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INFLUENCE OF SHORT-TERM CROP ROTATIONS WITH DIFFERENT PROPORTIONS OF SUNFLOWER ON SOIL WATER REGIME

Z.O. Dehtiarova, Ph.D. student
State Biotechnological University, Kharkiv 61000, Ukraine;
https://orcid.org/0000-0002-1055-4811; e-mail: zinaidasamosvat@gmail.com

Abstract. *The article analyses the features of water consumption of sunflower in short-term crop rotations. Presents the results of the 2020–2021 research carried out in the experimental field of Kharkiv National Agrarian University named after V.V. Dokuchaev, located in the area of the Left Bank Forest-Steppe of Ukraine. The soil cover of the experimental field is represented by typical chernozem heavy loam on loess-like loam. Soil moisture was determined by gravimetric technique. Sunflower water consumption was calculated using the water balance method. The sunflower yield was recorded manually. The purpose of our research was to determine how short-term crop rotations with different sunflower saturation affect the formation of the soil water regime and the yield of the crop itself. The experimental design included five-field crop rotations with sunflower saturation of 0, 20, 40 and 60%. The control in the experiment was a five-field crop rotation without sunflower. It was determined that the yield of sunflower seeds depended on the variants and ranged from 3.21 to 3.57 t/ha. The increase in the share of sunflower in crop rotation was accompanied by a decrease in its yield, in particular, due to the deterioration of moisture supply. Soil moisture consumption was the highest in crop rotation with sunflower saturation of 60% (2969 m^3/ha). Against the background of reducing the share of sunflower to 40 and 20%, moisture consumption was 2713 and 2824 m^3/ha. The water consumption coefficient was high due to an increase in the share of sunflower in short-term crop rotations. It was determined that in crop rotation with sunflower saturation of 40% the coefficient of water consumption was the lowest. At the same time, this variant has the highest yield of sunflower seeds (3.57 t/ha). Increasing the saturation of short-term crop rotations with sunflower up to 60% should occur under conditions of the high culture of agriculture. Therefore, ways of efficient use of soil moisture to increase the yield of sunflower in short-term crop rotations are being developed.*

Key words*: *sunflower, water consumption, soil moisture, saturation, yield

The relevance of the study. Crop rotation plays a major role in crop yielding [1; 2]. The preceding crops must be carefully chosen for obtaining higher yields and seed quality. Some scientists are working to determine the optimal crop rotation and the influence of the predecessor [3–6]. Sunflower has a leading place in the agrarian sector of Ukraine. Ukraine fully meets its own needs in sunflower seed processing products and is also an exporter of sunflower oil on the world market. Over the past 10 years, the area under this crop has increased almost 3 times [7; 8]. Sunflower is a very cost-effective crop. According to Grain Trade, prices in Ukraine for its seeds are $700 per ton [9].

According to Johnston et al. [10], sunflower is usually grown in 3–4-year rotations with cereals, oilseed rape, and legumes. Production programs of agrarian enterprises are aimed at obtaining high incomes. This is manifested in the design of short-term crop rotations, where the share of sunflower can reach 50%. The integration of sunflower in the cropping system has many advantages [11]. This crop is simple, flexible, adaptable to a wide range of pedoclimatic situations and cropping systems, appreciated for its environmental impact, and for leaving the soil in a favorable condition for subsequent crops. At the same time, it is necessary to take into account soil and climatic conditions, precursors, cultivation technologies, mineral nutrition and plant protection systems [12].

Adaptation to a changing climate is something that modern agriculture is facing. In such circumstances, water management is particularly important [13–15]. During the growing season, field crops use a significant amount of moisture. At the same time, the reserves in the soil decrease, reaching a minimum at the time of harvesting [15]. It is important to prevent this process at the beginning of the growing season of agricultural crops [16–19]. One of the ways to regulate the water regime of the soil is the use of drought-resistant sunflower hybrids, science-based crop rotations and tillage systems. This ensures the accumulation and most rational use of moisture [20].

Analysis of the latest research and publications. Crop rotation is an appropriate measure to increase crop yields, and reduce adverse environmental impacts [21]. According to the results of scientific research, it is proved that crop rotation is an inviolable basis for the stability of agriculture. They have a positive effect on all important soil indicators, in particular soil moisture.

Agricultural crops do not use soil moisture equally for crop formation. Crops that intensively use moisture from the soil do not create agroecological negative. The less moisture remains in the soil after harvesting, the better it will be absorbed during precipitation. Total moisture consumption from early spring to harvesting by sunflower is higher than in other crops. It is known that soil moisture reserves in sunflower agrocenoses in crop rotation during the period of intensive plant development are lower than at the beginning of the growing season [22; 23]. Scientists note that in sunflower crops moisture consumption in the period from sowing to 5–6 leaves are 1250–1330 m^3/ha. By the end of the vegetation period, plants grow intensively and moisture consumption increases to 3140–3160 m^3/ha. Given the residual moisture reserves in the soil at harvest time, sunflower is very drying to the soil [24]. After it, insignificant reserves of available moisture remain in the soil – 890–930 m^3/ha [25]. In the post-harvest period, the processes of moisture accumulation in the soil begin to prevail. The accumulation of precipitation during this period in the fields after sunflower is 52–62 %.

The purpose of the research was to determine the influence of the share of sunflower in short-term crop rotations on water consumption and crop yield.

Materials and methods of the research. Research to determine the water consumption of sunflower in 2020–2021 was conducted on the basis of the chair of Farming named after O.M. Mozheiko of the experimental field of Kharkiv National Agrarian University named after V.V. Dokuchaev (KhNAU). The complexity of the climatic conditions of the Kharkiv region of Ukraine for agriculture is also revealed in not existing guaranteed annual sufficient moisture. In addition, in some years, thermal resources are much less than the needs of crops. According to the meteorological station of KhNAU, during the growing season of sunflower, the average long-term precipitation was 278 mm, and the air temperature was +17.7°C. During the growing season of sunflower in 2020, precipitation was 114 mm less than normal, and the average air temperature was 19.8°C, which is 2,1°C higher than the climatic norm. Atmospheric precipitation during the growing season of sunflower in 2021 was showery in June – 81.9 mm, which is 22.9 mm higher than the average long-term norm. In July and August, precipitation was less than the long-term average by 51.5 and 44.2 mm, respectively. Precipitation in 2021 was 197.7 mm, which is 81.3 mm less than the long-term average, and the excess of the average daily air temperature by 2.5°C compared to the long-term average. Therefore, sunflower vegetation during this period took place in relatively unfavorable conditions.

The physical properties of the soil are affected by many factors that change vertically with depth, laterally across fields and temporally in response to climate and human activity [26]. Different soils have distinct physical and chemical properties depending on the nature of mineral and organic components, their relative amounts, and how minerals and organic matter interact [27]. The soil cover of the experimental field is represented by typical chernozem heavy loam on loess-like loam. In terms of agrophysical and agrochemical properties, it is one of the most favorable soils for growing field crops. It is characterized by high reserves of nutrients available to plants, high humus content and intense biological activity. The arable layer of the soil (0–30 cm) contains humus (according to Tyurin) – 4.9–5.1 %, easily hydrolyzable nitrogen (according to Kornfield) – 81 mg/kg of soil, mobile forms of phosphorus and potassium (according to Chirikov) – 100 and 200 mg/kg of soil. Content of exchangeable cations: calcium – 37.8 %, magnesium – 6.6 %, sodium – 0.49 %, potassium – 0.5 %, hydrogen – 21 mg-equiv./kg soil. The soil reaction – pH: aqueous – 7.0, salt – 5.2–5.6. Groundwater lies at a depth of about 18 m [28].

Sunflower hybrid – Cruiser LG59580. The size of the sowing area is 750 m^2, the accounting area is 100 m^2. Variants of short-term (5-field) crop rotations with different proportions of sunflower in the structure of the sown areas were studied (Table 1). The control in the experiment was a five-field crop rotation without sunflower.

Soil moisture was determined by Gravimetric Technique [29]. The formula for calculating moisture:

$$W_d,\%=\frac{W2-W3}{W3-W1}\times 100, \quad (1)$$

where W1 – the weight of the container (g), W2 – the weight of moist soil + container (g), and W3 – the weight of dried soil + container (g).

The determination of moisture reserves in the soil was carried out taking into account the known field moisture (% moisture by weight of

1. Crop rotation structure, %

Pea	Winter wheat	Corn	Winter rye	Fallow	Sunflower
20	20	20	20	–	**20**
20	20	–	20	–	**40**
–	20	–	20	–	**60**
–	20	40	20	20	**0**

absolutely dry soil), a certain soil layer (h, cm) and its density (dv) on an area of 1 ha (10 000 m^2).

The formula for calculating soil moisture reserves in m^3/ha:

$$W= h \times dv \times Wt, \qquad (2)$$

where W – moisture reserves in the soil, m^3/ha; h – thickness of a certain soil layer, cm; dv – density of soil composition, g/cm^3; Wt, – actual field moisture of the soil, determined by the gravimetric method,% of the completely dry mass of the soil.

The total water consumption was determined by the difference between the spring supply of available moisture and its balance at the end of the growing season of the crop. To this indicator, we added precipitation that fell during the vegetation period. The end result is the calculation of the water consumption coefficient. Two variants can be used to determine the water consumption coefficient: calculation per unit of dry aboveground biomass and per unit of main production [30]. In our study, the efficiency of moisture use for crop formation was assessed taking into account seed yield. Statistical data processing was performed using the CORREL function, which is included in the data analysis package in MS Office Excel 2017.

Research results and discussion. The results of our research show the content of available moisture in the soil layer 0–150 cm. On average, in 2020–2021, at the time of sowing sunflower, it was within 1562–1763 m^3/ha (Table 2). Most moisture (1763 m^3/ha) was accumulated in the crop rotation with a share of sunflower 20 %, and the least – in the crop rotation with a saturation of 40 %. During the spring-summer period of sunflower vegetation, there was a predominance of moisture consumption from the soil over its accumulation. Before harvesting sunflower, the most moisture in the soil remained under control. High moisture accumulation (749 and 658 m^3/ha) was recorded in crop rotations with sunflower saturation of 20 and 40 %. When the share of sunflower increased to 60 %, moisture reserves decreased (488 m^3/ha).

In 2020, at the beginning of sunflower sowing, moisture reserves in the 1,5-meter soil layer were high. They were the highest in the field of crop rotation with sunflower saturation of 20 % – 1840 m^3/ha (Fig. 1). At the end of the growing season of sunflower, moisture reserves acquired minimum values (254 m^3/ha) in crop rotation, where its share was 60 %. Crop rotation without sunflower ensured the residual amount of moisture in the soil at the level of 1094 m^3/ha.

The year 2021 was more favourable in terms of humidity due to sufficient precipitation in the autumn-winter period. At the time of sunflower sowing, moisture reserves in the 1.5-meter soil layer were in the range of 1518–1721 m^3/ha. Most of the available moisture was accumulated in crop rotation with a share of sunflower 60 %. The lowest amount of moisture was in the control variant – 1518 m^3/ha. In the phase of full ripeness of sunflower, the most moisture was recorded in the variant with a share of 20 % (985 m^3/ha). Crop rotation with 60 percent saturation of sunflower was characterized by minimal moisture reserves in the soil – 721 m^3/ha.

Due to the root system sunflower has a rather high level of water consumption. For the formation of a high yield of sunflower, 1650–1850 m^3/ha of moisture in the root layer (0–150 cm) and a sufficient amount of precipitation (300–400 mm) during the growing season are necessary [31]. Gorobets et al. [32] draw attention to the inverse relationship

2. Available moisture reserves in the soil under sunflower, (average for 2020–2021)

Share of sunflower in crop rotation, % (variant)	Available moisture content in the soil layer 0–150 cm, m^3/ha	
	during sowing	before harvesting
20	1763	749
40	1562	658
60	1647	488
0 (control)	1649	985
LSD0.5	116	69

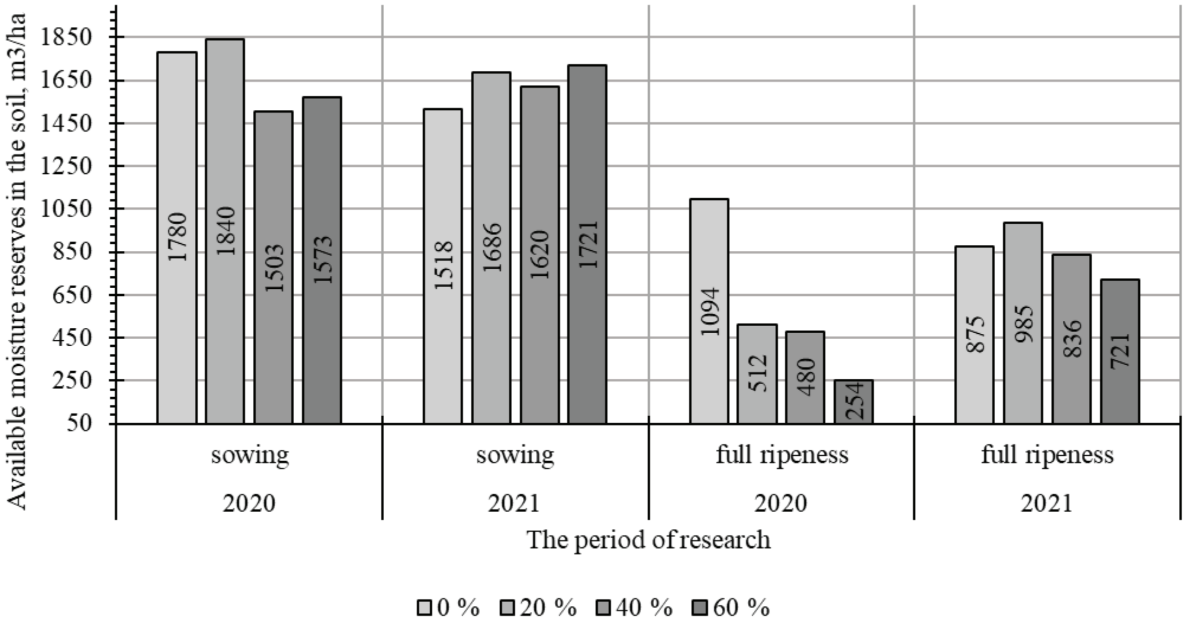

Fig. 1. Available moisture content in the 150-centimeter soil layer, in 2020 and 2021

Note: 20 %, 40 %, 60 %, 0 % – the share of sunflower in crop rotation

between the amount of residual (during sunflower harvest) and accumulated moisture in the soil. If moisture in the soil layer 0–150 cm contains 1580 m^3/ha, it will accumulate at the level of 530–580 m^3/ha. With residual reserves of 350 m^3/ha, the soil absorbs 1880–1920 m^3/ha of available moisture. It was found that after sunflower, the reserves of available moisture in the soil in spring were in the range from 1800 to 1840 m^3/ha. Scientists note that the coefficient of water consumption of sunflower is 450–600 m^3/t, and this is much higher than that of corn, sugar beet and cereals [33; 34].

Kovalenko [35] determined that during the growing season sunflower spends 2581–2764 m^3/ha of moisture on evaporation from the soil. While the share of moisture from the soil is 33.3–37.4 %, and from precipitation – 62.3–66.7 %. Moisture loss from the topsoil (0–10 cm) during the growing season was 49–91 m^3/ha or 5.0–12.6 % of total water consumption. The highest water consumption occurred when placing sunflower in crop rotation with fallow – 12.6 %, and the lowest – with peas – 5.0 %. Domaratsky and Kozlova [30] determined that during sunflower sowing, the available moisture reserves in the meter layer of soil were 1300 m^3/ha. This qualifies as the lower threshold of average moisture availability. When plants reach full ripeness, moisture reserves decreased to 150–300 m^3/ha. During the growing season, sunflower plants used 1150–1000 m^3/ha of moisture from the soil. Together with precipitation, moisture reserves determine the size of the total water consumption, which in the LG 5580 hybrid was 2556 m^3/ha.

The Left-Bank Forest-Steppe of Ukraine is characterized as a subzone of unstable moisture. Therefore, it is important that crops effectively use the moisture reserves accumulated in the soil during the sowing period and precipitation that fell during the growing season. In our studies, sunflower water consumption was closely related to its share in crop rotation.

On average, in 2020–2021, the maximum water consumption (2969 m^3/ha) was observed in crop rotation with its share of 60 % (Table 3). In the variant of 40 % saturation, the level of moisture consumption decreased by 256 m^3/ha. The process of water consumption had an impact on the yield of sunflower plants. With a sunflower yield of 3.21 t/ha in crop rotation with a saturation of 60 %, the water consumption coefficient was at the level of 926 m^3/t. In other crop rotations with sunflower yields of 3.43 and 3.57 t/ha, the water consumption coefficient was 823 and 761 m^3/t. Thus, when the crop rotation is saturated with sunflower 20 and 40 %, the plants used soil moisture more efficiently to form a unit of the main product.

In 2020, the amount of precipitation during the growing season of sunflower was 164 mm. Taking this into account, the total water consumption varied by experimental variants in the range of 2326–2968 m^3/ha (Table 2). The maximum water consumption (2968 m^3/ha) was in crop

3. Sunflower water consumption depending on the saturation of short-term crop rotations

Share of sunflower in crop rotation, % (variant)	Soil moisture, m^3/ha	Total water consumption, m^3/ha	Sunflower yield, t/ha	Water consumption coefficient, m^3/t
2020				
20	1328	2968	3.73	796
40	1023	2663	3.77	706
60	1319	2959	3.24	913
0 (control)	686	2326	–	–
2021				
20	701	2678	3.13	856
40	784	2761	3.36	822
60	1000	2977	3.17	939
0 (control)	643	2620	–	–
Average for 2020–2021				
20	1015	2824	3.43	823
40	904	2713	3.57	761
60	1160	2969	3.21	926
0 (control)	665	2474	–	–

rotation with sunflower saturation of 20 %. The level of culture water consumption decreased by 305 m^3/ha in crop rotation with a share of 40 %. At the same time, its yield level was the highest – 3.77 t/ha. To form this amount of yield, sunflower plants used 1187 m^3/ha of moisture, of which 38 % is soil moisture and 62 % is precipitation. A similar trend was observed for all variants in both years of research. Crop rotation with the share of sunflower 60 % provided the minimum yield – 3.24 t/ha.

In 2021, during the growing season of sunflower, 198 mm of precipitation fell. Under such conditions, the lowest total moisture loss was characterized by the variant of crop rotation without sunflower – 2620 m^3/ha. Sunflower plants on the field with a share in the crop rotation of 60 % had the maximum need for water for the formation of the yield. The difference with the control variant was 357 m^3/ha. Reducing the saturation of sunflower crop rotation to 20 % provided the most efficient use of moisture by plants (2678 m^3/ha).

We have established a direct relationship between water consumption and sunflower yield, as evidenced by the correlation level – 0.99. This corresponds to the calculations of Kovalenko et all [36]. According to their data, the correlation coefficient between soil moisture and sunflower seed yield averaged 0.85±0.12. In the experiment Neshev [37] higher and more stable yields were found when the sunflower was sown after winter wheat – 2.54 t/ha. A severe yield decrease was observed when the sunflower was grown as a monoculture. In the first year of the study (2018) the seed yields were 2.53 t/ha and diminished to 1.64 t/ha in the third experimental year (2020).

When evaluating the studied variants for crop rotation, it is also necessary to take into account the moisture consumption for the formation of a unit of the main product. Calculations of water consumption coefficients per 1 t of seeds make it possible to estimate changes in total water consumption and crop yields from the share of sunflower in crop rotations.

In 2020, a high-water consumption coefficient was determined in the variant of crop rotation with 60 % saturation with sunflower – 913 m^3/t. And the plants used moisture less efficiently and formed a low yield (3.24 t/ha). In crop rotations with a saturation of 20 and 40 %, there was a decrease in the coefficient of water consumption (by 117 and 207 m^3/t) for the formation of sunflower yield.

In 2021, sunflower crops used moisture least efficiently in the field of crop rotation with a share of 60 % – 939 m^3/t. The introduction of crop rotations with sunflower saturation of 20 and 40 % led to a decrease in the consumption coefficient by 83 and 117 m^3/t. Thus, a saturation of crop rotation at the level of 40 % provides a high yield of sunflower and reduces water consumption per 1 t of seeds.

Conclusions. Research data indicate a decrease in the efficiency of moisture use by sunflower in case of increasing its share in crop rotation. Saturation of crop rotations with sunflower at the level of 60 % leads to an increase in water consumption coefficient (2969 m^3/t). There is a relationship between sunflower yield and total water consumption within the studied variants. The yield of sunflower seeds was the highest (3.57 t/ha) in the crop rotation with a share of 40%. At the same time, the water consumption coefficient was the lowest – 761 m^3/t. So, with the increase in the saturation of short-term crop rotation with sunflower, the moisture consumption for the formation of its yield increases. Further research will be aimed at studying the dynamics of the influence of saturation of short-term crop rotations with sunflower on agrophysical indicators of soil fertility, which were not reflected in this work. Also, variance analysis will be conducted and correlations between sunflower seed yield and agrophysical indicators of soil fertility will be established depending on the research variants.

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ВПЛИВ КОРОТКОРОТАЦІЙНИХ СІВОЗМІН З РІЗНОЮ ЧАСТКОЮ СОНЯШНИКУ НА ВОДНИЙ РЕЖИМ ҐРУНТУ

З.О. Дегтярьова, аспірант

Державний біотехнологічний університет, Харків, 61000, Україна,
https://orcid.org/0000-0002-1055-4811; e-mail: zinaidasamosvat@gmail.com

Анотація. *В статті проаналізовано особливості водоспоживання соняшнику у короткоротаційних сівозмінах. Представлено результати досліджень 2020–2021 рр., проведених на дослідному полі Харківського національного аграрного університету ім. В.В. Докучаєва, розташованому в зоні Лівобережного Лісостепу України. Ґрунтовий покрив дослідного поля представлений чорноземом типовим важкосуглинковим на лесоподібному суглинку. Вологість ґрунту визначали гравіметричним методом. Водоспоживання соняшника розраховували за методом водного балансу. Облік врожайності проводили вручну. Метою наших досліджень було встановити як впливають короткоротаційні сівозміни із різним насиченням соняшнику на формування водного режиму ґрунту та урожайність самої культури. Схема досліду передбачала п'ятипільні сівозміни із насиченням соняшнику 0, 20, 40 і 60%. Контролем у досліді була п'ятипільна сівозміна без соняшнику. Визначено, що врожайність насіння соняшнику залежала від варіантів і коливалася від 3,21 до 3,57 т/га. Збільшення частки соняшнику у сівозміні супроводжувалося зниженням його врожайності, зокрема, за рахунок погіршення вологозабезпеченості. Загальні витрати вологи з ґрунту виявилися найбільшими у сівозміні з насиченням соняшнику 60% (2969 м³/га). На фоні зменшенням частки соняшнику до 40 і 20% витрати вологи становили 2713 і 2824 м³/га. Коефіцієнт водоспоживання був високим за рахунок збільшення частки соняшнику в короткоротаційних сівозмінах. Тому волога, яку рослини витрачають на формування одиниці врожаю, використовувалася менш ефективно. Визначено, що у сівозміні із насиченістю соняшником 40% коефіцієнт водоспоживання був найнижчим. При цьому на даному варіанті спостерігається найвища врожайність насіння соняшнику – 3,57 т/га. Насичення польових сівозмін соняшником можна розглядати у межах 20–60% до загальної посівної площі. Це слід робити за умов високої культури землеробства, використання високопродуктивних гібридів соняшнику, стійких до ураження хворобами, шкідниками та бур'янами. На підставі даного дослідження розробляються шляхи ефективного використання ґрунтової вологи для підвищення врожайності соняшнику в короткоротаційних сівозмінах.*
Ключові слова: *соняшник, водоспоживання, вологість ґрунту, насиченість, урожайність*