization, where it is possible, is evident because minimum tillage is one of the most helpful measures of organic carbon emission into the atmosphere, further global warming prevention, and, at the same time, minimum tillage reduces energy consumption of agrotechnologies that leads to resource-saving (Branca et al., 2011, Jat et al., 2014).

The improvements in cultivation technologies of major crops do not end on the tillage minimization. They embrace a number of different optimization tasks related to water and irrigation systems management, fertilization, cropping systems, etc. (Hoef & Siemens, 1975; Vitosh, 1977; Shaozhong, 1998; Diaz et al., 2009). However, the question remains discovered insufficiently at the moment. So, the goal of our study was to determine the best options of plowing depth, fertilization doses and plants density for sweet corn cultivated at irrigation that will provide the best relationship between the crop productivity and efficient use of energy resources.

Material and Methods

Location of the experimental field

The field experiments dedicated to the study of sweet corn cultivation technology were carried out within 2014-2016 at the irrigated plots of the basic experimental field of Kherson State Agrarian University, which is located in Bilozerskyi district of Kherson region (latitude 46°43′N, longitude 32°17′E, altitude of 42 m above the level of the Black Sea) in the South of Ukraine.

Design of the study

The study was performed by using randomized split plot design method in four replications. The studied factors and their variants are as follows:

Factor A – plowing depth (20–22, 28–30 cm);

Factor B – fertilization doses (no fertilizers, NP 60 kg/ha of active substance, NP 120 kg/ha of active substance);

Factor C – plants density at the stage of harvesting (35, 50, 65, 80 thousands of plants/ha).

Soil properties

The soil is represented by the dark-chestnut middle-loamy slightly saline soil that was formed on the basis of loess. The soil is characterized with intermediate natural fertility. The content of humus is 2.5%, potentially available nutrients content in the upper (0–30 cm) layer of the soils: Nitrogen – 35 mg/kg, Phosphorus – 32 mg/kg, Potassium – 430 mg/kg. Water-holding capacity of 0–30 cm layer is 20.5%, wilting point – 7.1%. The bulk density of the soil is 1.22, 1.29, and 1.35 in 0–30, 0–50, and 0–100 cm layer respectively.

Climate and weather conditions

The climate of the zone is semi-arid (Beck et al., 2018). The value of the coefficient of humidity by Selianinov is 0.5-0.7 during the last decades (Ushkarenko et al., 2014). The average annual air temperature is 9.8°C, rainfall amount – 399 mm.

Weather conditions during the experimental researches were contrast. The sum of the effective air temperatures above 10°C averaged to 1880.7°C during the period of the study, while the hottest year was 2014 – 1960.1°C. The driest year was 2016 with 110.6 mm of rainfall during the vegetation of sweet corn. Better conditions of natural humidifica-

Table 1. The list of agrotechnological operations performed at the crop of sweet corn during the experimental researches

The operation	The aggregate used
Stubble plowing at the depth of 10-12 cm	T-150, BDP-6.3
Mineral fertilizers' application	MTZ-100, MVU-900
Plowing (depth with accordance to the design of the experiment)	T-150, PLN-5-35
Harrowing at the depth of 3-4 cm	T-150, ZBR-24
Cultivator tillage in the early spring period at the depth of 8-10 cm	T-150, S-11U, KPS-4
Application of herbicide Harnes (active substance – *acetochlor*, 900 g/L)	MTZ-80, OP-2000
Cultivator tillage (pre-sowing) at the depth of 4–6 cm	T-150, S-11U, KPS-4
Sowing at the depth of 4–5 cm, inter-row spacing of 70 cm (seed rate with accordance to the design of the experiment)	MTZ-80, UPS-12
Application of insecticide Karate Zeon (*lambda cyhalothrin*, 50 g/L)	MTZ-80, OP-2000
Application of herbicide Master Power (*foramsulfuron*, 31.5 g/L; *iodosulfuron*, 1g/L; *thiencarbazone-methyl*, 10 g/L)	MTZ-80, OP-2000
Application of insecticide Koragen (*chlorantraniliprole*, 200 g/L)	MTZ-80, OP-2000
Hand-harvesting	

tion were in 2014 – 122 mm of rainfall. And the best ones were observed in 2015 with 213.6 mm of rainfall (showers were observed most of the summer period).

Cultivation technology

The cultivation technology of sweet corn in the experiments based on the generally accepted recommendations adopted for the crop cultivation in the irrigated conditions of the South of Ukraine. The list of agrotechnological measures performed at the crop is given in Table 1. We used sweet corn Brusnytsia cultivar (*su* type) created at the Institute of Vegeculture and Melon-growing of NAAS (Ukraine).

Data collection

Sweet corn yield was determined in the marketable ears (without husks) by hand-harvesting of the entire area of the experimental plot. Energy efficiency of the cultivation technology was determined by the methodology of Ushkarenko et al. (1997) through the calculation of the coefficient of energy efficiency (Ke), which is the ratio of the energy output to the energy input of the agrotechnology. The coefficient values of <1 testify about bad energy management of agrotechnology, and the coefficients of > 1 (the more the better) are believed to be the proof of rational energy resources use by the cultivation technology of crop. The calculations of the energy efficiency took into account not only the energy inputs for the technology itself but also the energy expenditures related to transporting of the yield to the point of its sale.

Statistical analysis

Significance of the differences in sweet corn yields by the studied variants was evaluated by using the standard technique of multi-factor ANOVA. The calculations were made in automatic mode within MS Excel Software extension AgroStat developed by the scientists of the Institute of Irrigated Agriculture of NAAS and Kherson State Agrarian University (Ushkarenko et al., 2014). Significance of the differences was established bu the least significant difference (LSD) test at the probability level of 95% ($p < 0.05$).

Results and Discussion

The results of cultivation technology energy efficiency evaluation could not be obtained separately without estimation of yield. The results of sweet corn yield evaluation and statistical processing are provided in Table 2.

It was proved that all the studied factors and their interaction had significant effect on the crop yield. The strongest impact on the yield of sweet corn caused fertilization management (with the share of influence by the results of ANOVA – 82.5%), the slightest – tillage depth (the share of the effect – 3%). The best yield was obtained at the variants with tillage depth of 20–22 cm, application of mineral fertilizers in the dose of NP 120 kg/ha of active substance, and plants density of 65 thousands of plants/ha – 10.93 t/ha. The increase of tillage depth to 28–30 cm decreased the crop yield by 13.4–14.1%. Besides, this measure considerably increased energy consumption of the agrotechnology and led to decrease of the energy efficiency, while the increased fertilization doses provided the best productivity under the maximum efficiency of energy use (Table 3). Thickening of sweet corn crops had positive effect on the energy efficiency and productivity only when the raise was from 35 to 65 thousands of plants/ha. Further increase of

Table 2. Yield of sweet corn marketable ears in dependence on the depth of plowing, fertilization and plants density, t/ha (in average for the period of 2014–2016)

Plowing depth, cm (Factor A)	Plants density, thousands of plants/ha (Factor C)	Fertilization doses (Factor B)			Average by the Factor A
		No fertilizer	NP 60 kg/ha	NP 120 kg/ha	
20–22	35	2.67	5.56	7.53	6.22
	50	2.85	6.31	8.81	
	65	3.01	7.67	10.93	
	80	2.96	6.80	9.58	
28–30	35	3.00	4.89	6.23	5.45
	50	3.34	5.55	7.36	
	65	3.57	6.25	8.59	
	80	3.37	5.64	7.56	
Average by the Factor B		3.10	6.08	8.32	
Average by the Factor C		4.98	5.70	6.67	5.99
LSD_{05}: Factor A – 0.10 t/ha; Factor B – 0.07 t/ha; Factor C — 0.12 t/ha; interaction of the Factors ABC – 0.32 t/ha. All the studied variants are significantly different at $p < 0.05$					

Table 3. Energy efficiency of sweet corn cultivation technology (in average for the period of 2014-2016)

Fertilization doses	Plants density, thousands of plants/ha	Indices			
		Energy consumption (MJ/ha)	Energy output (MJ/ha)	Energy increase (MJ/ha)	Coefficient of energy efficiency
Plowing depth of 20–22 cm					
No fertilizers	35	7295.0	9612.0	2317.0	1.32
	50	7582.3	10260.0	2677.7	1.35
	65	7869.2	10836.0	2966.8	1.38
	80	7925.5	10656.0	2730.5	1.34
NP 60 kg/ha	35	10251.9	20016.0	9764.1	1.95
	50	11190.0	22716.0	11526.0	2.03
	65	12796.1	27612.0	14815.9	2.16
	80	11941.9	24480.0	12538.1	2.05
NP 120 kg/ha	35	12337.0	27108.0	14771.0	2.20
	50	13704.3	31716.0	18011.7	2.31
	65	16098.5	39348.0	23249.5	2.44
	80	14829.6	34488.0	19658.4	2.33
Plowing depth of 28–30 cm					
No fertilizers	35	7816.9	10800.0	2983.1	1.38
	50	8273.5	12024.0	3750.5	1.45
	65	8615.9	12852.0	4236.1	1.49
	80	8523.4	12132.0	3608.6	1.42
NP 60 kg/ha	35	9746.4	17604.0	7857.6	1.81
	50	10599.8	19980.0	9380.2	1.88
	65	11470.5	22500.0	11029.5	1.96
	80	10873.1	20304.0	9430.9	1.87
NP 120 kg/ha	35	11256.3	22428.0	11171.7	1.99
	50	12451.5	26496.0	14044.5	2.13
	65	13862.1	30924.0	17061.9	2.23
	80	12821.1	27216.0	14394.9	2.12

plants density caused significant yield and inefficient energy losses.

The energy analysis showed that cultivation technology of sweet corn was efficient at all the studied options with the coefficient of energy efficiency >1 (1.32-2.44). The highest energy efficiency was obtained under the treatment with tillage depth of 20-22 cm, application of mineral fertilizers in the dose of NP 120 kg/ha of active substance, and plants density of 65 thousands of plants/ha – 2.44. The increase of tillage depth to 28-30 cm decreased the energy efficiency by 4.94%, while optimal fertilization (NP 120 kg/ha of active substance) and plants density formation (65 thousands of plants/ha) increased the energy efficiency of the technology by 59.48% and 4.76% respectively.

Quite similar results were obtained by Revto (2013). The author reported about the best energy efficiency of corn cultivation at irrigation in the South of Ukraine by using the agrotechnological complex with plowing at the depth of 28-30 cm, application of NP 120 kg/ha of active substance, and plants density of 100 thousands of plants/ha. The difference with our results is in the depth of plowing, however, we can put it on the peculiarities of overhead sprinkler irrigation technique used by Revto (2013) in the study. Srivastava (2003) and Vilde et al. (2004) claimed about the significant increase of energy efficiency of crop cultivation with minimization of tillage. Alluvione et al. (2011) reported about considerable input in the increase of energy efficiency of cultivation technologies through the balancing of Nitrogen fertilization (the share of influence was 64.7%) and tillage practices (the share of influence was 11.2%). These results are in agreement with ours in regard to the fertilization. The share of tillage in our study was two times less (4.76%). An additional effect of fertilization optimizing might be obtained by proper irrigation management (Mohammadi et al., 2014). Plants density impact on the energy efficiency of crops cultivation has not been studied sufficiently. However, the results of the study with Miscanthus proved that plants density is an efficient way of increasing the net energy output of the crop (Ercoli et al., 1999). Similar results were stated in regard to potato (Koga et al., 2013). All the above-mentioned scientific reports are mainly in agreement with the results of our scientific research. However, the subject still remains insufficiently discovered and needs further thorough investigations.

Conclusions

The maximum energy efficiency of sweet corn cultivation at drip irrigation in the South of Ukraine, together with the highest productivity of the crop, were provided by the following technological operations: plowing at the depth of 20–22 cm, fertilization NP 120 kg/ha of active substance, plants density of 65 thousands of plants/ha. Therefore, we recommend farmers of the South to cultivate sweet corn in the above-mentioned conditions by using this agrotechnological complex.

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Received: June, 5, 2019; *Accepted:* August, 23, 2019; *Published:* August, 31, 2020