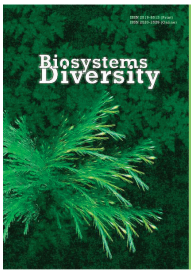

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The effect of tillage system and fertilization on corn yield and water use efficiency in irrigated conditions of the South of Ukraine

R. A. Vozhehova*, M. P. Maliarchuk*, I. M. Biliaieva*, O. Y. Markovska**,
A. S. Maliarchuk*, A. V. Tomnytskyi*, P. V. Lykhovyd*, V. V. Kozyrev*

**Institute of Irrigated Agriculture of the National Academy of Agrarian Sciences of Ukraine, Kherson, Ukraine*
***Kherson State Agrarian University, Kherson, Ukraine*

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Institute of Irrigated Agriculture of the National Academy of Agrarian Sciences of Ukraine, Naddniprianske, Kherson, 73483, Ukraine.
Tel.:+38-066-062-98-97.
E-mail: pavel.likhovid@gmail.com

Kherson State Agrarian University, Stritenska st., 23, Kherson, 73005, Ukraine.
Tel.: +38-050-106-73-08.
E-mail: botanika@ksau.kherson.ua

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Efficient water management in agriculture is an important part of the general programme on water resources preservation. This study is devoted to the determination of the effects of soil processing system and mineral fertilization on the water use efficiency and productivity of grain corn (*Zea mays* Linnaeus, 1753). The trials were conducted in 2017–2018 on irrigated land in the South of Ukraine. The field experiments were carried out on the experimental plots of the Institute of Irrigated Agriculture of the NAAS in four replications. We studied the following agrotechnological parameters and their combinations: Factor A – primary tillage type and depth within different tillage systems in the short crop rotation (grain corn – grain sorghum – winter wheat – soybean); Factor B – application rates of mineral fertilizers (N_0P_0, $N_{120}P_{60}$, $N_{180}P_{60}$). We established that the highest yield of grain accompanied by the best water use efficiency was provided by the cultivation technology with disk cultivator tillage on the depth of 8–10 cm within the differentiated tillage system in the crop rotation under the maximum nutritive background of $N_{180}P_{60}$. This agrotechnological variant resulted in a corn grain yield of 14.51 and 14.59 t/ha in 2017 and 2018 years of the study, respectively. The coefficient of water use efficiency, which is the relation of the water used by the crop to the yield, in this variant was the lowest – 39.6 and 42.0 mm/t in 2017 and 2018, respectively, which indicates the optimum response of corn grain to watering. The worst indexes of water use efficiency and corn productivity were determined in the experimental variant with disk cultivator tillage on the depth of 12–14 cm within the subsoil tillage system within the crop rotation under non-fertilized conditions. We determined that strengthening of the crop nutrition under the rational tillage system in crop rotation is helpful in optimization of the crop water use in the irrigated conditions of the South of Ukraine, which is very important in the current conditions of freshwater scarcity.

Keywords: corn; irrigation; mineral fertilizers; tillage system; water use efficiency; yield.

Introduction

Water is one of the main renewable resources used in the agricultural sector. It is of great importance for agricultural production sustainability. Water resources are unevenly distributed throughout the world. A number of regions (for example, Northern Africa, Central and Western Asia) suffer from severe freshwater scarcity (Rijsberman, 2006), while others have sufficient amounts of available water and even more than necessary for their needs. However, water resources should be evaluated not only by their amounts. Water quality is also a very important factor of suitability for the satisfaction of different needs. And water which is used for irrigation purposes in agriculture has to meet certain requirements because if it fails to do so its application on the fields is harmful and dangerous both for soils and crops (Ayers & Westcott, 1985; Lykhovyd & Lavrenko, 2017; Lykhovyd & Kozlenko, 2018). So, even regions with apparently sufficient water resources may suffer from the lack of this resource because of low water quality. Besides, population increase also leads to a significant rise in the demand for water (Postel, 1992). Therefore, protection and rational use of water resources are among the most important challenges for preservation and sustainable development of almost every branch of the modern economy and healthy life of people.

Plant production requires more water than any other branch of modern industry (Falkenmark, 1989). Sustainable and continuous water supply is an important condition of further development of agriculture in semi-arid and arid regions (Gleick, 1993). The South of Ukraine, especially Kherson region and southern part of Mykolaiv and Zaporizhzhya regions, is characterized as the region of risky agriculture. The climate of the South of Ukraine is semi-arid, with high heat and low precipitation income during the vegetation period. According to one of the classifications, the South of Ukraine belongs to the cold arid zone (Beck et al., 2018). It was determined that according to the observations of the Ukrainian Hydrometeorological Center, the climate of Kherson region can be considered as the warmest and driest in the country (Shevchenko et al., 2014). And it has a tendency to further warming with just a little increase of precipitation that will unavoidably lead to an increase of severity of drought in the region (Lykhovyd, 2018). Therefore, the artificial supply of crops with water will be vital for preservation of sustainable plant production in the modern climatic conditions, which are drastically changing under the impact of global warming processes (Vozhehova et al., 2018). Besides, we should not forget that global changes in climate are also an additional factor of changes in water resources and, perhaps, their increasing scarcity (Meehl et al., 2007).

The questions related to increasing water use efficiency of crops are on the table for modern agrarian science. One of the ways of increasing crop water use efficiency is the introduction of modern cultivation practices based on scientifically substantiated methods of agrotechnology, viz., tillage, fertilization, irrigation scheduling, planting dates, etc. Phene & Beale (1976) stated that implementation of rational agrotechnology can save great amounts of freshwater and increase the efficiency of water use in agricultural production. Howell (2001) is in agreement with the previously mentioned scientists. The previously conducted studies with sweet corn revealed that soil processing method has a significant effect on the efficiency of water use by the crop (Petersen et al., 1985). Improved plant nutrition also resulted in an increase in considerable water use efficiency of corn crops (Souza et al., 2016) as well as with usage of different hybrids (Howell et al., 1998), irrigation rates and population of plants (Al-Kaisi & Yin, 2003; El-Hendawy et al., 2008), tillage improvements (Wagger & Cassel, 1993). However, water use efficiency by crops is dependent on soil and climatic peculiarities of the zone where the certain research was conducted (Garcia y Garcia et al., 2009). That is why it is so important to perform experimental studies related to crop water use efficiency for particular climatic and soil conditions to get an adequate result and provide practical recommendations for agricultural producers.

The main objective of our study determining the effect of two agrotechnological treatments (tillage and fertilization) used for corn cultivation in the climatic conditions of the South of Ukraine on its productivity and water use efficiency. Corn cultivation technology should not only provide the highest yield but it has to be a resource-saving one, especially, when we are talking about water resources.

Materials and methods

Field experiments were conducted on the irrigated lands of the Institute of Irrigated Agriculture of the National Academy of Agrarian Sciences of Ukraine during the period of 2017–2018. The coordinates of the experimental plots are: 46°44′33″ N, 32°42′28″ E. The altitude of the experimental field is 60 m.

The experiments were carried out with accordance to the modern recommendations on conducting field experiments under the conditions of irrigated agriculture (Ushkarenko et al., 2014). The study was conducted in 4 replications. The total area of the experimental plot was 450 m^2, the accounted area was 50 m^2.

The soil of the experimental field was represented by dark-chestnut middle-loamy soil with the depth of humus layer of 40 cm, humus content of 2.3%, total nitrogen content of 0.17%, total phosphorus content of 0.09%, pH of water extract at the level of 6.8–7.3 (neutral).

The study embraced investigation of the impact of two agrotechnological factors on the yield and water use efficiency of corn (*Zea mays* Linnaeus, 1753) crops, namely:

1) Soil tillage (Factor A). We have studied different types of tillage on different depths, paying particular attention to definition of the differences between moldboard, disk and chisel tillage within the short four-field crop rotation (grain corn – grain sorghum – winter wheat – soybean). The design of the study was:

Variant 1 – moldboard plowing on the depth of 20–22 cm within the moldboard tillage system in the crop rotation (A1);

Variant 2 – chisel plowing on the depth of 20–22 cm within the subsoil tillage system in the crop rotation (A2);

Variant 3 – disk cultivation on the depth of 12–14 cm within the subsoil tillage system in the crop rotation (A3);

Variant 4 – disk cultivation on the depth of 8–10 cm within the differentiated tillage system in the crop rotation (A4);

Variant 5 – moldboard plowing on the depth of 18–20 cm after disk cultivation on the depth of 14–16 cm under the previous crop within the differentiated tillage system in the crop rotation (A5).

2) Application rates of mineral fertilizers (Factor B): N_0P_0 (B1); $N_{120}P_{60}$ (B2); $N_{180}P_{60}$ (B3). Mineral fertilizers used in the experiments were ammonium nitrate and super phosphate.

Corn cultivation technology used in the experiments was standard for the irrigated conditions of the South of Ukraine. The previous crop was soybean. Primary tillage in the experiments was conducted with accordance to the experimental design. Mineral fertilizers were applied by the means of a centrifugal fertilizer spreader in two stages. The total amount of phosphorus fertilizers and a half of the nitrogen fertilizers were applied under the primary soil tillage, which was conducted with accordance to the design of the study. In early spring period (March) the rest of the application of nitrogen fertilizers accompanied by harrowing was conducted. The herbicide Acetochlor (900 g/L) in the dose of 2.5 L/ha was applied in pre-sowing period under the cultivator tillage. The hybrid Sov-329SV was sown using a pneumatic seed drill with the rate of 80,000 seeds per hectare on the 28th of April in 2017, and on the 1st of May in 2018. The inter-row spacing was 70 cm. The crop was rolled after sowing. At the early stages of the crop development, the herbicide Rimsulfuron (250 g/kg) in the dose of 50 g/ha was applied to control weeds. Further one inter-row cultivator tillage was performed to keep the crops clean from weeds. Corn grain yield was determined by the harvesting of the entire area of the experimental plot by using a Slavutych harvester on the 13th of September in 2017, and on the 20th of September in 2018. The obtained yield values were further recalculated to the standard moisture of 14%.

Soil moisture during the vegetation of corn was kept up at the level of 75% of the soil water-holding capacity in the layer of 0–100 cm using an overhead sprinkler irrigation machine DDA-100MA. The irrigation norm for the crop was 380 mm in 2017, and 350 mm in 2018. The norm was applied to the field on the demand in the form of irrigation with the rates, which were determined by the formula (Ushkarenko, 1994):

$$m = 10 \times h \times d \times (W_{WC} - W_f),$$

where m is the irrigation rate (mm), h is the depth of soil layer, which should be humidified (cm), d is the bulk density of the soil layer (g/cm^3), W_{WC} is the water-holding capacity of the soil (%), W_f is the current actual soil moisture (%).

The bulk density of the soil was determined by the methodology of Modina, Dolgov and Polsky (Vadiunina & Korchagina, 1986).

Soil moisture was determined in the layer of 0–100 cm every 10 cm using the balance-drier method (Ushkarenko et al., 2014), and it was calculated as a percentage by using the formula:

$$W = \frac{P_e}{P_s} \times 100,$$

where W is the moisture of soil (%), P_e is the mass of the evaporated water (g), P_s is the mass of the absolutely dry soil (g).

There were 6 waterings by 50 mm and 2 waterings by 40 mm in 2017, and 7 waterings by 50 mm in 2018.

The total water consumption of the crop was determined by the balance method of Kostiakov (1960) using the formula:

$$TWC = W + ER + IW,$$

where TWC is the total water consumption, W is the amount of soil moisture used by the crop during its vegetation, ER is the amount of effective rainfall during the crop vegetation, IW is the amount of irrigation water applied to the field.

Water use efficiency by corn was determined by calculation of the coefficient of water use efficiency:

$$WUE = \frac{TWC}{Y},$$

where WUE is the coefficient of water use efficiency (mm/t), TWC is the total water consumption (mm), Y is the yield of corn grain (t).

The amounts of the effective rainfall were obtained at the field agrometeorological station.

Statistical processing of the experimental data was performed by using the standard procedures of the double-factor analysis of variance (ANOVA) at the probability level of 95% by the means of AgroStat add-in for Microsoft Excel package (Ushkarenko et al., 2014).

Results

The study of the soil moisture dynamics under the crops (Tables 1, 2) allowed us to observe such tendencies: the highest amounts of the soil moisture (on average for 2017–2018 – 279.1 mm) during the years of the study at the beginning of the crop vegetation were observed at the moldboard plowing at the depth of 20–22 cm, while the lowest ones (on average for 2017–2018 – 268.6 mm) were under the treatment with disk cultivator at the depth of 12–14 cm. To the maturity stage of corn, the situation with the soil moisture changed. The highest moisture content was at the moldboard plowing at the depth of 18–20 cm and disk cultivation at the depth of 12–14 cm (on average for 2017–2018 – 182.6 mm), while the lowest one (on average for 2017–2018 – 174.1 mm) was under the shallow disk tillage at the depth of 8–10 cm. The highest deficit of the soil moisture in the critical (10–11 leaves and tasseling) stages of the crop growth and development was fixed (100.1 mm in 2017, and 145.2 mm in 2018) under the primary tillage with disks at the depth of 8–10 cm. The best moisture supply in these stages, which is obvious through the lowest water deficit, was provided in the variant with disk cultivator tillage at the depth of 12–14 cm in 2017 (80.4 mm), and in the variant with moldboard plowing on the depth of 18–20 cm in 2018 (121.3 mm).

The above-mentioned facts and some discrepancy between the soil moisture contents and water deficits certify that the highest amounts of the soil moisture are not the guarantee of avoidance of the water stress because it does not necessarily provide the best water use regime and cannot ensure the absence of high water deficit.

It is also obvious that we could not avoid great water deficit in the crops, which reached the values of more than 100 mm in the both years of the study before the maturity stage.

Table 1
Dynamics of the soil moisture in the layer of 0–100 cm under the corn crops at different tillage treatments in 2017

Tillage variant	Soil moisture content by the stages of the crop growth and development, mm											
	first leaf collar			10–11 leaves			tasseling			maturity		
	total	productive	deficit	total	productive	deficit	total	productive	deficit	total	productive	deficit
Moldboard plowing, 20–22 cm	272.1	138.2	28.2	210.1	76.1	90.2	291.9	157.9	8.5	170.6	36.7	129.7
Chisel plowing, 20–22 cm	270.7	136.8	29.6	215.7	81.8	84.6	296.1	162.2	4.2	163.6	29.6	136.7
Disk cultivation, 12–14 cm	267.9	134.0	32.4	220.0	86.0	80.4	300.3	166.4	0.0	169.2	35.2	131.1
Disk cultivation, 8–10 cm	270.7	136.8	29.6	211.5	77.6	88.8	289.1	155.1	11.3	166.4	32.4	134.0
Moldboard plowing, 18–20 cm	269.3	135.4	31.0	212.9	79.0	87.4	294.7	160.7	5.6	172.0	38.1	128.3

Table 2
Dynamics of the soil moisture in the layer of 0–100 cm under the corn crops at different tillage treatments in 2018

Tillage variant	Soil moisture content by the stages of the crop growth and development, mm											
	first leaf collar			10–11 leaves			tasseling			maturity		
	total	productive	deficit	total	productive	deficit	total	productive	deficit	total	productive	deficit
Moldboard plowing, 20–22 cm	286.2	152.3	14.1	221.4	87.4	79.0	239.7	105.8	60.6	184.7	50.8	115.6
Chisel plowing, 20–22 cm	280.6	146.6	19.7	227.0	93.1	73.3	246.8	112.8	53.6	188.9	55.0	111.4
Disk cultivation, 12–14 cm	269.3	135.4	31.0	232.7	98.7	67.7	242.5	108.6	57.8	196.0	62.0	104.3
Disk cultivation, 8–10 cm	273.5	139.6	26.8	218.6	84.6	81.8	236.9	102.9	63.4	181.9	47.9	118.4
Moldboard plowing, 18–20 cm	282.0	148.0	18.3	231.2	97.3	69.1	248.2	114.2	52.2	193.2	59.2	107.2

The highest amounts of the soil moisture, which were used by corn crops in the experiments per one day, were determined under the moldboard and chisel tillage on the depth of 20-22 cm: 4.71, 4.72, 4.75 mm in 2017, and 4.71, 4.64, 4.64 mm in 2018, respectively. The lowest rate of water use per one day was determined during the disk cultivator tillage on the depth of 12-14 cm: 4.61 mm in 2017, and 4.50 mm in 2018, respectively (Tables 3, 4).

Table 3
Total water consumption of corn from the soil layer of 0–100 cm depending on tillage in 2017 (mm)

Indexes	Tillage variants				
	A1	A2	A3	A4	A5
Starting soil water content	282.0	276.4	267.9	282.0	277.8
Final soil water content	170.6	163.6	169.2	166.4	172.0
Soil water used	111.4	112.8	98.7	115.6	105.8
Effective rainfall	78.8	78.8	78.8	78.8	78.8
Irrigation water applied	380.0	380.0	380.0	380.0	380.0
Total water consumption	570.2	571.6	557.5	574.4	564.6
Daily evapotranspiration	4.71	4.72	4.61	4.75	4.67

Table 4
Total water consumption of corn from the soil layer of 0–100 cm depending on tillage in 2018 (mm)

Indexes	Tillage variants				
	A1	A2	A3	A4	A5
Starting soil water content	286.2	280.6	269.3	273.5	282.0
Final soil water content	184.7	188.9	196.0	181.9	193.2
Soil water used	101.5	91.6	73.3	91.6	95.9
Effective rainfall	170.5	170.5	170.5	170.5	170.5
Irrigation water applied	350.0	350.0	350.0	350.0	350.0
Total water consumption	622.0	612.1	593.8	612.1	616.4
Daily evapotranspiration	4.71	4.64	4.50	4.64	4.67

Total water consumption of corn crops reached the maximum of 574.4 mm for the variant with disk cultivator tillage at the depth of 8–10 cm in 2017, whereas the highest value of the index (622.0 mm) in 2018 was determined for the variant with moldboard plowing at the depth of 20–22 cm. This difference in the water consumption was related to the differences in rainfall amounts and distribution, differences in the temperature regime of the vegetative period. The least volume of the soil water used by the crops was determined in the variants with disk cultivation at the depth of 12–14 cm both in 2017 and 2018 years of the study: 98.7 and 73.3 mm, respectively. A general decrease for all the studied tillage treatments in the soil water uptake rates by corn in 2018 was caused by significantly higher (2.2 times) amounts of the effective rainfall in comparison to 2017.

The analysis of total water consumption of corn in the experiments allowed us to detect general tendencies of the structure of the crop water use depending on tillage (Table 5). The main incoming part of the water balance of the experimental field belonged to irrigation water with the share of 66–68% in 2017, and 57–59% in 2018. The share of the effective rainfall in 2018 was much higher than in 2017 due to the weather conditions. This caused a decrease in the value of the available soil moisture for the crop from 18–20% in 2017 to 12–16% in 2018.

It does not matter how eloquent are the above-mentioned results of the study, they are insufficient to make general conclusions without calculation of the main parameter of water use efficiency – the coefficient of water use by the crop. Calculation of this index needs consideration of the crop yield. Corn grain productivity is presented in the Tables 6, 7. The yield was determined by taking into account not only different soil tillage methods but also different nutrition of the crops.

We determined that the highest productivity of the crop was provided by the cultivation technology with disk cultivation on the depth of 8–10 cm (10.30 and 9.95 t/ha on average by the variant in 2017 and 2018, respectively). However, the productivity in 2018 with moldboard plowing at the depth of 20–22 cm was not significantly less than the above, as is proved by the ANOVA results (the difference of 0.27 t/ha is lower than the LSD value of 0.41 t/ha). Thus, it is also considered as a good option for the crop cultivation. Significantly better productivity of corn was achieved in the variants with the maximum rate of mineral fertilizers application $N_{180}P_{60}$. The yield of grain in these variants averaged 13.20 and 13.45 t/ha in 2017 and 2018, respectively. The other two nutrition backgrounds were considerably worse and could not reach the competitive level of the crop productivity. As a result of yield and water consumption estimation we calculated the value of the coefficient of water use efficiency (Tables 8, 9).

As it was determined, the lowest value of the coefficient (72.4 and 80.3 mm/t) was provided by disk cultivator tillage at the depth of 8–10 cm. The most irrational water use was observed in the variants with disk cultivation at the depth of 12–14 cm, which resulted in the highest values of the coefficient (107.8 mm/t in 2017 and 107.0 mm/t in 2018). However, the above mentioned differences could not be considered statistically reliable by the results of ANOVA. Concerning another studied factor (rates of application of mineral fertilizers), we established an evident tendency of considerable decrease in the water use coefficient with an increase in the rates of application of mineral fertilizers, especially, when comparing the variants of N_0P_0 and $N_{120}P_{60}$, $N_{180}P_{60}$. The decrease was not so dramatic with further strengthening of the crop nutrition to $N_{180}P_{60}$ .Moreover, it is insignificant by the ANOVA results. Therefore, the best water use efficiency was provided by the variant with disk cultivation at the depth of 8–10 cm under the nutritive background of $N_{180}P_{60}$, namely, 39.6 mm/t in 2017 and 42.0 mm/t in 2018.

Table 5
Water balance of the experimental field depending on tillage in 2017–2018

Tillage variant	Total water consumption, mm		Water balance											
			soil water used				effective rainfall				irrigation water			
			2017		2018		2017		2018		2017		2018	
	2017	2018	mm	%	mm	%	mm	%	mm	%	mm	%	mm	%
A1	570.2	622.0	111.4	20	101.5	16	78.8	14	170.5	27	380.0	66	350.0	57
A2	571.6	612.1	112.8	20	91.6	15	78.8	14	170.5	28	380.0	66	350.0	57
A3	557.5	593.8	98.7	18	73.3	12	78.8	14	170.5	29	380.0	68	350.0	59
A4	574.4	612.1	115.6	20	91.6	15	78.8	14	170.5	28	380.0	66	350.0	57
A5	564.6	616.4	105.8	19	95.9	16	78.8	14	170.5	27	380.0	67	350.0	57

Table 6
Corn grain yield depending on tillage
and mineral fertilizers in 2017 (t/ha, 4 replications)

Tillage variant (Factor A)	Mineral fertilizer application rates (Factor B)			Average by the Factor A
	N_0P_0	$N_{120}P_{60}$	$N_{180}P_{60}$	
Moldboard plowing, 20–22 cm	4.21	11.35	14.09	9.88
Chisel plowing, 20–22 cm	3.82	10.78	13.57	9.39
Disk cultivation, 12–14 cm	2.87	7.77	9.72	6.79
Disk cultivation, 8–10 cm	4.43	11.97	14.51	10.30
Moldboard plowing, 18–20 cm	3.92	10.52	13.87	9.43
Average by the Factor B	3.85	10.50	13.20	–

Note: the LSD at P < 0.05 is: A – 0.43, B – 1.22, AB – 2.08 t/ha.

Table 7
Corn grain yield depending on tillage
and mineral fertilizers in 2018 (t/ha, 4 replications)

Tillage variant (Factor A)	Mineral fertilizer application rates (Factor B)			Average by the Factor A
	N_0P_0	$N_{120}P_{60}$	$N_{180}P_{60}$	
Moldboard plowing, 20–22 cm	3.89	10.82	14.32	9.68
Chisel plowing, 20–22 cm	3.57	10.39	13.75	9.24
Disk cultivation, 12–14 cm	3.06	8.25	10.11	7.14
Disk cultivation, 8–10 cm	4.17	11.09	14.59	9.95
Moldboard plowing, 18–20 cm	3.46	10.81	14.09	9.45
Average by the Factor B	3.63	10.35	13.45	–

Note: the LSD at P < 0.05 is: A – 0.41, B – 1.59, AB – 6.15 t/ha.

Table 8
The coefficient of water use efficiency
of corn in 2017 (mm/t, 4 replications)

Tillage variant (Factor A)	Mineral fertilizers application rates (Factor B)			Average by the Factor A
	N_0P_0	$N_{120}P_{60}$	$N_{180}P_{60}$	
Moldboard plowing, 20–22 cm	135.4	50.2	40.5	75.4
Chisel plowing, 20–22 cm	149.6	53.0	42.1	81.6
Disk cultivation, 12–14 cm	194.2	71.8	57.4	107.8
Disk cultivation, 8–10 cm	129.7	48.0	39.6	72.4
Moldboard plowing, 18–20 cm	144.0	53.7	40.7	79.5
Average by the Factor B	150.6	55.3	44.1	–

Note: the LSD at P < 0.05 is: A – 40.42, B – 71.33, AB – 28.79 mm/t; the difference between the variants of mineral fertilizers application rates of $N_{120}P_{60}$ and $N_{180}P_{60}$ on the water use efficiency of corn was insignificant; tillage did not cause significant effect on the index.

Discussion

The results of our study proved significant dependence of the water use by corn crops upon tillage options in the short four-field crop rotation and mineral fertilization rates. Some scientists outside Ukraine have also researched the problem of agrotechnological regulation of the above-mentioned parameter. For example, there was a study reporting about the dependence of the water use efficiency and productivity of baby corn on the irrigation regime and plants spacing (Dutta et al., 2015). Strong dependence of corn water use efficiency on the irrigation regimes and rates was also clearly determined by some other scientific groups in different environmental and agrotechnological conditions (Irmak et al., 2016; Kresovic et al., 2016). The high impact of the terms of sowing on the crop water use efficiency was established by the Chinese scientists (Lu et al., 2017). Besides, significant differences in corn productivity and water use efficiency were established under the conditions of China in dependence on tillage: subsoil tillage resulted in 12.7–15.2% increase of the water use efficiency in comparison to rotary plowing, not to mention crucial increase in the yield (by 644.5–673.9 kg/ha) (Tao et al., 2015). This fact supports the results obtained in our study, namely, that minimization of tillage leads to water conservation and increases efficiency of its usage. Jones et al. (1969) have proved that the no-till option both with and without mulch provided the best soil moisture saving, resulted in corn yield increase by 1932 kg/ha, and was the most favourable soil processing option for water conservation. In the dryland studies conducted in 1991–1995 near Garden City, KS, corn also provided very good response to no-till soil processing, so no-till was considered to be a good option for soil and water resources preservation (Norwood, 1999). A comparison of no-till, pure conventional plowing, and plowing followed by disking on different types of soils showed that no-till was not appropriate for corn cultivation only on heavy clay, poorly drained soils (Dick & Van Doren, 1985). So, the tendency, which was discovered in our study and in the researches outside Ukraine, is evident: the less the depth of tillage is, the better water use efficiency of corn is. But in some cases deep ripping of soil is better than other tillage practices on irrigated lands because it provides better rooting of the crop, and results in higher yields and water use efficiency (Bennie & Botha, 1986).

Table 9
The coefficient of water use efficiency
of corn in 2018 (mm/t, 4 replications)

Tillage variant (Factor A)	Mineral fertilizers application rates (Factor B)			Average by the Factor A
	N_0P_0	$N_{120}P_{60}$	$N_{180}P_{60}$	
Moldboard plowing, 20–22 cm	159.9	57.5	43.4	86.9
Chisel plowing, 20–22 cm	171.5	58.9	44.5	91.6
Disk cultivation, 12–14 cm	190.4	72.0	58.7	107.0
Disk cultivation, 8–10 cm	146.8	52.0	42.0	80.3
Moldboard plowing, 18–20 cm	178.2	57.0	43.7	93.0
Average by the Factor B	169.4	59.5	46.5	–

Note: the LSD at P < 0.05 is: A – 28.73, B – 82.73, AB – 21.34 mm/t; the difference between the variants of mineral fertilizers application rates of $N_{120}P_{60}$ and $N_{180}P_{60}$ on the water use efficiency of corn was insignificant; tillage did not cause significant effect on the index.

Fertilizers have a direct effect on water use efficiency of crops due to their ability to change transpiration intensity, growth pattern and productivity of crops (Viets, 1962). For example, fertilized corn succeeded better in consumption of soil moisture during trials conducted on sandy soils because of better root development and distribution by the soil profile (Linscott et al., 1962). Nitrogen fertilizers were proved to change water requirements of crops, which will inevitably lead to changes in water use efficiency. For example, rational fertilization improved water use efficiency of crops cultivated in the experiments in Nebraska by 29% (Olson et al., 1964). Corn water use efficiency is significantly improved by higher nitrogen rate (from 1.93–2.33 to 2.51–2.62 kg/m), as shown in the Ph. D. research of Singh (2013). An increased nitrogen nutrition was proved to be an important factor of efficiency increase in irrigation water use: the best index in field experiments conducted in Iran was 1.8 kg of grain per 0.1 mm of water, and this value was obtained under the treatment of crops with the maximum nitrogen fertilizer dose of 200 kg/ha (Gheysari et al., 2015). However, the study also reports the possible rise in the sensitivity of crops to water stress under the higher nitrogen fertilization. Besides, drip fertigation with sufficient amounts of mineral fertilizers drastically increases corn grain yield and water use efficiency (Wu et al., 2019). And there are several reports which are in contradiction to our results. Hernandez et al. (2015) found no significant effect of nitrogen fertilization on the parameter of water use efficiency in the rain-fed conditions with limited volume of available water for corn plants. Research by Hatfield & Prueger (2001) proved the absolutely opposite to our tendency of corn water use efficiency, namely, they stated about the decrease of the crop water use efficiency with strengthening of nitrogen nutrition. We should mention the fact that separate enhancement of water or nitrogen supply of corn cannot result in considerable improvement of the crop yield and water use efficiency, these two elements of cultivation technology have to be optimized simultaneously to obtain the best performance (Li et al., 2019). The results of our study certify that significant increase in corn productivity and water use efficiency in irrigated conditions is possible with increased mineral fertilization.

That is to say that the main reason for the strong connections between the water use efficiency and cultivation technology elements is in the changes related to productivity of crops, which occur as a result of the agrotechnological effect on them. Therefore, significant increase of water use efficiency could be achieved by improvement of cultivation technology with the aim of providing the highest crop productivity under the particular agro-environmental conditions. This statement was proved by the results of our study, because it was established that the most rational and effective use of water resources was provided by the crops with the highest productivity because in this case the additionally applied water for irrigation gives the highest outlet in the form of the yield. The results of Welde & Gebremariam (2016) also showed strong direct correlation between corn yield and irrigation water use efficiency.

Besides, the results of our study are true for the irrigated conditions of the South of Ukraine with its climatic peculiarities. Also, it should be taken into account that the research was conducted in the particular short crop rotation (corn-sorghum-winter wheat-soybean) with specific tillage. Therefore, the obtained results have some limitations and should not be extrapolated to other territories with different agro-environmental and agrotechnological conditions of agricultural production without previous assessment.

Conclusions

The highest grain productivity of corn was provided by the cultivation technology with disk primary tillage at the depth of 8–10 cm (within the differentiated tillage system in the crop rotation) and mineral fertilizers dose of $N_{180}P_{60}$ – 14.51 t/ha in 2017, and 14.59 t/ha in 2018, respectively. Comparatively equal corn grain yields were achieved by the agrotechnological complex with plowing at the depth of 20–22 cm (within the moldboard tillage system in the crop rotation) under the same nutrition – 14.09 tha in 2017, and 14.32 t/ha in 2018, respectively.

The most efficient water use of the crops, which is proved by the lowest coefficient of water consumption per the unit of yield, was determined for the experimental variants with disk primary tillage on the depth of 8–10 cm (within the differentiated tillage system in the crop rotation) and mineral fertilizers dose of $N_{180}P_{60}$ – 39.6 mm/t in 2017, and 42.0 mm/t in 2018, respectively. Taking into account the above-mentioned statements achieved in the results of our experimental research work we recommend corn grain producers of southern Ukraine to cultivate corn on irrigated lands within crop rotations by using the differentiated tillage system, and use shallow disk tillage at the depth of 8–10 cm as a primary soil processing for the corn crops. We also recommend providing the crop with sufficient amount of nutrition, namely, application of mineral fertilizers in the dose of $N_{180}P_{60}$ in two stages: first, application of half of the total nitrogen amount and full phosphorus amount in the fall period, and further application of the remaining amount of nitrogen under the pre-sowing cultivator tillage. The recommended elements of corn cultivation technology will provide the best productivity of the crop accompanied by efficient water use, and ensure sustainable grain production in the region under the condition of economical use of water resources.

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