Scientific Papers. Series A. Agronomy, Vol. LXV, No. 1, 2022
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

WATER CONSUMPTION AND EFFICIENCY OF IRRIGATION OF MAIZE HYBRIDS OF DIFFERENT FAO GROUPS IN THE SOUTHERN STEPPE OF UKRAINE

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Abstract

The results of research on the influence of irrigation methods and regime on the processes of total water consumption and irrigation efficiency in the cultivation of maize hybrids of different FAO groups in the Southern Steppe of Ukraine are presented. It is confirmed that the method of irrigation, the genotype of the hybrid significantly affects the formation of water regime of the soil and the productivity of corn. The use of drip irrigation provides the highest levels of grain yield (16.09-16.72 t·ha^{-1}*) at the lowest specific water consumption for the formation of the unit of yield (water use efficiency) – 365.90-376.13 m*^{3}*·t*$^{-1}$*, the highest payback of irrigation water by yield increase (3.95-4.16 kg·m*$^{-3}$*) when using FAO 400-440 hybrids adapted to irrigation conditions. According to the absolute parameters of irrigation water consumption, surface drip irrigation is the most economical. Hybrids with adequate response to the level of soil moisture and provide grain yield: without irrigation - 2.89-3.01 t·ha*$^{-1}$* (drought-resistant), with water-saving irrigation regime - 9.45-9.51 t·ha*$^{-1}$* (homeostatic type), with the optimal irrigation regime - 14.85-16.72 t·ha*$^{-1}$* (intensive type).*

Key words: *irrigation methods, water consumption, maize, hybrids, water use efficiency.*

INTRODUCTION

Climate change is leading to an increase in areas of insufficient natural moisture, which puts agriculture at risky production conditions. This is especially true of the Southern Steppe, where there is an annual shortage of natural moisture. In this region, soil and air droughts have recently become more frequent, which does not allow to realize the yield potential of agricultural crops, in particular corn. Among cereals, corn is one of the most productive and important crops in the world. It is quite drought–resistant and responds well to improved soil moisture, so much of the area in southern Ukraine is sown with corn on irrigated lands, where it provides two to three times higher yields (Vozhehova et al., 2021).

Only thanks to irrigation, the south of Ukraine remains a zone of guaranteed production of high-quality corn grain. Of great importance is the choice of environmentally friendly technologies, technical means of irrigation, and hybrids of corn of different FAO groups with an appropriate response to agri-environmental growing conditions (Shatkovsky et al., 2020).

The need for rational use of water resources in irrigated agriculture and increase the productivity of reclaimed lands logically follows from the economic essence and features of irrigation as the main factor in increasing soil fertility in conditions of insufficient moisture.

Obtaining high yields of irrigated crops is ensured by conducting a range of agro-ameliorative techniques and measures. Irrigation regime serves in this complex as the core in which other agronomic techniques are formed. Violation of the irrigation regime causes an antagonistic ratio of elements of soil fertility, resulting in a sharp decrease in watering efficiency (Lobell and Field, 2007).

Irrigation regime is primarily determined by soil and climatic conditions and biological characteristics of crops. It is also significantly influenced by the method and technique of irrigation, water supply, hydromodule of irrigation, hydrogeological and geomorphological conditions, the level of agricultural technology, the degree of drainage of the territory and others. All this leads to the use of almost different options for irrigation. In a particular agro–climatic zone, it must meet the water needs of plants throughout their growth, ensure high crop yields and increase the fertility of irrigated lands, preventing erosion, waterlogging and salinization of the soil (Silber et al., 2003).

With the optimization of all components of the irrigated agriculture system, it is possible to obtain consistently high yields of crops annually. Thus, by improving the water and nutrient regimes of the soil at a high technological level of agriculture, it is possible to increase yields by 2-3 times, and in dry years - by 4-5 times (Barlog & Frckowiak-Pawlak, 2008).

An important component of the agricultural system is the method of irrigation, which, along with improving the moisture content of plants, enhances the action of other factors in the direction of increasing yields and increasing net income. In addition, it is important to study the characteristics of water consumption of plants, as these experimental data can be used to optimize artificial moisture by supplying the required amount of water during periods of maximum need (in the so-called "critical periods" of plant growth and development) (Gadzalo et al., 2020).

In the modern practice of irrigated agriculture in Ukraine, two main methods of irrigation are used – sprinkling and drip surface irrigation. Drip surface irrigation is spreading rapidly in arid conditions and in Ukraine, where it is currently used on more than 70 thousand hectares. This method of irrigation allows you to quickly adjust soil moisture, but the technical efficiency and cost-effectiveness of this method is still poorly understood (Romashchenko et al., 2016).

The timeliness of the next vegetative watering is the main condition in the development and implementation of the irrigation regime. Several methods are used to set the timing of irrigation of crops, including corn for grain. The most scientifically sound and proven in production is the method of assigning the next term of watering by soil moisture. Of great importance is the correct installation of the lower threshold of moisture, at which time it is recommended to water again. The threshold is expressed as a percentage of LM (lowest moisture content) of the soil - the amount of water retained by the soil in natural (field) conditions after complete drainage of gravitational moisture. The size of LM characterizes the water holding capacity of the soil. The main criterion in determining the timing of vegetative irrigation is the lower limit of optimal soil moisture, which varies in the range of 60-90% of the lowest moisture content (LM). Soil drying, in which soil moisture exceeds this limit, leads to a sharp decrease in crop yields (Gheysari et al., 2021; Allen et al., 1998).

The amount of annual precipitation and their seasonal distribution are crucial for agricultural production (Sun et al., 2010). It was found that low water content in the soil during sowing slows down the germination process, reduces the percentage of germination and sowing density (Passioura et al., 2006; Domínguez et al., 2011). However, if plants use too much water before flowering, further water stress caused by lower rainfall leads to premature aging of the plant, low yields or poor grain quality (Angus & van Herwaarden, 2001).

Water use efficiency (WUE) of plants depends on the quantities, timing and watering rates. Deficit irrigation, defined as the use of water below the total needs of plants, is an important tool to reduce the use of water for irrigation. Improving the efficiency of irrigation through the use of scarce irrigation is an important management practice, especially in regions with severe water shortages. Increasing the frequency of irrigation with a reduced rate can increase the evaporation of moisture from the soil surface, affect yields, as well as WUE, which must be taken into account when planning a method of irrigation (Zhang et al., 2010; Garcia y Garcia et al., 2009).

Studies conducted by Oktem A. (2008) to determine the ratio of yield and quality of maize grown under drip irrigation in Sanliurfa

(Turkey), showed, that the yield response factor (ky) or the ratio of decrease in relative yield to decrease in relative water consumption varied from 0.82 to 1.43, and the water-saving rate ranged from 10.9 to 31.1%. The relationship between cob yields and irrigation was statistically significant ($P < 0.01$), and yields decreased with increasing irrigation deficit. Maximum values of leaf area index were obtained at full irrigation, whereas the lowest values were found at 30% water deficiency. The values of the deficit irrigation stress index increased with decreasing water application. (Oktem, 2008).

An important element of water consumption is the genotypic characteristics of corn. A field survey to obtain the characteristics of seed and grain maize using the CROPWAT model allowed the calculated water demand for irrigation (IWR) of these two types of maize. Water needs for irrigation of seed and grain corn during the growing season were 470.1 and 488,5 mm respectively. However, there were large differences in the sequence of water consumption for these two types of corn. Prior to mid – July, evapotranspiration and IWR of seed corn were 14.3% and 20.1% higher, respectively, than those of field corn. In September, the IWR of the two corn types began to decrease, with a value of 82.3 mm for seed corn, which was 32.1% lower than the IWR of field corn (108.7 mm) during the same period , but significant differences in watering time and water quantity during one-time watering of seed and grain corn in the study area was not (Tan & Zheng, 2017).

In the irrigation regime of corn, it is important to consider the depth of water absorption. It was found that in the Great Plains of China, corn showed significant plasticity relative to the depth of water absorption. It mainly absorbed water from a depth of 0-10 cm (23.4-46.7%), 10-20 cm (33.3-35.8%) and 20-40 cm (20.9-26.3%) in the early stages of growth, and then changed the sources of water absorption - absorbed it from a depth of 10-20 cm (22.3-24.7%), 20-40 cm (23.7-28.1%) and 40-60 cm (25.7-39.0%) at later stages of growth (Sun et al., 2010).

In the study, water was applied to sweet corn as 100, 90, 80 and 70% of evaporation from corresponding to 2-, 4-, 6- and 8- day irrigation frequencies, respectively. The highest values of total water efficiency (TWUE) were 1.38 and 1.24 kg m^{-3} at 4-day watering frequency in two different years, respectively. The highest values for irrigation water use efficiency (IWUE) was 1.66 kg m^{-3} at 4-day irrigation frequency and 1.59 kg m^{-3} at 6-day irrigation frequency. The results of this research indicate that a 2-day irrigation frequency, with 100% ET water application by a drip system, will be optimal for sweet corn grown in semi-arid regions similar to that in Turkey where the work was conducted (Oktem et al., 2003).

In the work of Lv et al. (2011) changes in water consumption of wheat and corn under different humidification conditions (optimal level of irrigation and water conservation) were studied. The efficiency of water use and the potential of water savings in the irrigation of corn and wheat are analyzed. Grain yield at the optimal level of irrigation was higher compared to the water–saving irrigation regime, with higher water efficiency. Thus, optimization of irrigation can simultaneously achieve a stable yield and high water efficiency (Lv et al., 2011).

Yield and water consumption are two important indicators of water conservation and high-yield farming (Gornott & Wechsung, 2016; Liu et al., 2018). Studies of water consumption by crops of different stages of growth of corn at relative soil moisture 60%, 70% and 80% showed that the maximum corn grain yield was obtained by maintaining the lower soil moisture limit of 70%, but with a shortage of water resources for conventional irrigation should recommend a lower limit of relative soil moisture, i.e. 60% (Wang et al., 2015).

Studies of Ertek A. & Kara B. (2013) and to determine the effects of different levels of irrigation (I_{100}: full irrigation; I_{85}: 15% deficit; I_{70}: 30% deficit; I_{55}: 45% deficit and I_{40}: 60% deficit) on yield and yield components, sugar and protein content in fresh sweet corn showed that the lowest and the highest plant water consumptions (E_t) were found in I_{40} (240-406 mm) and I_{100} (348-504 mm) treatments in both years. Water scarcity has affected the yield of fresh maize, the components of the crop, the quality and efficiency of water use. The lowest fresh ear yields were determined in I_{40} treatments in both years, respectively. The highest fresh ear yields were obtained from I_{100}. Maize fresh ear yields were significantly affected by water deficits. Low irrigation levels decreased the ear yields. However, it was clearly observed that I_{70} treatment could be a water-saving treatment without a significant decrease in yield. In addition, the highest protein content and sugar amount was also observed in I_{70} treatment (Ertek & Kara, 2013).

The limiting factor in the productivity of grain corn in the steppe of Ukraine is the unfavorable water regime of soils (Dudka, 2013). Possible areas for obtaining high and sustainable yields in these conditions are the creation of new drought–resistant hybrids and the development of more efficient methods of adaptive cultivation technologies aimed at maximizing moisture conservation (Vozhehova et al., 2022; Marchenko, 2019). The increase in yield from the optimization of water regime is the most significant and ranges from 100 to 380% compared to non-irrigated conditions (Shatkovskyi, 2015). High irrigation efficiency has contributed to the expansion of irrigated areas under corn in Ukraine to 175 thousand hectares (Fomichov, 2019), and the main method of irrigation is sprinkling. Therefore, the use of new irrigation methods and optimization of soil water regime is the main stabilizing factor in maize cultivation.

An important factor in increasing the grain yield of corn with different moisture content is the use of modern innovative maize hybrids, created by special breeding programs and have a genotypically adaptive response to specific agri-environmental conditions (Dziubetskyi & Cherche, 2017).

Therefore, substantiation of optimal methods of moisture supply and selection of hybrids that adequately respond to soil moisture is an important issue to increase the efficiency of agricultural production in the arid conditions of southern Ukraine.

MATERIALS AND METHODS

The research was conducted during 2018-2020 in the research field of the Institute of Irrigated Agriculture of the NAAS of Ukraine, located in the agro-ecological zone of the Southern Steppe of Ukraine. The soil of the experimental area is dark chestnut, slightly saline, medium loamy. The total amount of annual precipitation is on average according to long-term data - 373 mm, including during the growing season of corn - 150 mm.

Soil moisture was determined by thermostatic weighting method in four replicates. Soil samples were taken in layers 10 cm at a depth of 0-50 cm after five days to determine the timing of irrigation and 0-100 cm to calculate the total water consumption of corn.

Total water use of the crops - by the method of water balance without considering the recharge of groundwater (Allen et al., 1998; Vozhehova, 2012).

The total water use for the growing season, as well as for the separate interphase periods of the crops in the crop rotation, was determined by the method of water balance by the formula (1) (Allen et al., 1998; Vozhehova, 2012):

$$E = M + O + (Wh - Wk), \qquad (1)$$

where: E - total water use, $m^3 \cdot ha^{-1}$; M - irrigation rate, $m^3 \cdot ha^{-1}$; O - precipitation, $m^3 \cdot ha^{-1}$; Wh - moisture content in the active soil layer at the beginning of the growing season, $m^3 \cdot ha^{-1}$; Wk - moisture content in the active soil layer at the end of the growing season, $m^3 \cdot ha^{-1}$.

The coefficient of water use of crops in the crop rotation on irrigated lands was determined by the formula (2) (Allen et al., 1998; Vozhehova, 2012):

$$WUE = E/Y, \qquad (2)$$

where: WUE - water use efficiency, $m^3 \cdot t^{-1}$; E - total water use for the growing season, $m^3 \cdot ha^{-1}$; Y - yield of the crop, $t \cdot ha^{-1}$.

To establish the indicators of total water consumption and irrigation efficiency of maize hybrids of different FAO groups under different irrigation methods used: sprinkler irrigation, drip surface irrigation, natural moisture. Repeat four times, sown area of the second order - 75 m^2, accounting - 50 m^2. To establish the rate of response of maize hybrids of different FAO groups to irrigation regimes, we used a pre–surprise humidity level of 60, 80% for sprinkler irrigation and 80, 85% for drip irrigation.

The research used modern innovative hybrids of corn, which were created under special programs for drought resistance and adaptability to irrigation (Dziubetskyi & Cherchel, 2017; Marchenko, 2019).

Agricultural techniques for growing maize hybrids in the experiments were generally accepted for the southern part of Ukraine.

The predecessor is soy. Processing of research results was carried out by the method of analysis of variance using a package of computer programs Agrostat (Ushkarenko et al., 2014).

The aim of our research was to determine the response of maize hybrids of different FAO groups to different methods of irrigation and moisture.

RESULTS AND DISCUSSIONS

Proper design of water regime and its regulation in accordance with agri-environmental conditions are based on information about the biological needs of crops in moisture. Thus, the key issue of the irrigation regime is the total water consumption, which means the amount of moisture consumed by plants for transpiration and evaporation from the soil surface. Total water consumption is a complex indicator that reflects the amount of water consumed by the crop for transpiration and formation of biological mass of plants, as well as for physical evaporation from the soil. Total water consumption is not a constant indicator, it varies considerably depending on the weather conditions of the growing season, the moisture content of plants, the level of agricultural technology, etc (Xue, 2017).

Our observations in 2018-2020 showed that the total water consumption of crops varies depending on the hybrid composition (factor A). On average, by FAO hybrid groups, the maximum total water consumption of maize plants 2923-6560 $m^3 \cdot ha^{-1}$ was found in FAO hybrids 420-440 by all methods of sowing moisture. According to the factor B (method of moisture supply), the highest indicator was found for sprinkler irrigation - 4216-6560 $m^3 \cdot ha^{-1}$ depending on the FAO group (Table 1).

Table 1. Simple water consumption of maize hybrid plants of different FAO groups and its components

Method of moisture supply of crops	Total water consumption, $m^3 \cdot ha^{-1}$	Components of the water consumption balance					
		moisture used from soil reserves		precipitation		irrigation rate	
		$m^3 \cdot ha^{-1}$	%	$m^3 \cdot ha^{-1}$	%	$m^3 \cdot ha^{-1}$	%
FAO hybrids 180-190							
Without watering, control	2719	1240	46	1479	54	0	0
drip irrigation	3959	830	21	1479	37	1650	42
sprinkling	4216	877	21	1479	35	1860	44
hybrids 250-290							
without watering, control	2801	1314	47	1487	53	0	0
drip irrigation	4464	847	19	1487	33	2130	48
sprinkling	4732	885	19	1487	32	2360	49
FAO hybrids 300-380							
without watering, control	2847	1360	48	1487	52	0	0
drip irrigation	5647	910	16	1487	26	3250	58
sprinkling	5812	945	16	1487	26	3380	58
FAO hybrids 420-440							
without watering, control	2923	1386	47	1537	53	0	0
drip irrigation	6052	915	15	1537	23	3600	59
sprinkling	6560	956	15	1537	25	4067	62

The maximum total water consumption of 6052-6560 $m^3 \cdot ha^{-1}$ in the soil layer 0-100 cm on average for 2018-2020 was established in FAO hybrids 420-440 under drip irrigation and sprinkling.

The maximum amount of moisture used by crops of maize hybrids from soil reserves was observed in the option without watering – 46-48%.

It was found that when growing hybrids of corn without irrigation, water consumption of hybrids is due to rainfall and soil moisture and depended on the FAO group. In late–maturing hybrids, the rate of utilization of soil moisture and precipitation increased due to the lengthening of vegetation by 58-146 $m^3 \cdot ha^{-1}$. The share of precipitation and soil moisture in the total water consumption of hybrids of all

FAO groups was almost the same – 52-54% and 46-48%.

The total water consumption of hybrids increased mainly due to irrigation. In the water balance, the share of irrigation moisture increased from 42% in precocious hybrids to 62% in late–ripe FAO 440 hybrids. FAO 180-190 hybrids showed less dependence on soil moisture reserves and precipitation.

During the cultivation of maize under irrigation, the total water consumption of FAO 320-380 and FAO 420-440 hybrids over the years of research increased compared to control areas, almost doubled and amounted to 5647-5812 and 6052-6560 $m^3 \cdot ha^{-1}$ in accordance. At the same time, the irrigation rate in the total water consumption of FAO 320-380 hybrids and FAO 420-440 hybrids accounted for an average of 58 and 62%. The use of soil moisture by FAO 320-380 hybrids was 16%, and precipitation was used by 26%, which is almost twice less than the crops of hybrids of the same FAO group without irrigation. FAO 420–440 hybrids had a similar structure of moisture use, which indicates that these hybrids are predominantly dependent on artificial irrigation.

Under irrigation, the amount of precipitation during the growing season is a significant (23, 37%) share of the balance of total water consumption of maize hybrids. The share of precipitation use is much higher in FAO hybrids 180-290 (32, 37%), which indicates a lower need for moisture in hybrids with a shortened growing season. Thus, in years with a high level of natural moisture supply, the need for irrigation of these hybrids decreases.

The efficiency of moisture use, as shown by the experience of domestic and foreign researchers, can be determined on the basis of the indicator of moisture efficiency - WUE (water use efficiency) (Allen, 1998) and payback of irrigation water by increasing grain yield under irrigation. All these parameters are determined by the value of total water consumption, irrigation rate and crop yield. Thus, the coefficient of water consumption characterizes the total amount of moisture consumed per unit yield; the coefficient of irrigation efficiency characterizes the consumption of irrigation water per unit increase in yield from irrigation and moisture efficiency – the amount of crop produced per unit of moisture used.

Our research has shown that improving the conditions of moisture supply by artificial irrigation leads to a decrease in WUE in maize hybrids of different FAO groups (Table 2).

According to factor A (hybrid) the smallest water use efficiency , on average over the years of research, was observed in hybrids of FAO 420-440 Hileia and DN Olena - 365.90 and 376.13 $m^3 \cdot t^{-1,}$ respectively. The method of irrigation had a significant impact on the total water consumption. The minimum values of this indicator by factor B (irrigation method) – 365.90 $m^3 \cdot t^{-1}$ recorded in the hybrid Hileya under drip irrigation. The method of irrigation by sprinkling increased the water consumption coefficient by 15-19%. Without irrigation, WUE increased sharply in FAO 180-190 almost twice to 814.07 to 826.44 $m^3 \cdot t^{-1}$. Even greater WUE growth was observed in later FAO 300–380 hybrids from 1330.37-1388.78 $m^3 \cdot t^{-1}$ to 1554.79-1873.72 $m^3 \cdot t^{-1}$ in FAO 420–440. On average, for all irrigation methods, the lowest WUE rates were observed for drip irrigation.

WUE indicators of maize hybrids indicate an increased level of moisture efficiency for the formation of 1 ton of grain under drip irrigation using intensive maize hybrids. Stepovyi, Pyvykha (FAO 180-190) maize plants use moisture most efficiently with natural moisture supply. These hybrids are created according to special selection programs for drought resistance, so they are suitable for growing without watering.

An indicator such as the payback of irrigation water by the additionally obtained grain harvest due to irrigation is also quite important (see Table 2). On the average for three years of researches on all hybrids with carrying out vegetative watering this indicator varied from 2.87 $kg \cdot m^{-3}$ at watering by sprinkling, to 4,16 $kg \cdot m^{-3}$ on drip irrigation, which indicates the prospects for the use of drip irrigation.

This indicates the need to grow maize hybrids on irrigated lands of the relevant FAO groups. With natural moisture, it is necessary to use hybrids with high drought resistance. The drought resistance coefficient of such hybrids should be in the range of 0.3-0.4 (see Table 2), only FAO hybrids 180-190 can provide grain yield without irrigation in the range of 3-3.5 $t \cdot ha^{-1}$, with an additional increase in grain yield increased in hybrids with a longer growing season. The highest payback of irrigation water was observed in FAO 420-440 hybrids 3.95-4.16 kg·m^{-3}, created for irrigated agriculture.

Table 2. Water use efficiency, drought resistance and payback of irrigation water of maize hybrids of different FAO groups depending on irrigation methods (average for 2018-2020)

The method of moisture supply (factor A)	Hybrid (factor B)	Crop capacity, t·ha^{-1}	Total water consumption, m^3·ha^{-1}	Water use efficiency, m^3·t^{-1}	Drought resistance coefficient	Payback of irrigation water by increasing grain yield, kg·m^{-3}
FAO hybrids 180-190						
Without watering, control	DN Pyvykha	2.89	2719	826.44	–	–
	Stepovyi	3.01	2719	814.07	–	–
drip surface	DN Pyvykha	8.84	3959	447.85	0.327	3.61
	Stepovyi	9.01	3959	439.40	0.334	3.64
sprinkling	DN Pyvykha	8.52	4216	494.84	0.339	3.03
	Stepovyi	8.34	4216	505.52	0.361	2.87
hybrids 250-290						
Without watering, control	DN Halateia	2.55	2801	1098.43	–	–
	Skadovs\`kyi	2.47	2801	1134.01	–	–
drip surface	DN Halateia	10.55	4464	423.13	0.242	3.76
	Skadovs\`kyi	10.73	4464	416.03	0.230	3.88
sprinkling	DN Halateia	10.14	4732	466.67	0.251	3.22
	Skadovs\`kyi	10.25	4732	461.66	0.241	3.30
FAO hybrids 300-380						
Without watering, control	DN Demetra	2.05	2847	1388.78	–	–
	Tronka	2.14	2847	1330.37	–	–
drip surface	DN Demetra	14.53	5647	388.64	0.141	3.84
	Tronka	14.05	5647	401.92	0.152	3.66
sprinkling	DN Demetra	13.87	5812	419.03	0.148	3.50
	Tronka	13.55	5812	428.93	0.158	3.38
FAO hybrids 420-440						
Without watering, control	Hileia	1.56	2923	1873.72	–	–
	DN Olena	1.88	2923	1554.79	–	–
Drip surface	Hileia	16.54	6052	365.90	0.094	4.16
	DN Olena	16.09	6052	376.13	0.117	3.95
sprinkling	Hileia	16.05	6560	408.72	0.097	3.56
	DN Olena	15.56	6560	421.59	0.121	3.36
LSD$_{05}$, t·ha^{-1} factor A	0.13					
factor B	0.15					
AB interaction	0.17					

The fundamental direction of increasing the yield of corn is the introduction of new hybrids of intensive type, because the grain productivity of the hybrid is a genetic trait, and not every hybrid will be able to recoup the cost of harvesting under irrigation.

Today, in a fairly wide range of hybrids of this grain crop grown in Ukraine, only some have the genetic ability (potential) to ensure the proper cultivation technology to obtain high yields at 14-17 t·ha^{-1}.

An important role in increasing yields and improving the quality of corn grain belongs to the correct selection of hybrids for cultivation (Lavrynenko et al., 2015).

To establish the response of newly created hybrids to soil moisture regime and irrigation methods, studies were conducted with options: 1) irrigation by sprinkling with a pre-irrigation soil moisture level of 65% LW (pre-irrigation moisture level 65%, water-saving regime); 2) irrigation sprinkling pre-irrigation moisture level 80% LW; 3) drip irrigation with a pre-irrigation soil moisture level of 80% LW; 4) drip irrigation with pre-irrigation moisture level 85% (pre-irrigation moisture level 85%, optimal mode). Such irrigation regimes and irrigation methods correspond to the most typical parameters of corn cultivation technologies on irrigated lands (Table 3).

Table 3. Grain yield ($t \cdot ha^{-1}$) of modern maize hybrids under different irrigation methods and irrigation regime

Hybrid	FAO	Irrigation by sprinkling, RPVG 65% HB	Irrigation by sprinkling, RPVG 80% HB	Drip irrigation, RPVG 80% HB	Drip irrigation, RPVG 85% HB
DN Pyvykha	180	8.32	8.52	8.84	9.03
Stepovyi	190	7.87	8.34	9.01	9.38
DN Halateia	260	8.45	10.14	10.55	10.78
Skadovs`kyi	290	9.51	10.25	10.73	10.89
DN Demetra	300	8.14	13.87	14.53	14.85
Tronka	390	9.08	13.55	14.05	14.49
DN Olena	420	8.35	16.05	16.54	16.72
Hileia	420	8.94	15.56	16.09	16.36
LSD_{05}		0.23	0.28	0.31	0.33

Hybrids of FAO 180-190 DN Pyvykha, Stepovyi showed stability of yield under different irrigation regimes. The use of FAO hybrids 180-190 is expedient under conditions of water-saving irrigation regimes on irrigated lands with low hydromodule.

Hybrids of FAO 260-290 DN Halateia and Skadovs`kyi show the maximum yield under drip irrigation of pre-irrigation moisture level 85% LW 10.78-10.89 $t \cdot ha^{-1}$ and reduce the yield under water–saving irrigation - 65% LW. But the reduction in yield is not critical, so it is permissible to grow FAO 260-290 hybrids on irrigation systems with low hydromodule.

The hybrids of DN Demetra and Tronka (FAO 300-390) showed a strong reaction of the hybrids to the ecological gradient of cultivation. The yield of hybrids of this type decreases sharply with the use of water-saving irrigation regimes. These hybrids are of the intensive type and dramatically reduce grain yields compared to FAO 190-280 hybrids. The use of FAO 300-390 hybrids under water–saving irrigation regimes is impractical and may lead to poor yields. The genotypic productivity potential of these hybrids can be revealed only under the conditions of intensive technologies. For pre-irrigation moisture level 85% and drip irrigation grain yield of hybrids Tronka, DN Demetra reached 14.49-14.85 $t \cdot ha^{-1}$.

In the FAO group 400-420 hybrids of corn of intensive type DN Olena, Hileia provide grain yield of 15.56-16.72 $t \cdot ha^{-1}$ under drip irrigation and sprinkling. Hybrids of this type should not be used on irrigated lands with low hydromodule and water-saving irrigation regimes, as this leads to significant crop losses and they become uncompetitive with modern FAO hybrids 190-280.

The conducted research confirmed the perspective direction of research of scientists (Romashchenko et el 2015; Repilevsky and Ivaniv, 2021) in the direction of improving the irrigation regime of crops taking into account the reduction of irrigation water costs, increasing the efficiency of irrigation in climate change in the direction of aridity. Irrigation, in combination with other agricultural practices, is a key factor in intensifying growth corn in the south of Ukraine. The south of Ukraine has a strong potential for grain production, but suffers from insufficient natural moisture. Therefore, today an important area of stabilization of crop production is the scientific justification of artificial moisture supply of plants through the use of new irrigation methods and the use of varietal productivity potential of modern varieties and hybrids adapted to specific agri-environmental conditions and technologies (Dziubetskyi & Cherchel, 2017; Prysiazhnuk et al., 2016). Created new innovative maize hybrids have broad adaptive capabilities, but the process of determining agronomic indicators of varieties and hybrids requires the development of varietal technologies to provide specific recommendations for production (Gadzalo, 2020; Babych, 2014; Kokovikhin & Bilyaeva, 2017). The presented research materials extend the direction of research that combines breeding and genetic development and improvement of varietal technologies with the definition of adaptation parameters of new genotypes and further recommendations for production.

CONCLUSIONS

On the basis of the conducted researches it is confirmed that irrigation, in a complex with other agricultural receptions, is the key factor of intensification of growth processes and formation of productivity of grain corn crops.

Studies have shown that the maximum total water consumption of 6052-6560 $m^3 \cdot ha^{-1}$ in the soil layer 0–100 cm on average for 2018-2020 was established in FAO hybrids 420-440 under drip irrigation and sprinkling .

It was investigated that on average for three years of research on all hybrids with vegetative irrigation the payback rate of irrigation water ranged from 2.87 kg m^{-3} for sprinkling to 4.16 kg m^{-3} on drip irrigation, which indicates the prospects of using drip irrigation.

The maximum grain yield was shown by maize hybrids of intensive type DN Olena, Hileia under drip irrigation of pre-irrigation moisture level 85% - 16.36-16.72 $t \cdot ha^{-1}$.

When growing maize hybrids with a longer growing season, the payback of irrigation water increased compared to early and middle-early groups. This gives grounds to recommend drip irrigation as the best method of irrigation for growing corn in the steppes of Ukraine with a severe shortage of water resources. Maize hybrids of different FAO groups with selectively programmed response to water-saving and optimal irrigation regimes have been established. You are divided into drought-resistant homeostatic hybrids that can be used in non-irrigated conditions.

REFERENCES

Allen, R.G., Pereira, L.S., Raes, D., & Smith, M. (1998). Crop evapotranspiration – guidelines for computing crop water requirements. *FAO Irrigation and Drainage, 300*(9), D05109.

Angus, J.F., & van Herwaarden, A.F. (2001). Increasing water use and water use efficiency in dryland wheat. *Agronomy Journal, 93*. 290–298.

Babich, A.O. (2014). Soybean irrigation regime in drought and dry conditions. *Agrarian Week, 15*. 24–25.

Barlog, P., & Frckowiak-Pawlak, K. (2008). Effect of mineral fertilization on yield of maize cultivars differing in maturity scale. *Acta Sci. Pol. Agricultura, 7*. 5–17.

Domínguez, A., Tarjuelo, J.M., de Juan, J.A., López-Mata, E., Breidy, J., & Karam, F. (2011). Deficit irrigation under water stress and salinity conditions: The MOPECO-salt model. *Agricultural Water Management, 98*(9), 1451–1461.

Dudka, V.V. (2013). Cereals on drip irrigation. *Proposal, 3–4*(213–214), 72–82.

Dziubetskyi, B., & Cherchel, V. (2017). Productivity of grain of early hybrids of corn of different strain changings. *Bulletin of Agricultural Science, 95*(8), 19–23.

Ertek, A., & Kara, B. (2013). Yield and quality of sweet corn under deficit irrigation. *Agricultural Water Management, 129*. 138–144.

Fomichov, M. (2019). Irrigation as the factor enhancing the efficiency of agricultural crops production in Ukraine. *Ekonomika ta derzhava, 4*. 92–96.

Gadzalo, Ya.M., Vozhehova, R.A., Kokovikhin, S.V., Bilyaeva, I.M., & Drobitko, A.V. (2020). Scientific substantiation of corn cultivation technologies on irrigated lands taking into account hydrothermal factors and climate change. *Irrigated Agriculture, 73*. 21–26.

Garcia y Garcia, A., Guerra, L.C., & Hoogenboom, G. (2009). Water use and water use efficiency of sweet corn under different weather conditions and soil moisture regimes. *Agricultural Water Management, 96*(10), 1369–1376.

Gheysari, M., Pirnajmedin, F.P., Movahedrad, H., Majidi, M.M., & Zareian, M.J. (2021). Crop yield and irrigation water productivity of silage maize under two water stress strategies in semi-arid environment: Two different pot and field experiments. *Agricultural Water Management, 255*. 106999.

Gornott, C., & Wechsung, F. (2016). Statistical regression models for assessing climate impacts on crop yields: A validation study for winter wheat and silage maize in Germany. *Agricultural and Forest Meteorology, 217*. 89–100.

Kokovikhin, S.V., & Bilyaeva, I.M. (2017). Productivity and economic efficiency of growing of hybrids of the corn depending on the methods of watering and protection of plants in the south of Ukraine. *Scientific reports of the National University of Life and Environmental Sciences of Ukraine, 4*(168), 1–9.

Lavrynenko, Yu.O., Hlushko, T.V., & Marchenko, T.Yu. (2015). Adaptive potential of maize hybrids of FAO groups 190-500 in the southern of Ukraine. *Irrigated agriculture, 63*. 24–28.

Liu, Z., Yu, X., Jia, G., Zhang, J., & Zhang, Z. (2018). Water consumption by an agroecosystem with shelter forests of corn and Populus in the North China Plain. *Agriculture, Ecosystems & Environment, 265*. 178–189.

Lobell, D.B., & Field, C.B. (2007). Global scale climate-crop yield relationships and the impact of recent warming. *Environmental Research, 2*. 1–7.

Lv, L., Wang, H., Jia, X., & Wang, Z. (2011). Analysis on water requirement and water-saving amount of wheat and corn in typical regions of the North China Plain. *Frontiers of Agriculture in China, 5*. 556–562.

Marchenko, T.Yu. (2019). Innovative elements of cultivation technology of corn hybrids of different FAO groups in the conditions of irrigation. In *Natural sciences and modern technological* *solutions: knowledge integration in the XXI century*. Lviv, Torun: Liha-Pres.

Oktem, A. (2008). Effect of water shortage on yield, and protein and mineral compositions of drip-irrigated sweet corn in sustainable agricultural systems. *Agricultural Water Management, 95*(9), 1003–1010.

Oktem, A., Simsek, M., & Oktem, A.G. (2003). Deficit irrigation effects on sweet corn (*Zea mays saccharata* Sturt) with drip irrigation system in a semi-arid region: I. Water-yield relationship. *Agricultural Water Management, 61*(1), 63–74.

Passioura, J. (2006). Increasing crop productivity when water is scarce-from breeding to field management. *Agricultural Water Management, 80*. 176–196.

Prysiazhniuk, L.M., Shovhun, O.O., Korol, L.V., & Korovko, I.I. (2016). Assessment of stability and plasticity of new hybrids of maize (*Zea mays* L.) under the conditions of Polissia and Steppe zones of Ukraine. *Plant Varieties Studying and Protection, 2*(31), 16–21.

Repilevsky, D.E., & Ivaniv, M.O. (2021). Moisture supply and water consumption of crops of hybrids of corn at various ways of watering in the conditions of the south of Ukraine. *European Journal of Technical and Natural Sciences Scientific journal, 6*. 25–32.

Romashchenko, M.I., Tarariko, Y.O., Shatkovsky, A.P., Saidak, R.V., & Soroka, Yu.V. (2015). Scientific principles of agricultural development in the Steppe zone of Ukraine. *Bulletin of Agricultural Science, 10*. 5–9.

Romashchenko, M., Shatkowski, A., & Zhuravlev, O. (2016). Features of application of the Penman–Monteith method for conditions of a drip irrigation of the steppe of Ukraine (on example of grain corn). *Journal of Water and Land Development,* 31(X–XII), 123–127.

Shatkovsky, A.P., Cherevichny, Yu.A., Zhuravlev, A.V., & Marinkov, O.A. (2015). Improving the technology of drip irrigation of corn hybrids DEKALB®. *Grain, 6*(111), 150–151.

Shatkovskyi, A.P. (2016). Drip irrigation regimes, water consumption and productivity of corn in the Steppe zone of Ukraine. *Taurian Scientific Bulletin, 95*. 100–105.

Shatkovskyi, A.P., Zhuravlov, O.V., & Ovchatov, I.M. (2020). Irrigation regimes and water consumption of soybeans and corn depending on irrigation methods. *Taurian Scientific Bulletin, 115*. 262–269.

Silber, A., Xu, G., & Wallach, R. (2003). High irrigation frequency: The effect on plant growth and on uptake of water and nutrients. *Acta Horticulturae, 627*. 89–96.

Sun, H., Shen, Y., Yu, Q., Flerchinger, G.N., Zhang, Y., Liu, C., & Zhang, X. (2010). Effect of precipitation change on water balance and WUE of the winter wheat – summer maize rotation in the North China Plain. *Agricultural Water Management, 97*. 1139–1145.

Tan, M., & Zheng, L. (2017). Different irrigation water requirements of seed corn and field corn in the Heihe River basin. *Water, 9*(8), 606.

Ushkarenko, V.O., Vozhegova, R.A., Goloborodko, S.P., & Kokovikhin, S.V. (2014). Methods of field experiment (Irrigated agriculture). Kherson: Grin D.S.

Wang, S., Liu, D., Wang, K., & Meng, P. (2015). Fuzzy comprehensive evaluation on water consumption characteristics and yield of summer corn under different furrow irrigation patterns. *Transactions of the Chinese Society of Agricultural Engineering, 31*(24), 89–94.

Xue, J., Guan, H., Huo, Z., Wang, F., Huang, G., & Boll, J. (2017). Water saving practices enhance regional efficiency of water consumption and water productivity in an arid agricultural area with shallow groundwater. *Agricultural Water Management, 194*. 78–89.

Vozhehova, R., Lavrynenko, Yu., Kokovikhin, S., & Pysarenko, P. (2012). *Guidelines on executive calculation of irrigation regimes and forecasting crops irrigation by moisture deficit: scientific and methodical guidelines*. Kherson: IZZ NAAS.

Vozhehova, R., Marchenko, T., Piliarska, O., Lavrynenko, Y., Halchenko, N., & Lykhovyd, P. (2021). Grain corn product yield and gross value depending on the hybrids and application of biopreparations in the irrigated conditions. *Scientific Papers Series "Management, Economic Engineering in Agriculture and Rural Development" 21*(4), 611–619.

Vozhehova, R., Marchenko, T., Lavrynenko, Y., Piliarska, O., Zabara, P., Zaiets, S., Tyshchenko, A., Mishchenko, S., & Kormosh, S. (2022). Productivity of lines – parental components of maize hybrids depending on plant density and application of biopreparations under drip irrigation. *Scientific Papers Series "Management, Economic Engineering in Agriculture and Rural Development", 22*(1), 695–704.

Zhang, X.Y., Chen, S.Y., Sun, H.Y., Wang, Y.M., & Shao, L.W. (2010). Water use efficiency and associated traits in winter wheat cultivars in the North China Plain. *Agricultural Water Management, 97*. 1117–1125.