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DRIP IRRIGATION REGIMES AND EFFICIENCY OF WATER USE BY SUNFLOWER HYBRIDS

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Abstract. *The article presents the results of experimental research on the effect of drip irrigation system designs on the formation of irrigation regimes, productivity, and efficiency of water use by sunflower hybrids. In addition, the main components of evapotranspiration were taken into account, and coefficients of water consumption (WCC), irrigation efficiency (IE), and irrigation water use efficiency (WUE) were chosen as criteria for the efficiency of drip irrigation. Short-term field research was carried out during 2020–2022 on the lands of the Brylivske experimental field of the Institute of Water Problems and Reclamation of the National Academy of Agricultural Sciences (Kherson region, subzone of the Dry Steppe). Analytical and mathematical as well as statistical methods were used to process experimental data. The scheme of the three-factor field experiment provided various options for laying irrigation pipelines of drip irrigation systems (in the horizontal and vertical planes), as well as the implementation of a pulsed water supply mode (standard). The version with a natural moisture supply (without irrigation) was the control. The results of experimental research proved that the method of laying drip irrigation pipelines had a direct effect on the parameters of the formation of drip irrigation regimes and the productivity of sunflower hybrids in the conditions of the Dry Steppe. The mechanism of evapotranspiration formation of sunflower crops in irrigated and non-irrigated conditions has been determined. It was statistically proven that the application of subsoil drip irrigation with the laying of irrigation pipelines at a depth of 0.3 m and a distance between them of 1.0 m is the most appropriate for growing sunflower hybrids. This is explained by biological features, namely drought resistance of this crop. Thus, in field experiments, the variant with in-soil laying of drip irrigation pipelines provided almost identical yield (4.01–4.09 t/ha) when having lower crop water consumption coefficients (1088.7–1125.7 m^3/t) and higher efficiency of irrigation water use – 2.27–2.41 kg of grain per 1 m^3 of irrigation water.*

Keywords**:** *drip irrigation, subsoil drip irrigation, water consumption coefficient, irrigation efficiency coefficient, evapotranspiration, irrigation regime, sunflower*

Relevance of research. Over the past decades, the agricultural sector of the southern region of Ukraine has reoriented itself to the cultivation of drought-resistant, highly liquid, and marginal crops. In this regard, sunflower has a leading place, as this crop occupies the largest cultivated areas. Thus, as of 2021, sunflowers occupied about 20% or 6.43 million ha of the total crop structure [1]. Such dynamics can be considered negative, as it does not meet the requirements of scientifically based crop rotations and reduces soil fertility [2; 3; 4]. At the same time, the climate change trend towards aridity [5; 6; 7] is a significant factor in the further increase in the cultivated area of this crop. It is obvious that this path of development is extensive. An alternative and, at the same time, intensive direction is the application of irrigation. Over the past 5–10 years, the irrigated areas under sunflowers have grown dynamically and by 2022 they amounted to more than 70.000 hectares, of which more than 90% was under sprinkling [8].

The "Strategy of Irrigation and Drainage in Ukraine" [9] defines that the development of irrigation should be based exclusively on a new, water- and energy-saving concept. Micro-irrigation methods are ideal for this: drip irrigation with above-ground and underground placement of irrigation pipelines, as well as pulsed drip irrigation. Because of this, the conducted research on the substantiation of irrigation regimes and determination of the efficiency of water use by sunflower hybrids under drip irrigation is relevant.

Analysis of recent research and publications. Both domestic and foreign scientists have conducted a fairly significant set of studies aimed at studying the water regime and effectiveness of irrigation for sunflowers. In Ukraine, these experiments were carried out mainly when using sprinkler irrigation [10; 11; 12], while foreign scientists paid considerable attention to the cultivation of sunflowers by applying drip irrigation. They, in particular, specified the optimal parameters of the water regime [13], evapotranspiration and water use efficiency [14], growth processes and productivity on saline soils [15], and when using mineralized water for irrigation [16]. In the Steppe zone of Ukraine, very little attention has been paid to the efficiency of water use by sunflower crops under drip irrigation, and some local experiments were conducted by the Institute of Irrigated Agriculture of the National Academy of Agricultural Sciences [17; 18].

Therefore, **the research aimed** to specify the actual regimes of drip irrigation, and crop productivity and determine the efficiency of water use by sunflower hybrids depending on different designs of drip irrigation systems.

Research materials and methods. Field research was carried out within the land of the EE "EF "Brylivske" of the Institute of Water Problems and Land Reclamation of the National Academy of Agricultural Sciences (Privitne village, Vynogradivska rural community of Kherson District, Kherson Region, Dry Steppe subzone, 46°40' n. 33°12' e.) during 2020–2022. The parameters of the soil water regime were studied depending on the following designs of irrigation systems: drip irrigation (DI) with surface laying of irrigation pipelines (IP), and subsoil drip irrigation (SDI) with laying of IP to a depth of 30 cm. In addition, the design parameter was the distance between IP, which was 0.7 and 1.4 m. The variant of subsoil drip irrigation with pulsed water supply mode (PSDI) was reference, and the conditional control was the variant with natural moisture supply – without irrigation. The research was carried out according to generally accepted methods: placement of plots – systematic, repetition – four times, area of record plots – 32 m^2 [19; 20], sunflower hybrids for confectionery use – Ukrainian F1 and Rimisol F1.

The soil of the experimental site is a dark chestnut light loam, the density of the 0–50 cm layer is 1.47 g/cm^3, humus content is 1.44%, alkaline hydrolyzed nitrogen content (determination method by Kornfield) (DSTU7863:2015, 2016) is 7.0 mg/100g of soil, mobile compounds of phosphorus and potassium content (determination method by Chirykov) (DSTU4115:2002, 2003) is 32.3 mg/100g and 9.3 mg/100g of soil, respectively.

The amount of productive precipitation during the growing season of sunflowers was different during the years of research. Thus, in 2020, it was only 68 mm, which is 35.5% of the climatic norm, in 2021 it was 393.8 mm or 205.5%, which is also an abnormal phenomenon for the conditions of the Dry Steppe, and in 2022 r. it was 167.6 mm or 87.5% of the climatic norm. The rate of antecedent soil water in experiments was 80% of the minimum moisture-holding capacity of the 0–50 cm soil layer. The following tools were used to determine the timing of watering: the Drill and Drop Sentek moisture meter probe and the iMetos soil moisture station with Echo Probe EC-5 sensors [21]. Statistical analysis of research results was carried out by dispersion, correlation, and regression methods using the Statistica 6.0 program.

Research results and their discussion. Data on crop evapotranspiration (ETs), and sunflowers in particular, are the basis for specifying irrigation regimes [22]. The study of irrigation regimes and ETs parameters based on the method of soil water balance showed that the water regime and ETs were formed depending on the initial soil moisture reserves, productive precipitation during the growing season, and irrigation elements – structures of drip irrigation systems (method of laying IP) (Table 1).

Meteorological conditions of the growing season (primarily productive precipitation) significantly influenced the formation of evapotranspiration (ETs). For example, for the Ukrainian F1 hybrid in the extremely dry year 2020 (68 mm of precipitation) on the irrigated experimental plots, the share of precipitation in the formation of evapotranspiration was from 9.2% to 13.1%. At the same time, in the abnormally wet 2021 (393.8 mm), the share of precipitation in the formation of ETs increased sharply – up to 65.8–73.4%. In the moderately dry year (2022), the share of precipitation in the formation of ETs was from 23.5% to 31.0%. For a more correct analysis of the data on the evapotranspiration of sunflower crops, data for individual years were averaged. It was determined that, on average, for 2020–2022, on the irrigated experimental plots, productive precipitation and irrigation water formed ETs in almost equal proportions. Thus, the share of irrigation water was in the range from 39.2% (subsoil irrigation, the distance between IP was 1.0 m) to 45.8%, and productive precipitation – from 41.3% (drip irrigation, the

1. Drip irrigation regimes, evapotranspiration (ETs), and yield of sunflower hybrids (2020–2022)

Variant of experiment			Number of waterings	Irrigation rates, m³/ha	Precipitation, m³/ha	Soil moisture, m³/ha	ETs, m³/ha	Yield, t/ha
A factor	B factor	C factor						
Rimisol F1	DI	0.7	18	1960	2098	670	4728	4.19
		1.4	14	2313		827	5238	3.70
	SDI (–30 cm)	1.0	13	1667		597	4362	4.01
		1.4	11	1872		490	4460	3.64
	control (W/I)		–	–		840	2938	1.59
Ukrainian F1	DI	0.7	19	2140		624	4862	4.41
		1.4	14	2427		557	5082	3.91
	SDI (–30 cm)	1.0	14	1803		703	4604	4.09
		1.4	11	1963		563	4624	3.69
	control (W/I)		–	–		950	3048	1.66
Impulse mode of water supply when applying subsoil drip irrigation								
Ukr. F1	PSDI (–30 cm)	1.0	148	2222	2098	530	4850	4.50

distance between IP was 1.4 m) up to 45.6% (subsoil irrigation, the distance between IP was 1.0 m) (Figure 1).

Naturally, productive precipitation was the basis of ETs formation on the control variant of the experiment (without irrigation) – 68.8%, while the share of soil moisture was only 31.2%.

One of the important criteria for determining the efficiency of water use by plants is the so-called water consumption coefficient (WCC) – the ratio of total water consumption to the formation of a unit of the yield of productive organs of a certain crop [23]. An additional criterion for determining the efficiency of irrigation measures is water use efficiency (WUE) [24, 25] and the irrigation efficiency coefficient (IEC) [26]. The irrigation efficiency coefficient is the physical amount of irrigation water that provides an increase in the yield of a unit of productive organs compared to non-irrigated conditions, and the efficiency of irrigation water use is the total amount of agricultural products produced by a unit of used irrigation water.

To analyze the efficiency of water use by sunflower hybrids, three coefficients were calculated (Table 2) [25].

According to the calculations given in Table 2, the highest water consumption for the formation of a product unit (WCC was equal to 1839.8–1848.8 m³/ton) was in the control plot in non-irrigated conditions. On the other hand, water was more effectively used by sunflower hybrids on the plot with sub-soil laying of irrigation pipelines (–30 cm), where the weighted average coefficient of water consumption was equal to 1157.55 m³/t (hybrid Rimisol F1) and

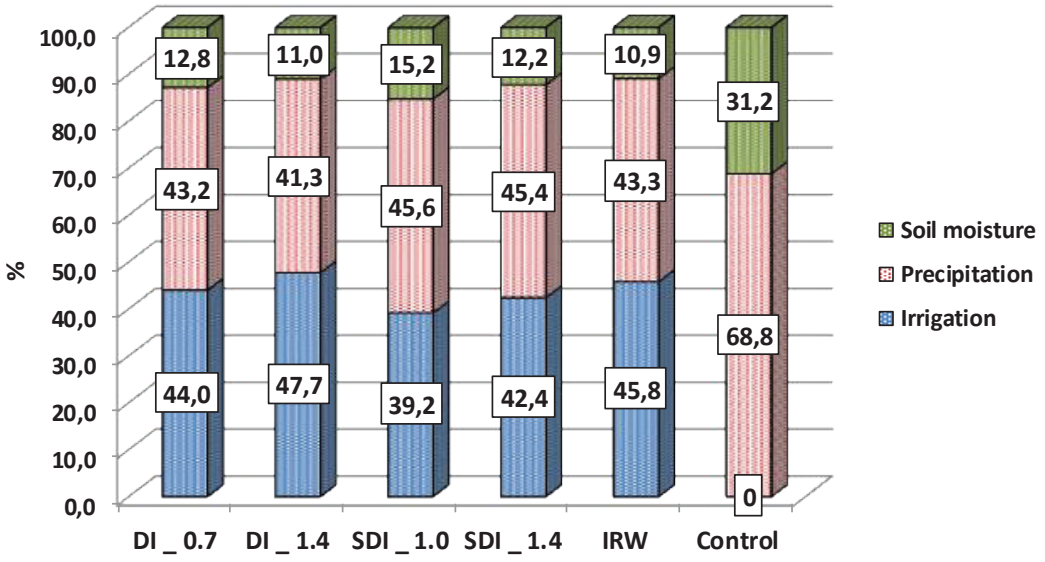

Figure 1. The structure of evapotranspiration (ETs) formation for the Ukrainian F1 sunflower hybrid, depending on design of micro-irrigation systems (the method of irrigation system laying)

2. Efficiency of water use by sunflower hybrids depending on the designs of drip irrigation systems (2020–2022)

Variant of experiment			ETs, m^3/ha	Water consumption coefficient, m^3/t	Irrigation efficiency coefficient, m^3/t	WUE, kg/m^3	Yield, t/ha
A factor	B factor	C factor					
Rimisol F1	DI	0.7	4728	1127.5	753.8	2.14	4.19
		1.4	5238	1414.4	1096.2	1.60	3.70
	SDI (–30 cm)	1.0	4362	1088.7	688.8	2.41	4.01
		1.4	4460	1226.4	913.2	1.94	3.64
	control (W/I)		2938	1848.8	–	–	1.59
Ukrainian F1	DI	0.7	4862	1102.5	778.2	2.06	4.41
		1.4	5082	1298.6	1078.7	1.61	3.91
	SDI (–30 cm)	1.0	4604	1125.7	742.0	2.27	4.09
		1.4	4624	1254.2	967.0	1.88	3.69
	control (W/I)		3048	1839.8	–	–	1.66
Search experiment – pulse mode of water supply when applying subsoil drip irrigation (2021–2022)							
Ukr. F1	SDI (–30 cm)	1.0	4850	1077.8	782.4	2.05	4.50

1189.95 m^3/t (hybrid Ukrainian F1); 1.94–2.41 and 1.88–2.27 kg of grain were got for 1 m^3 of irrigation water, respectively. In these variants of the experiment, the irrigation efficiency coefficient was 688.8–913.2 m^3 of irrigation water for obtaining an additional ton of grain yield of Rimisol F1 hybrid and 742.0–967.0 m^3 of water for obtaining 1 ton of grain of Ukrainian F1 hybrid.

A certain "intermediate" place was occupied by the variants of a field experiment with the surface laying of irrigation pipelines, namely: 1127.5–1414.4 m^3 and 778.2–1078.7 m^3 of water were used for the formation of 1 ton of sunflower seeds of Rimisol F1 and Ukrainian F1 hybrids, respectively. For 1 m^3 of irrigation water, an additional 1.60–2.14 kg of sunflower seeds of Rimisol F1 hybrid and 1.61–2.06 kg of Ukrainian F1 hybrid were obtained, and 753.8–1096.2 m^3 and 778.2–1078.7 m^3 of irrigation water were used to form 1 ton of additional products, respectively.

The search variant with a pulse water supply mode for subsoil drip irrigation was the most expedient (effective) from the point of view of total water consumption. Thus, only 1077.8 m^3 of moisture was spent on the formation of 1 ton of sunflower seeds. However, slightly less production (2.05 kg of grain) was obtained per 1 m^3 of irrigation water than when applying the usual subsoil regime of irrigation. The coefficient of irrigation efficiency also had a certain tendency to increase the consumption of irrigation water to obtain additional production from irrigation (IEC = 782.4 m^3/t).

Conclusions. The results of experimental research proved that the method of irrigation pipelines laying of drip irrigation systems has an effect on the parameters of irrigation regime formation and the yield of sunflower hybrids in the conditions of the Dry Steppe zone. It was proved that the application of subsoil drip irrigation with the IP laying to a depth of 0.3 m with a distance between the pipelines of 1.0 m is the most appropriate for growing sunflower hybrids, which is explained by the drought resistance of this crop. In the field experiments, the variant with sub-soil laying of irrigation pipelines provided almost identical yield (4.01–4.09 t/ha) with lower crop water consumption coefficients (1088.7–1125.7 m^3/t) and higher efficiency of irrigation water use (WUE – water use efficiency) – 2.27–2.41 kg of grain per 1 m^3 of irrigation water.

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РЕЖИМИ КРАПЛИННОГО ЗРОШЕННЯ ТА ЕФЕКТИВНІСТЬ ВИКОРИСТАННЯ ВОДИ ГІБРИДАМИ СОНЯШНИКУ

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Анотація. *У статті наведено результати експериментальних досліджень із вивчення впливу конструкцій систем краплинного зрошення на формування режимів зрошення, продуктивності та ефективність використання води гібридами соняшнику. За цього враховано основні складові евапотранспірації, а у якості критеріїв ефективності краплинного зрошення обрано коефіцієнти водоспоживання (КВ), ефективності зрошення (Кез) та ефективності використання поливної води (WUE – water use efficiency). Польові короткотермінові дослідження проведено протягом 2020–2022 рр. на землях Брилівського дослідного поля Інституту водних проблем і меліорації НААН (Херсонська область, підзона Степу Сухого). Для обробки експериментальних даних використано аналітичні та математично-статистичні методи. Схемою трифакторного польового експерименту було передбачено різні варіанти укладання поливних трубопроводів систем краплинного зрошення (у горизонтальній та вертикальній площині), а також реалізація імпульсного режиму водоподачі (еталон). Контрольним був варіант з природнім вологозабезпеченням (без зрошення). Результатами експериментальних досліджень доведено, що спосіб укладання поливних трубопроводів систем краплинного зрошення достовірно впливав на параметри формування режимів краплинного зрошення та врожайність гібридів соняшнику в умовах Степу Сухого. Встановлено закономірності формування структури евапотранспірації посівів соняшнику у зрошуваних та незрошуваних умовах. Статистично доведено, що впровадження підґрунтового краплинного зрошення з укладанням поливних трубопроводів на глибину 0,3 м і відстанню між ними 1,0 м є найбільш доцільним за вирощування гібридів соняшнику. Це пояснюється біологічними особливостями, а саме – посухостійкістю цієї культури. Так, у польових дослідах варіант із внутрішньоґрунтовим укладанням поливних трубопроводів краплинного зрошення забезпечив практично ідентичні параметри врожайності (4,01–4,09 т/га) за нижчих коефіцієнтів водоспоживання культури (1088,7–1125,7 м^3/т) та вищій ефективності використання поливної води– 2,27–2,41 кг зерна на 1 м^3 поливної води.*

Ключові слова: *краплинне зрошення, підґрунтове краплинне зрошення, коефіцієнт водоспоживання, коефіцієнт ефективності зрошення, евапотранспірація, режим зрошення, соняшник*