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IMPROVEMENT OF TECHNOLOGICAL ELEMENTS OF SUNFLOWER CULTIVATION UNDER THE INFLUENCE OF WATER AND NUTRIENT REGIMES AND PLANT DENSITY UNDER DRIP IRRIGATION CONDITIONS IN MOLDOVA

411.08 – Crop Production

Abstract of the PhD Thesis in Agricultural Sciences

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LIST OF ABBREVIATIONS

t – ton

ha – hectare

mm – millimetres of precipitation

m^3 – cubic metres

FC – field capacity

a.i. – active ingredient

NI – non-irrigated (without irrigation)

NF – non-fertilized (without fertilization)

LSD – least significant difference

MJ – megajoules

GJ – gigajoules

GENERAL CHARACTERISTICS OF THE THESIS

Relevance and importance of the research topic. The Republic of Moldova is well provided with heat resources and has fertile soils; however, the moisture regime is mainly formed by precipitation, the amount of which covers no more than 50% of the crop water requirements. For the southern regions, irrigation represents an important technological component that allows obtaining high yields. In Moldova, sunflower is the main oilseed crop, cultivated on an area exceeding 300 thousand hectares [34]. Its productivity varies significantly from year to year and on average does not exceed 1.5–1.9 t/ha; in Ukraine it ranges between 1.7–1.9 t/ha, while in Russia it varies between 1.2–1.5 t/ha [1, 7].

Under irrigation conditions, sunflower productivity is considerably higher. In the Rostov region, southern Ukraine and the North Caucasus it reaches 2.5–3.6 t/ha of seeds [6, 24], while in Moldova it reaches 3.6–4.5 t/ha [8, 25].

Moldova belongs to drought-prone regions. With a low forest cover (8.3%) and a high level of soil degradation (over 35%), the country is becoming increasingly vulnerable to climate change. The climate is moderately continental, characterized by short, mild winters with little snowfall, a long growing season, hot summers and relatively low precipitation, usually occurring in the form of short-term showers. These conditions may seem favorable for agriculture; however, to obtain high crop yields, the annual precipitation should reach 730–800 mm, while the minimum water requirement is estimated at 350–400 mm. In the Republic, every second or third year is droughty, and the consequences of such droughts negatively affect the agricultural sector, causing significant losses to farmers [29].

Due to the low water reserves in the soil at the beginning of spring, agriculture in the region is considered risky. During the active vegetation period of crops (April–September), the average precipitation in the region over the last 75 years has been about 299 mm, which appears to be sufficient for plant development. Thus, meteorological conditions play a very important role [25], since in the south-eastern districts of Moldova drought conditions prevent the realization of the productive potential of crops, reducing the efficiency of the agro-industrial sector. The production of sunflower oilseeds remains relatively low and fluctuates significantly from year to year, which demonstrates the strong influence of precipitation on crop yields.

Under these conditions, stable and high sunflower productivity can only be achieved through irrigation combined with balanced fertilization. However, considering that irrigation systems in Moldova are technically and morally outdated, with low efficiency coefficients, and that the cost of irrigation water is increasing due to declining river levels as a result of climate warming, drip irrigation may represent a preferable alternative. In Moldova, the effect of this irrigation method on sunflower productivity has not yet been sufficiently studied, although its efficiency has been demonstrated for other crops.

State of research in the field and formulation of research tasks. In the Republic of Moldova, every second year is characterized by drought conditions. During the active vegetation period (April–September), approximately 300 mm of precipitation falls. However, the key factor – water supply – is not optimal. The water deficit varies between 400–1950 m^3/ha in rainy years and 2000–5400 m^3/ha in dry years [9]. Under these conditions, agriculture is risky and relatively inefficient. To optimize the soil water regime, irrigation is the only method that ensures not only high productivity but also good product quality. Previous studies on sunflower irrigation regimes were mainly carried out using sprinkler irrigation. However, current economic conditions require the development and implementation of resource-saving technologies, among which drip irrigation is of particular importance.

Aim of the research. The aim of the research was to develop technological elements for sunflower cultivation in crop rotation under drip irrigation conditions through the regulation of soil water and nutrient regimes and plant density in order to obtain economically profitable yields.

Research objectives:

1. To determine optimal drip irrigation regimes.
2. To study the soil water regime under different drip irrigation treatments.
3. To determine the interaction between drip irrigation, mineral fertilizer rates, and increased plant densities on sunflower productivity and seed quality.
4. To evaluate the economic and energy efficiency of the studied cultivation methods.
5. To establish the relationships “yield – irrigation regime” and “yield – fertilization rate” for their use in yield forecasting.

Research methodology. Three-factor experiments with different irrigation regimes, fertilizer rates, and planting densities of the Aromatic sunflower hybrid were conducted in an experimental field. The soil water balance was calculated according to the actual soil moisture at different stages of plant growth and development. The concentration of soil nutrients was determined using standard laboratory methods applied in the Laboratory of Irrigated Agriculture and Soil Fertility of the Research Institute of Agriculture, Tiraspol. The oil concentration of sunflower seeds was analyzed using the multiparameter analyzer NIR Granolyser. Statistical data were processed using the analysis of variance (ANOVA) method according to B.A. Dospehov [21]. All relationships were obtained using computer-based statistical programs.

Scientific novelty and originality. For the first time in the Republic of Moldova, on a typical heavy loamy chernozem soil, drip irrigation regimes, optimal fertilizer rates and planting densities ensuring high productivity, economic and energy efficiency, and good product quality were developed and recommended to producers.

The average daily and total water consumption, the soil water regime under different irrigation treatments, the soil nutrient regime depending on fertilizer rates and plant density, as well as the economic and energy efficiency of the studied technologies were determined.

Solution of the scientific problem. The soil water regime, nutrient regime and plant sowing density were scientifically substantiated, which made it possible to improve the technology of sunflower cultivation and to obtain high productivity levels with good product quality.

Theoretical significance. The relationships "yield – irrigation regime" and "yield – fertilization rate" were established, which can be used in forecasting the planned productivity levels of sunflower.

Practical significance. Optimal drip irrigation regimes for sunflower, appropriate fertilizer rates and planting densities were developed, ensuring high yields, efficient use of irrigation water, profit and profitability.

Main provisions submitted for defense

1. Technological methods of sunflower cultivation under drip irrigation that significantly influence the biometric indicators of plant growth and development.
2. The influence of irrigation, fertilization, plant density and precipitation regime on the soil nutrient regime.
3. Technological methods that improve the efficiency of the use of soil water reserves and irrigation water.
4. The optimal combination of irrigation regime, fertilizer rates and plant density ensuring yields of 4–5 t/ha.
5. Economic and energy efficiency of sunflower cultivation under drip irrigation.
6. The relationships "yield – irrigation regime" and "yield – fertilization rate", applicable for productivity forecasting.

Approval of the research results. The research results were presented and approved annually at the meetings of the Scientific Council of the Research Institute of Agriculture (Tiraspol) and reported at eight international scientific and practical conferences:

1. IV International Scientific and Practical Conference (within the VII Scientific Forum "Science Week in Kruty – 2022"), March 4, 2022, Kruty village, Chernihiv region, Ukraine.

2. V International Scientific and Practical Conference (within the VIII Scientific Forum “Science Week in Kruty – 2023”), March 3, 2023, Kruty village, Chernihiv region, Ukraine.
3. Scientific and Practical Conference of Students, Master’s Students and Teachers, March 27–28, 2024, Technical University of Moldova, Chișinău.
4. IV International Scientific and Practical Conference, November 23, 2023, T.G. Shevchenko Pridnestrovian State University, Agrarian-Technological Faculty, Moscow – Tiraspol.
5. International Scientific and Practical Conference “Science and Education at the Current Stage of Development: Experience, Problems and Ways of Their Solution for the Agro-Industrial Complex”, November 29, 2024, Voronezh – Tiraspol.
6. IV International Scientific and Practical Conference “International Forum of Young Researchers”, March 31, 2025, Petrozavodsk.
7. International Scientific and Practical Conference “Breeding, Seed Production and Cultivation Technologies of Agricultural Crops”, Tiraspol, 2025.
8. Multidisciplinary Conference on Sustainable Development, Section “Trends in European Agriculture Development”, Timișoara, May 15–16, 2025.

ANALYSIS OF THE THESIS CHAPTERS

1. LITERATURE REVIEW

1.1. Biological characteristics of sunflower. The first subchapter of the first chapter presents the history of sunflower origin and its geographical distribution. Based on information from scientific literature, the biological characteristics of the crop under cultivation in different soil and climatic zones are described, emphasizing its dependence on water supply at various stages of growth and development.

1.2. Main elements of sunflower cultivation technology. The second subchapter pays particular attention to the role of preceding crops in the cultivation technology and their influence on productivity and quality. Based on numerous literature sources, the role of irrigation, fertilization and plant density is described in detail. Studies on the influence of irrigation on sunflower productivity in different regions of neighboring countries have shown that the optimal soil moisture before irrigation ranges between 75–80% of field capacity. In some experiments, the efficiency of total evapotranspiration increased from 2490 m^3/t under non-irrigated conditions to 1745 m^3/t under irrigation and to 780–900 m^3/t when irrigation was combined with fertilization. Fertilizer rates for sunflower vary within a wide range—from N30P30 to N120P200K90 kg a.i./ha. Accordingly, productivity also varies significantly, ranging from 2.2 to 5.4 t/ha. Plant density largely depends on the variety or hybrid and irrigation conditions. It ranges from 20–40 thousand plants/ha (for confectionery varieties) to 60–70 thousand plants/ha (for oilseed varieties), depending on soil and climatic conditions, irrigation availability and fertilization.

2. RESEARCH METHODOLOGY

2.1. Soil and climatic conditions during the years of research. One of the tasks of the experimental station where the research was conducted is monitoring changes in the chemical and physical properties of the soil. Within this activity, in 2018 soil samples were taken along a soil profile by horizons, and several chemical and physical properties were determined.

Soil type**:** typical chernozem, slightly humified, moderately deep, clay-loam texture.

Within the experimental station, the humus concentration in the soil profile gradually decreased from 2.8% in the arable layer to 0.5% in the parent material. The carbonate concentration gradually increased along the soil profile, reaching maximum values (15.11–15.76%) at depths of 76–122 cm.

The main part of the adsorption complex of the typical chernozem is represented by adsorbed Ca^{2+} and Mg^{2+} ions. This had a positive influence on soil structure formation processes. It is well known that soil saturation with calcium and magnesium leads predominantly to the formation of large microaggregates (0.25–1 mm in size), whose binding material consists of fine silt and colloidal particles. As evidence, it was observed that the number of water-stable aggregates with sizes of 0.25–1 mm was significantly higher.

According to data from the Tiraspol Meteorological Station, the long-term average (over a 78-year observation period) of the mean daily temperature during the active vegetation period of agricultural crops is 18°C.

During the research years, the average temperature exceeded this value by 0.8–2.7°C, and in some decades by 5.9–7.7°C (Table 2.1.1).

In terms of precipitation supply, the research years differed: 2022 was dry, 2023 was moderately dry, and 2024 was average (Table 2.1.2).

In total, during the period April–September, precipitation amounted to 178 mm in 2022, 266 mm in 2023, and 314 mm in 2024, while the long-term average for this period (based on 78 years of observations) is 299 mm.

In the dry year 2022, only in two out of eighteen decades did precipitation exceed the long-term average values. The most critical period in terms of moisture supply was from April to July, when within a decade only 0.3–11.4 mm of precipitation was recorded.

Table 2.1.1. Average decadal temperature during the growing season

Month	Deca-de	**Long-term average**	Average decadal air temperature, °C				Deviations from the multi-year average, °C			
			2022	2023	2024	Average	2022	2023	2024	Average
April	I	**9,0**	11,4	7,7	14,9	11,3	+2,4	-1,3	+5,9	+2,3
	II	**10,3**	8,5	11,1	15,3	11,6	-1,8	+0,8	+5,0	+1,3
	III	**12,3**	13,2	10,6	12,8	12,2	+0,9	-1,7	+0,5	-0,1
Monthly average		**10,5**	**11,0**	**9,8**	**14,3**	**11,7**	**+0,5**	**-0,7**	**+3,8**	**+1,2**
May	I	**14,8**	13,7	12,2	15,7	13,9	-1,1	-2,6	0,9	-0,9
	II	**16,6**	17,2	16,5	12,9	15,5	+0,6	-0,1	-3,7	-1,1
	III	**17,7**	18,1	18,6	18,8	18,5	+0,4	+0,9	+1,1	+0,8
Monthly average		**16,4**	**16,3**	**15,8**	**15,8**	**16,0**	**0,0**	**-0,6**	**-0,6**	**-0,4**
June	I	**19,2**	21,9	19,3	23,3	21,5	+2,7	+0,1	+4,1	+2,3
	II	**20,3**	21,3	21,4	21,9	21,5	+1,0	+1,4	+1,6	+1,3
	III	**21,3**	22,8	22,7	23,6	23,0	+1,5	+1,4	+2,3	+1,7
Monthly average		**20,3**	**22,0**	**21,1**	**22,9**	**22,0**	**+1,7**	**+1,0**	**+2,7**	**+1,8**
Iulie	I	**21,7**	25,6	24,0	25,7	25,1	+3,9	+2,3	+4,0	+3,4
	II	**22,3**	22,3	24,4	30,0	25,6	0,0	+2,1	+7,7	+3,3
	III	**22,6**	24,7	23,8	24,2	24,2	+2,1	+1,2	+1,6	+1,6
Monthly average		**22,2**	**24,2**	**24,1**	**26,6**	**25,0**	**+2,0**	**+1,9**	**+4,4**	**+2,8**
August	I	**22,6**	24,3	23,8	23,9	24,0	+1,7	+1,2	+1,3	+1,4
	II	**22,1**	25,4	25,1	26,2	25,6	+3,3	+3,0	+4,1	+3,5
	III	**20,5**	18,4	27,1	24,2	23,2	-2,1	+6,6	+3,7	+2,7
Monthly average		**21,7**	**22,7**	**25,3**	**24,8**	**24,3**	**+1,0**	**+3,6**	**+3,0**	**+2,5**

Table 2.1.1. (continued)

September	I	**18,4**	18,4	20,3	21,0	19,9	0,0	+1,9	+2,6	+1,5
	II	**16,7**	17,4	20,1	19,3	18,9	+0,7	+3,4	+2,6	+2,2
	III	**14,6**	14,5	21,5	18,7	18,2	-0,1	+6,9	+4,1	+3,6
Monthly average		**16,6**	**16,8**	**20,6**	**19,7**	**19,0**	**+0,2**	**+4,1**	**+3,1**	**+2,5**
Average for the months IV-IX		**18,0**	**18,8**	**19,5**	**20,7**	**19,7**	**+0,8**	**+1,5**	**+2,7**	**+1,7**

Table 2.1.2. Average decadal precipitation during the growing season, 2022–2024

Month	Deca-de	Long-term average	Average decadal precipitation, mm				Deviations from the multi-year average, mm			
			2022	2023	2024	Average	2022	2023	2024	Average
April	I	**9,6**	28,4	37,1	0,3	21,9	+18,8	+27,5	-9,3	+12,3
	II	**11,7**	1,2	31,0	25,3	19,2	-10,5	+19,3	+13,6	+7,5
	III	**10,7**	7,1	17,0	23,9	16,0	-3,6	+6,3	+13,2	+5,3
Monthly average		**32,0**	**36,7**	**85,1**	**49,5**	**57,1**	**+4,7**	**+53,1**	**+17,5**	**+25,1**
May	I	**13,6**	0,5	1,3	3,1	1,6	-13,1	-12,3	-10,5	-12,0
	II	**12,6**	11,4	0	0,8	4,1	-1,2	-12,6	-11,8	-8,5
	III	**22,3**	10,5	28,8	35,8	25,0	-11,8	+6,5	+13,5	+2,7
Monthly average		**49,0**	**22,4**	**30,1**	**39,7**	**30,7**	**-26,1**	**-18,4**	**-8,8**	**-17,8**
June	I	**20,5**	4,3	0	40,3	14,9	-16,2	-20,5	19,8	-5,6
	II	**22,3**	8,3	19,5	40,2	22,7	-14,0	-2,8	+17,9	+0,4
	III	**27,7**	4,1	47,0	0	17,0	-23,6	+19,3	-27,7	-10,7
Monthly average		**70,5**	**16,7**	**66,5**	**80,5**	**54,6**	**-53,8**	**-4,0**	**+10,0**	**-15,9**
Iulie	I	**21,5**	0,5	28,8	0	9,8	-21,0	+7,3	-21,5	-11,7
	II	**18**	0,3	3,2	0,1	1,2	-17,7	-14,8	-17,9	-16,8
	III	**20**	18,3	17,1	14,1	16,5	-1,7	-2,9	-5,9	-3,5
Monthly average		**59,5**	**19,1**	**49,1**	**14,2**	**27,5**	**-40,4**	**-10,4**	**-45,3**	**-32,0**
August	I	**14,6**	3,4	32,0	15,0	16,8	-11,2	+17,4	+0,4	+2,2
	II	**15**	38,6	0	0	12,9	23,6	-15,0	-15,0	-2,1
	III	**18,1**	0,1	0	35,4	11,8	-18,0	-18,1	+17,3	-6,3
Monthly average		**47,7**	**42,1**	**32**	**50,4**	**41,5**	**-5,6**	**-15,7**	**+2,7**	**-6,2**
Septembe r	I	**12,3**	11,6	3,1	32,3	15,7	-0,7	-9,2	+20,0	+3,4
	II	**15,6**	21,5	0	46,9	22,8	+5,9	-15,6	+31,3	+7,2
	III	**12,7**	7,6	0,1	0	2,6	-5,1	-12,6	-12,7	-10,1
Monthly average		**40,6**	**40,7**	**3,2**	**79,2**	**41,0**	**+0,1**	**-37,4**	**+38,6**	**+0,4**
Average for the months IV-IX		**299**	**178**	**266**	**314**	**252**	**-121**	**-33**	**+15**	**-46**
Monthly precipitation regime IV-IX		**%**	99	66	42					
		According to the classification clasifi-cării	Dry	Moderately dry	Average					

2.2. Materials, Object, and Methods of Research

The research was carried out in a crop rotation with nine fields (lucerne year I, alfalfa lucerne II, lucerne year III, tomatoes without seedlings, onion, pea, winter wheat, sunflower, maize). The three-factor field experiment was located on the fourth terrace of the Dniester River, on the fields in Sucleia of the Institute of Scientific Research in Agriculture, Tiraspol. The soil is a moderately deep, slightly humified typical chernozem with loam-clay texture. The field capacity of the 0–50 cm layer is 25.3%, and for the 0–100 cm layer – 24.4%, with bulk densities of 1.19 and 1.34 g/cm³, respectively. The field layout used the split-plot design [21] with three spatial replications.

The experiment studied the effect of four irrigation variants, four fertilization variants, and two plant densities on the growth, development, and productivity of sunflower.

2.3. Observations, Analyses, and Determinations

The following observations, analyses, and determinations were carried out during the experiment:

1. Phenological observations [5].
2. Accounting for the density of plant density [27].
3. Soil moisture observations; soil samples were taken from a depth of 0–100 cm in the main growth and development stages of the crop, for all irrigation regimes, without fertilization, and at the medium fertilization dose (sampling was performed in rows, taking samples every 10 cm) – thermostat-gravimetric method [26].
4. Calculation of irrigation timing and number of irrigations for the studied regimes, according to the updated model of D.A. Shtoiko [37].
5. Determination of total evapotranspiration for all variants with and without irrigation, in the main growth and development stages and throughout the growing season [36].
6. Determination of average daily water consumption, depending on the variant.
7. Calculation of the components of the soil water balance for all irrigation variants.
8. Measurement of precipitation in the field.
9. Determination of soil NPK concentration in the 0–30 cm layer at three periods: at the beginning and end of the growing season, and during the phase of maximum biomass accumulation, for all irrigation regimes, without fertilization, and at the minimum and maximum fertilization doses [15, 16].
10. Determination of leaf surface area in all experimental variants, using calculation methods based on linear leaf parameters [4, 10].
11. Determination of yield for all variants.
12. Calculation of economic and energy efficiency for all variants.
13. Determination of irrigation water quality [11, 12, 13, 14, 18, 19, 20].

3. SUNFLOWER PRODUCTIVITY DEPENDING ON IRRIGATION, FERTILIZATION, AND PLANT DENSITY

3.1. Soil Water Balance Depending on Irrigation Regimes. To maintain the established irrigation regimes, in 2022, 8–17 irrigations were carried out with a water rate of 2530–3600 m³/ha; in 2023, 7–14 irrigations with 2086–3150 m³/ha; and in 2024, 7 irrigations with a water rate of 1400–2800 m³/ha.

Consequently, in the non-irrigated variant, after sunflower harvesting, the productive soil moisture reserves in the 0–50 cm layer varied by year from –336 to –663 m³/ha, while under irrigation they ranged from –27 to –548 m³/ha.

On non-irrigated fields, total evapotranspiration from the 0–50 cm soil layer was 1628–1691 m³/ha, whereas under irrigation it reached 3563–4582 m³/ha (Table 3.1.1). The sunflower root system primarily utilized the moisture from the 0–50 cm soil layer. The contribution of the 50–100 cm soil layer to total evapotranspiration under non-irrigated conditions was 25% and only 6% under irrigation.

High plant density sowings reduced total evaporation in the non-irrigated variant by 3.7%; at a preliminary soil moisture of 70% of field capacity – by 2.5%; at 80% of field capacity – by 3.8%; and at 90% of field capacity, it increased slightly by 0.3% (Fig. 3.1.1). For high-density plantings, the optimal variant was with preliminary soil moisture equal to 80% of field capacity, whereas for standard plant density, the optimal moisture was 90% of field capacity.

Table 3.1.1. Soil water balance, average for the years 2022–2024

Plant density, thousand plants/ha	Irrigation variant	Precipitation, m³/ha	Number of irrigations	Irrigation rate, m³/ha	Total evaporation m³/ha	Precipitation infiltration, m³/ha
0-50 cm						
57	NI	1293	-	-	1691	33
	70% a FC	1293	7	3183	4582	303
	80% a FC	1293	9	2600	4194	79
	90% a FC	1293	13	2005	3563	84
86	NI	1293	-	-	1628	31
	70% a FC	1293	7	3183	4467	343
	80% a FC	1293	9	2600	4034	181
	90% a FC	1293	13	2005	3572	96
0-100 cm						
57	NI	1293	-	-	2049	41
	70% a FC	1293	7	3183	4777	575
	80% a FC	1293	9	2600	4598	148
	90% a FC	1293	13	2005	3838	141
86	NI	1293	-	-	2089	84
	70% a FC	1293	7	3183	4463	570
	80% a FC	1293	9	2600	4371	300
	90% a FC	1293	13	2005	3859	63

In addition to precipitation, the soil water regime is also influenced by the irrigation regime. The irrigation regime represents a combination of the number, timing, and rates of watering of agricultural crops. If the irrigation rates depend on the level of preliminary soil moisture and its physical parameters (bulk density, field capacity, wetting layer), then the timing of irrigation depends on meteorological conditions, the plant development stage, and is established based on the average daily water consumption.

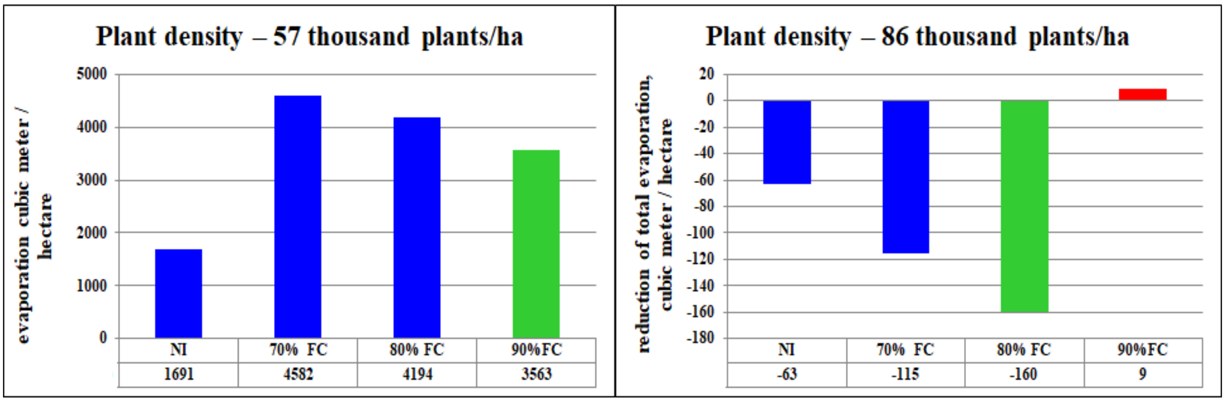


Figure 3.1.1. Effect of plant density on the reduction of total water consumption in the 0–50 cm soil layer

From the 0–50 cm soil layer, during the "seedlings – beginning of head formation" phase, sunflower plants used an average of 27–33 m³/ha of water per day. The maximum average daily water consumption (55 m³/ha) was reached during the "beginning of head formation – flowering" phase, when preliminary soil moisture was maintained at 70% FC. With an increase in preliminary soil moisture, consumption decreased to 41 m³/ha, and at harvest – to 14–18 m³/ha. In the non-irrigated variant, the average daily water consumption was minimal, gradually decreasing from 27 to 7 m³/ha. In high-density plantings, water was used more economically, and the average daily consumption decreased slightly, especially during the flowering phase.

3.2. Effect of the Studied Factors on the Soil Nutrient Regime. The application of fertilizers is one of the main anthropogenic factors influencing soil fertility and crop productivity, and under non-irrigated conditions, it plays a primary role. The most mobile nutrients in the soil are nitrates. Their amount depends on many factors: the quantity and timing of precipitation, the plant development stage, the presence of irrigation, the fertilizer dose, plant density, and others. Therefore, the annual differences in soil nitrate concentration were significant.

At any soil moisture level, from seedlings to harvest, the nitrate concentration decreased. During the seedlings phase, under irrigation, the nitrate amount was reduced 2.0–2.6 times compared to the non-irrigated variant. In the flowering phase, in addition to irrigation, nitrate concentration was also influenced by plant uptake, which resulted in larger differences – 3.4–5.1 times (Fig. 3.2.1). At the time of harvest, nitrogen consumption decreased, and the difference in nitrate concentration between the non-irrigated variant and the irrigated variants reduced to 2.9–4.0 times.

In high-density plantings, the nitrogen nutrient regime was weaker, especially during the seedlings phase and closer to harvest, indicating more intensive nitrogen uptake during these stages.

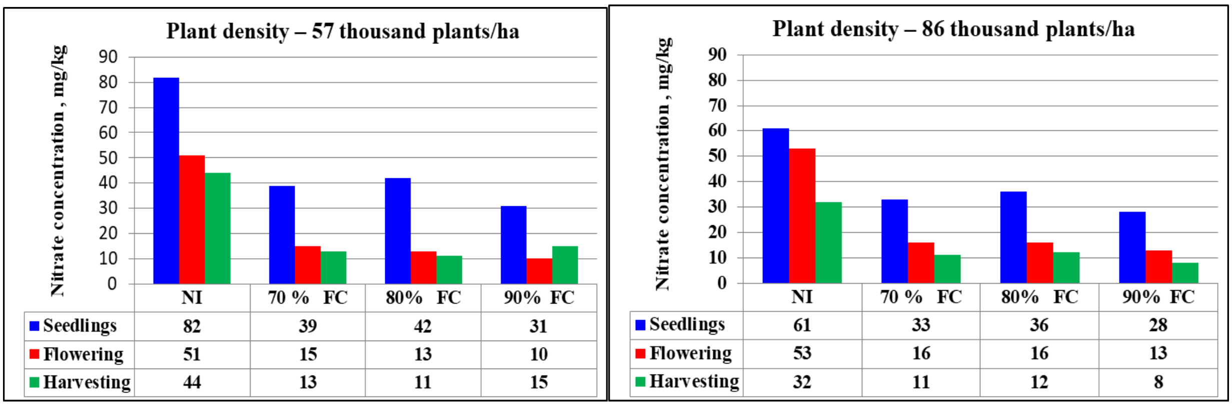
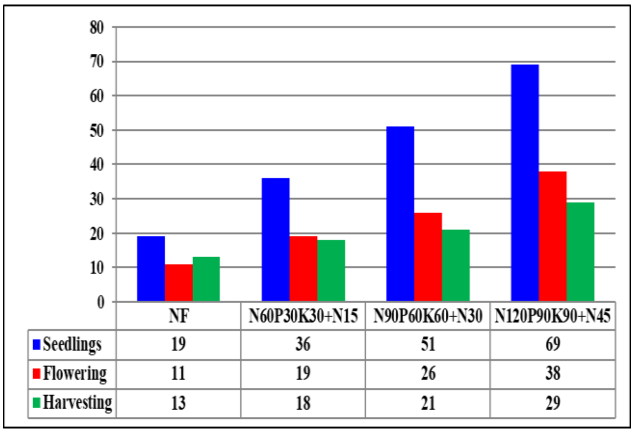


Figure 3.2.1. Effect of plant density and irrigation on nitrate dynamics in the 0–30 cm soil layer, mg/kg

The effect of applied fertilizers on the nitrogen nutrient regime was even more pronounced. Fertilizers applied before sowing, at doses of $N_{60}P_{30}K_{30}$ + N_{15} kg a.i./ha, increased soil nitrate concentration during the seedlings phase by 1.9 times; $N_{90}P_{60}K_{60}$ + N_{30} kg a.i./ha – by 2.7 times; and $N_{120}P_{90}K_{90}$ + N_{45} kg a.i./ha – by 3.6 times (Fig. 3.2.2). Subsequently, the positive effect of different fertilizer doses on the nitrogen nutrient regime persisted, but the differences became less significant.

On average, nitrogen consumption in high-density plantings was more intensive, as in all development stages, the nitrate concentration in the 0–30 cm soil layer was 12–24% lower (Fig. 3.2.3).



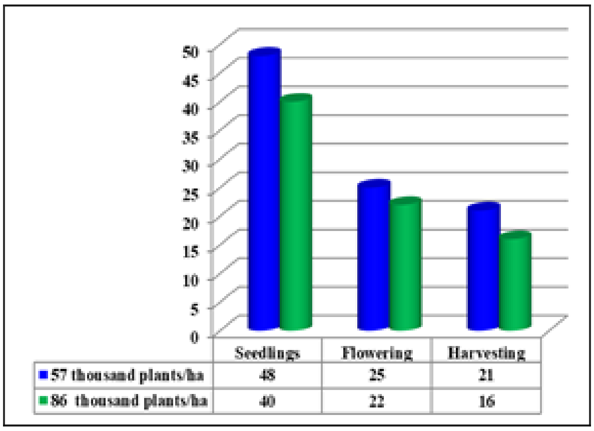


Figure 3.2.2. Effect of fertilizers on nitrate dynamics in the 0–30 cm soil layer, mg/kg

Figure 3.2.3. Effect of plant density on nitrate dynamics in the 0–30 cm soil layer, mg/kg

The phosphorus nutrient regime was more balanced and showed no clear patterns or regularities. Compared to nitrogen, phosphorus is less mobile and less influenced by precipitation and different irrigation regimes. The higher soil concentration during the initial development period (Fig. 3.2.4) in high-density plantings (especially in the non-irrigated variant) can be explained by the delayed biomass accumulation, since in this variant, the productive soil moisture reserves were always lower than in the irrigated control.

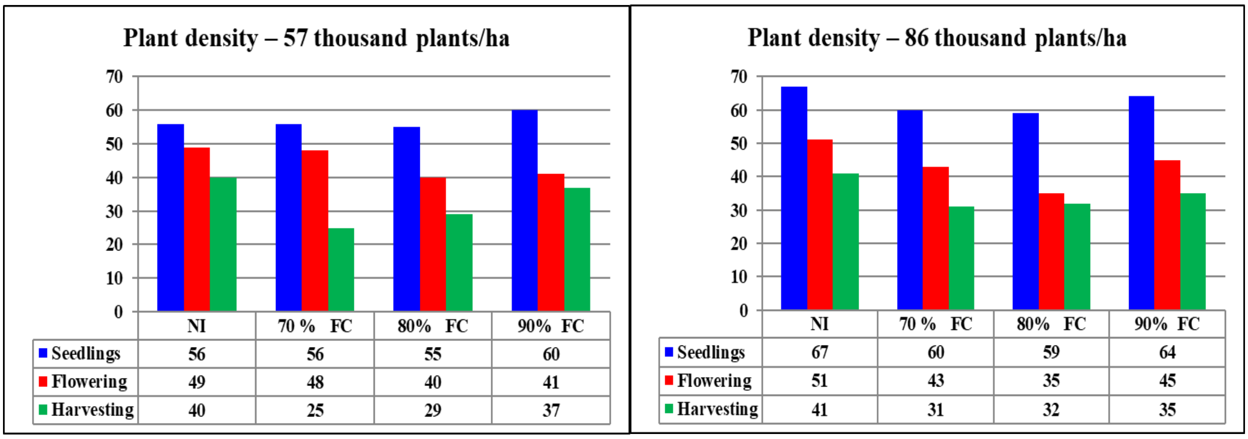


Figure 3.2.4. Effect of plant density and irrigation on mobile phosphorus dynamics in the 0–30 cm soil layer, mg/kg

In general, in the irrigated plots, the soil phosphorus concentration was lower than in the non-irrigated variant, indicating better plant development and, consequently, an increased phosphorus uptake.

As with nitrogen, fertilizers applied to the soil significantly increased the plants' phosphorus availability (Fig. 3.2.5) – during the "seedlings" phase from 38 to 80 mg/kg; in the "flowering" phase from 27 to 62 mg/kg; and in the "harvest" phase from 18 to 47 mg/kg. This figure clearly shows phosphorus uptake throughout the growing season, which nevertheless remains relatively high during the entire season.

Plant density had little effect on the phosphorus nutrient regime (Fig. 3.2.6).

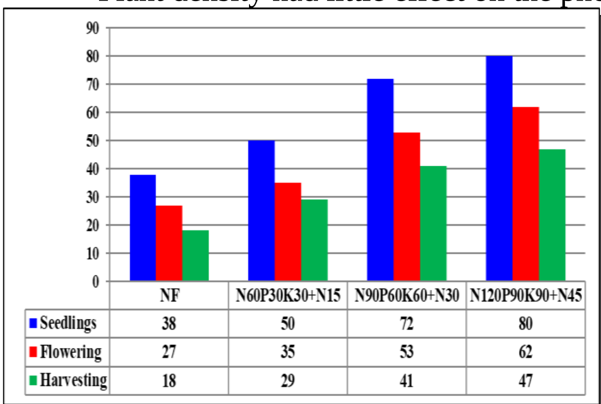


Figure 3.2.5. Effect of fertilizers on mobile phosphorus dynamics in the 0–30 cm soil layer, mg/kg

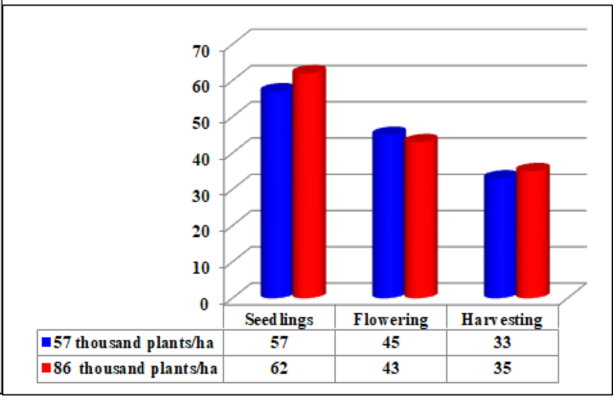


Figure 3.2.6. Effect of plant density on mobile phosphorus dynamics in the 0–30 cm soil layer, mg/kg

The studied irrigation regimes had practically no effect on the concentration of exchangeable potassium in the soil. Differences were observed only depending on the plant development stages. For example, under non-irrigated conditions, from seedlings to flowering, the potassium concentration decreased by 16%, and from flowering to harvest – by 12% (Fig. 3.2.7). Under irrigation, from seedlings to flowering, plants consumed 9–15% of the initial soil the potassium concentration, and from flowering to harvest – 11–14%. On average, throughout the experiment, irrigation reduced the potassium concentration by only 2–5%, indicating that the deterioration of the nutrient regime is largely due to potassium uptake.

Fertilizers significantly influenced the potassium nutrient regime. On average, during the growing season, in the non-fertilized variant, the exchangeable potassium concentration in the soil was 314 mg/kg. Application of the mineral fertilizer dose $N_{60}P_{30}K_{30}$ + N_{15} increased this concentration by 14%, the dose $N_{90}P_{60}K_{60}$ + N_{30} – by 27%, and the dose $N_{120}P_{90}K_{90}$ + N_{45} – by 39% (Fig. 3.2.8).

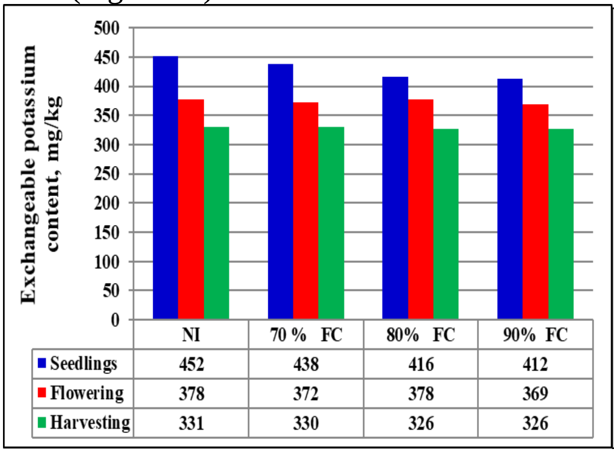


Figure 3.2.7. Effect of irrigation on the dynamics of exchangeable potassium concentration

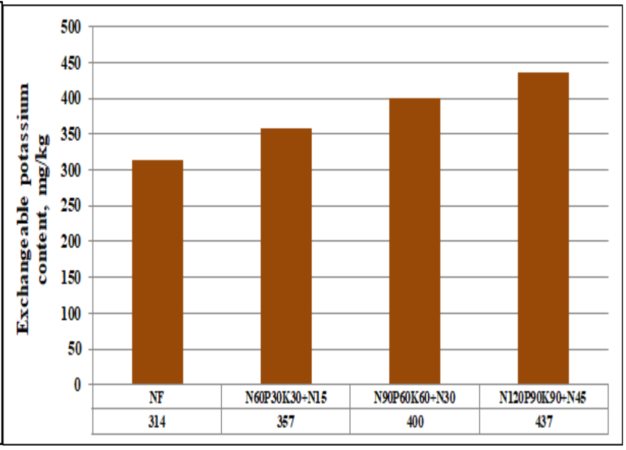


Figure 3.2.8. Effect of fertilizers on exchangeable potassium concentration

In our experiments, increasing plant density from 57 to 86 thousand plants/ha during the growing season reduced the exchangeable potassium concentration by 7–10% (Fig. 3.2.9). This indicates more intensive potassium uptake in plots with higher plant densities.

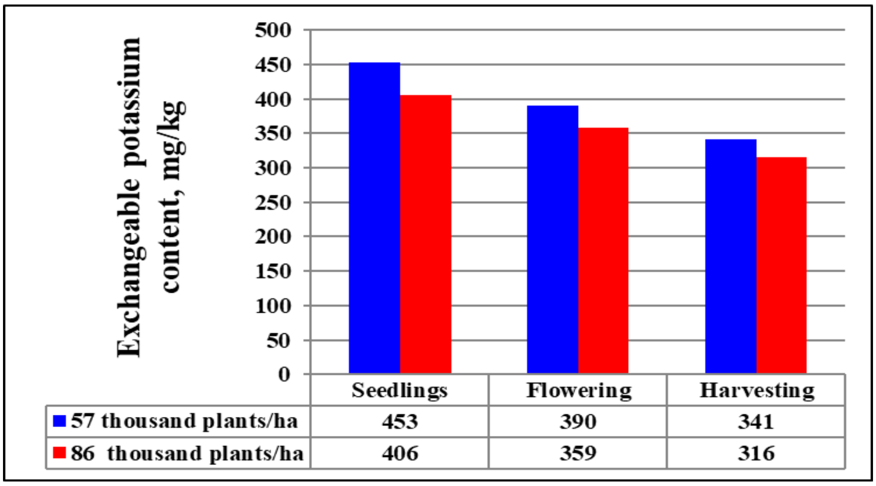


Figure 3.2.9. Effect of plant density on exchangeable potassium concentration the potassium concentration in the 0–30 cm soil layer

3.3. Effect of the Studied Factors on Plant Growth and Development. The effect of the studied factors on plant growth and development was evaluated using biometric indicators measured at the flowering stage of sunflower. Many authors [10, 22, 23, 32] emphasize the importance of biometric growth and development indicators for technological operations such as harvesting and associated yield losses. In this context, important indicators include plant height and head diameter.

The natural moisture deficit for sunflower growth was felt every year. In the non-irrigated variant, the head was smaller, and the lower leaves dried out too early, reducing the photosynthetic area, whereas under irrigation, the plants developed much better (Fig. 3.3.1).

a) b)

Figure 3.3.1. Sunflower plant development without irrigation (a) and with irrigation (b)

In the non-irrigated variant, the average plant height was 140 cm. Under irrigation, it reached approximately 172–175 cm, i.e., 23–25% taller than in the non-irrigated variant (Table 3.3.1). Under irrigation, the head diameter was 41–47% larger than in the non-irrigated variant.

Table 3.3.1. Effect of irrigation on biometric indicators of plant growth and development

Indicators	Irrigation variant			
	Without irrigation	70% FC	80% FC	90% FC
Plant height, cm	140	175	175	172
Capitulum diameter, cm	17	24	24	25
leaf surface area, thousand m²/ha	32,4	72,8	75,7	66,1
	Increase due to irrigation, %			
Plant height	-	25	25	23
Capitulum diameter	-	41	41	47
leaf surface area	-	125	134	104

The application of irrigation positively influenced leaf size, which was reflected in the leaf surface area. In the variant without irrigation, the leaf surface area was 32.4 thousand m²/ha, whereas with irrigation it increased by 104–134%, reaching 66.1–75.7 thousand m²/ha. Better plant development was achieved when maintaining the soil's preliminary moisture at 80% of field capacity (FC).

The effect of fertilizers was less significant than that of irrigation. With the application of the dose $N_{60}P_{30}K_{30}+N_{15}$ kg a.i./ha, plant height, capitulum diameter, and leaf surface area increased by 7%, 14%, and 52%, respectively; with $N_{90}P_{60}K_{60}+N_{30}$, by 10%, 18%, and 68%; and with $N_{120}P_{90}K_{90}+N_{45}$, by 13%, 24%, and 83% (Table 3.3.2).

Table 3.3.2. Influence of fertilizers on the biometric indicators of plant growth and development

Indicators	Fertilization variant			
	Without fertilizers	$N_{60}P_{30}K_{30}+N_{15}$	$N_{90}P_{60}K_{60}+N_{30}$	$N_{120}P_{90}K_{90}+N_{45}$
Plant height, cm	154	165	169	174
Capitulum diameter, cm	19,5	22,2	23,0	24,1
leaf surface area, thousand m²/ha	41,0	62,2	68,7	75,2
	Increase due to fertilization, %			
Plant height	-	7	10	13
Capitulum diameter	-	14	18	24
leaf surface area	-	52	68	83

In our experiments, increasing the plant density from 57 to 86 thousand plants per hectare increased the leaf surface area by 16% (Table 3.3.3), which later positively influenced crop productivity, since the leaf is the main organ that absorbs photosynthetically active solar radiation.

Table 3.3.3. Influence of plant density on the biometric indicators of plant growth and development

Indicators	Plant density	
	57 mii/ha	86 mii/ha
Plant height, cm	163	168
Capitulum diameter, cm	24	21
leaf surface area, thousand m²/ha	57,3	66,3
	Increase due to higher plant density	
Plant height	-	+3
Capitulum diameter	-	-12
leaf surface area	-	+16

3.4. Sunflower Seed Yield and Quality Depending on the Studied Factors. In 2022, a drought year in terms of precipitation, sunflower yield in our experiments ranged from 2.0 t/ha (under non-irrigated conditions) to 5.2 t/ha (with irrigation); in 2023, a medium-drought year, from 0.5 to 5.4 t/ha; and in the average year 2024, from 1.0 to 5.6 t/ha (Table 3.4.1).

Table 3.4.1. Influence of irrigation, fertilizers, and plant density on sunflower yield, t/ha

Variant			Year			Average
Irrigation	Plant density, thousand/ha	Fertilizare	2022	2023	2024	
1	2	3	4	5	7	8
NI	57	NI	2,7	0,5	1,1	1,4
		$N_{60}P_{30}K_{30}+N_{15}$	2,6	0,6	1,4	1,5
		$N_{90}P_{60}K_{60}+N_{30}$	2,4	0,6	1,6	1,5
		$N_{120}P_{90}K_{90}+N_{45}$	2,4	0,8	1,9	1,7
	Average		**2,5**	**0,6**	**1,5**	**1,5**
NI	86	NI	3,0	0,4	1,0	1,5
		$N_{60}P_{30}K_{30}+N_{15}$	2,6	0,5	1,4	1,5
		$N_{90}P_{60}K_{60}+N_{30}$	2,7	1,1	1,8	1,9
		$N_{120}P_{90}K_{90}+N_{45}$	2,0	1,3	2,1	1,8
	Average		**2,6**	**0,8**	**1,6**	**1,7**
Average for the irrigation regime			**2,55**	**0,7**	**1,5**	**1,6**

Table 3.4.1. (continued)

1	2	3	4	5	7	8
70% FC	57	NI	3,4	3,5	1,8	2,9
		$N_{60}P_{30}K_{30}+N_{15}$	4,4	4,1	2,7	3,7
		$N_{90}P_{60}K_{60}+N_{30}$	3,8	4,1	3,0	3,6
		$N_{120}P_{90}K_{90}+N_{45}$	3,7	4,3	3,5	3,8
	Average		**3,8**	**4,0**	**2,8**	**3,5**
	86	NI	4,0	4,2	2,2	3,5
		$N_{60}P_{30}K_{30}+N_{15}$	4,0	4,6	2,3	3,6
		$N_{90}P_{60}K_{60}+N_{30}$	4,4	4,8	2,8	4,0
		$N_{120}P_{90}K_{90}+N_{45}$	4,0	5,4	2,8	4,1
	Average		**4,1**	**4,8**	**2,5**	**3,8**
Average for the irrigation regime			**4,0**	**4,4**	**2,6**	**3,7**
80% FC	57	NI	3,1	3,0	2,2	2,8
		$N_{60}P_{30}K_{30}+N_{15}$	4,0	3,1	3,7	3,6
		$N_{90}P_{60}K_{60}+N_{30}$	4,5	3,6	4,0	4,0
		$N_{120}P_{90}K_{90}+N_{45}$	4,2	4,7	4,8	4,6
	Average		**4,0**	**3,6**	**3,7**	**3,7**
	86	NI	3,6	4,2	2,1	3,3
		$N_{60}P_{30}K_{30}+N_{15}$	4,5	4,6	3,5	4,2
		$N_{90}P_{60}K_{60}+N_{30}$	5,2	4,8	4,2	4,7
		$N_{120}P_{90}K_{90}+N_{45}$	4,7	5,4	4,8	5,0
	Average		**4,5**	**4,7**	**3,7**	**4,3**
Media pentru regimul de irigare			**4,2**	**4,2**	**3,7**	**4,0**
90% FC	57	NI	4,2	3,2	3,2	3,5
		$N_{60}P_{30}K_{30}+N_{15}$	4,2	3,3	3,6	3,7
		$N_{90}P_{60}K_{60}+N_{30}$	4,5	4,0	4,3	4,3
		$N_{120}P_{90}K_{90}+N_{45}$	4,4	4,9	5,5	4,9
	Average		**4,3**	**3,8**	**4,2**	**4,1**
	86	NI	2,8	4,2	3,3	3,4
		$N_{60}P_{30}K_{30}+N_{15}$	4,2	4,9	4,1	4,4
		$N_{90}P_{60}K_{60}+N_{30}$	3,8	5,1	4,6	4,5
		$N_{120}P_{90}K_{90}+N_{45}$	5,2	5,1	5,6	5,3
	Average		**4,0**	**4,8**	**4,4**	**4,4**
Average for the irrigation regime			**4,2**	**4,3**	**4,3**	**4,3**
$LSD_{0,95}$ – for the irrigation factor			**0,4**	**0,7**	**0,3**	**0,5**
for the fertilization factor			**0,4**	**0,7**	**0,3**	**0,5**
for the interaction of factors			**0,7**	**1,3**	**0,6**	**0,9**

Multifactorial experiments allow the evaluation of the role of each individual factor, as well as their interactions. The minimum increase in sunflower yield due to irrigation (1.3 t/ha) was obtained in the variant without fertilizers, with the soil's preliminary moisture maintained at 80% FC, while the maximum increase (3.5 t/ha) was observed in the variant with the application of $N_{120}P_{90}K_{90}+N_{45}$, on the background of preliminary soil moisture at 90% FC (Table 3.4.2).

Table 3.4.2. Increases in sunflower yield due to the studied factors
(average for the years 2022–2024)

Variant			Producti-vity, t/ha	Increase in productivity, t/ha, with			
Irrigation	Irrigation	Irrigation		irrigation	fertilization	increase in plant density	interaction of factors
NI	57	NI	1,4	-	-	-	-
		$N_{60}P_{30}K_{30}+N_{15}$	1,5	-	0,1	-	0,1
		$N_{90}P_{60}K_{60}+N_{30}$	1,5	-	0,1	-	0,1
		$N_{120}P_{90}K_{90}+N_{45}$	1,7	-	0,3	-	0,3
	Average		**1,5**	-	**0,17**	-	**0,17**
	86	NI	1,5	-	-	0,0	0,0
		$N_{60}P_{30}K_{30}+N_{15}$	1,5	-	0,0	0,0	0,1
		$N_{90}P_{60}K_{60}+N_{30}$	1,9	-	0,4	0,3	0,4
		$N_{120}P_{90}K_{90}+N_{45}$	1,8	-	0,3	0,1	0,4
	Average		**1,7**	-	**0,23**	**0,1**	**0,2**
Average for the irrigation regime			**1,6**	-	**0,20**	-	**0,2**
70% FC	57	NI	2,9	1,5	-	-	1,5
		$N_{60}P_{30}K_{30}+N_{15}$	3,7	2,2	0,8	-	2,3
		$N_{90}P_{60}K_{60}+N_{30}$	3,6	2,1	0,7	-	2,2
		$N_{120}P_{90}K_{90}+N_{45}$	3,8	2,1	0,9	-	2,4
	Average		**3,5**	**2,0**	**0,8**	-	**2,1**
	86	NI	3,5	2,0	-	0,6	2,0
		$N_{60}P_{30}K_{30}+N_{15}$	3,6	2,1	0,2	-0,1	2,2
		$N_{90}P_{60}K_{60}+N_{30}$	4,0	2,1	0,5	0,4	2,6
		$N_{120}P_{90}K_{90}+N_{45}$	4,1	2,3	0,6	0,2	2,6
	Average		**3,8**	**2,1**	**0,43**	**0,28**	**2,4**
Average for the irrigation regime			**3,7**	**2,1**	**0,62**	-	**2,2**
80% FC	57	NI	2,8	1,3	-	-	1,3
		$N_{60}P_{30}K_{30}+N_{15}$	3,6	2,1	0,8	-	2,2
		$N_{90}P_{60}K_{60}+N_{30}$	4,0	2,5	1,3	-	2,6
		$N_{120}P_{90}K_{90}+N_{45}$	4,6	2,9	1,8	-	3,1
	Average		**3,7**	**2,2**	**1,3**	-	**2,3**
	86	NI	3,3	1,8	-	0,5	1,9
		$N_{60}P_{30}K_{30}+N_{15}$	4,2	2,7	0,9	0,6	2,8
		$N_{90}P_{60}K_{60}+N_{30}$	4,7	2,9	1,4	0,7	3,3
		$N_{120}P_{90}K_{90}+N_{45}$	5,0	3,2	1,7	0,4	3,5
	Average		**4,3**	**2,6**	**1,33**	**0,55**	**2,9**
Average for the irrigation regime			**4,0**	**2,4**	**1,32**	-	**2,6**
90% FC	57	NI	3,5	2,1	-	-	2,1
		$N_{60}P_{30}K_{30}+N_{15}$	3,7	2,2	0,2	-	2,3
		$N_{90}P_{60}K_{60}+N_{30}$	4,3	2,7	0,8	-	2,8
		$N_{120}P_{90}K_{90}+N_{45}$	4,9	3,2	1,4	-	3,5
	Average		**4,1**	**2,6**	**0,77**	-	**2,7**
	86	NI	3,4	2,0	-	-0,1	2,0
		$N_{60}P_{30}K_{30}+N_{15}$	4,4	2,9	1,0	0,7	3,0
		$N_{90}P_{60}K_{60}+N_{30}$	4,5	2,6	1,1	0,2	3,1
		$N_{120}P_{90}K_{90}+N_{45}$	5,3	3,5	1,9	0,4	3,9
	Average		**4,4**	**2,8**	**1,33**	**0,3**	**3,0**
Average for the irrigation regime			**4,3**	**2,7**	**0,7**	-	**2,8**

In the non-irrigated variant, the average productivity was 1.6 t/ha. Maintaining the preliminary soil moisture in the 0–50 cm layer at the level of 70% of field capacity (FC) increased productivity to 3.7 t/ha, i.e., by 131%. An increase in preliminary moisture to 80% and 90% FC contributed to a rise in productivity to 4.0 and 4.3 t/ha, respectively, i.e., by 150% and 169% (Table 3.4.3). Compared with the non-irrigated variant, all yield increases in the irrigated plots were statistically significant with a probability of 0.95.

Table 3.4.3. The influence of irrigation on sunflower productivity

Indicator		Irrigation option			
		non-irrigated	70% FC	80% FC	90% FC
Productivity, t/ha		1,6	3,7	4,0	4,3
Supplement to irrigation	t/ha	-	2,1	2,4	2,7
	%	-	131	150	169

The average productivity over three years in the unfertilized treatment was 2.8 t/ha. The minimum fertilizer dose increased sunflower productivity to 3.3 t/ha, which represents an 18% increase compared with the control; the medium dose increased productivity to 3.6 t/ha, or 29%, while the maximum dose increased it to 3.9 t/ha, or 39% (Table 3.4.4). At a statistical significance threshold ($LSD_{0.95}$) for the fertilizer factor of 0.5 t/ha, all yield increases compared with the unfertilized treatment were significant. No significant differences were recorded between the fertilizer doses.

Table 3.4.4. The influence of fertilizers on sunflower productivity

Indicator		Fertilization option			
		Without fertilizers	$N_{60}P_{30}K_{30}+N_{15}$	$N_{90}P_{60}K_{60}+N_{30}$	$N_{120}P_{90}K_{90}+N_{45}$
Productivity, t/ha		2,8	3,3	3,6	3,9
Supplement to fertilization	t/ha	-	0,5	0,8	1,1
	%	-	18	29	39

At a plant density of 86 thousand plants/ha, the leaf assimilatory surface area was 16% higher than at a density of 57 thousand plants/ha, which ensured an increase in sunflower yield by 0.35 t/ha or 11% (Table 3.4.5).

Table 3.4.5. The influence of plant density on sunflower yield

Indicator		Plant density	
		57 thousand/ha	86 thousand/ha
Productivity, t/ha		3,2	3,55
Supplement to fertilization	t/ha	-	0,35
	%	-	11

The strong relationship between yield and the leaf surface area of plants was also confirmed by the correlation coefficients we calculated between these two indicators, which were 0.854 at a plant density of 57 thousand plants/ha and 0.905 at a density of 86 thousand plants/ha.

The calculated relationships between leaf surface area and yield also showed high coefficients of determination, ranging from 0.8281 to 0.8538 (Fig. 3.4.1).

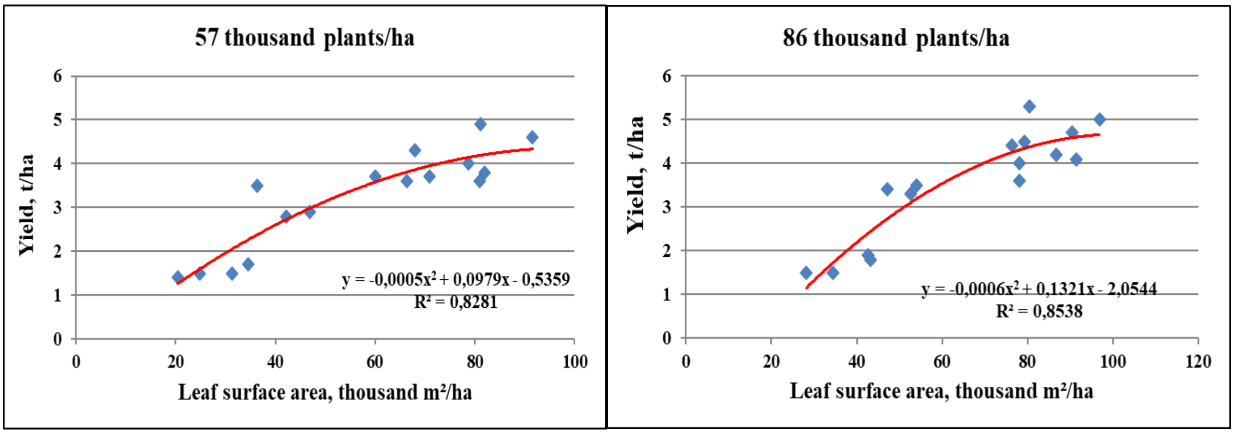


Figure 3.4.1. The relationship "Yield – leaf surface area"

The correlation between yield and the diameter of the plant capitulum at the flowering stage was also high, ranging from 0.952 to 0.956.

So far, we have analyzed the separate influence of each factor on productivity, however multifactorial experiments are valuable because they allow the determination of the interaction between different factors. In our experiments, the combined effect of irrigation and fertilization is of the greatest importance, since these factors have the strongest impact on sunflower productivity. The yield increases due to the combined action of the factors varied from 1.0 to 3.9 t/ha. These results are easier to analyze graphically (Fig. 3.4.2).

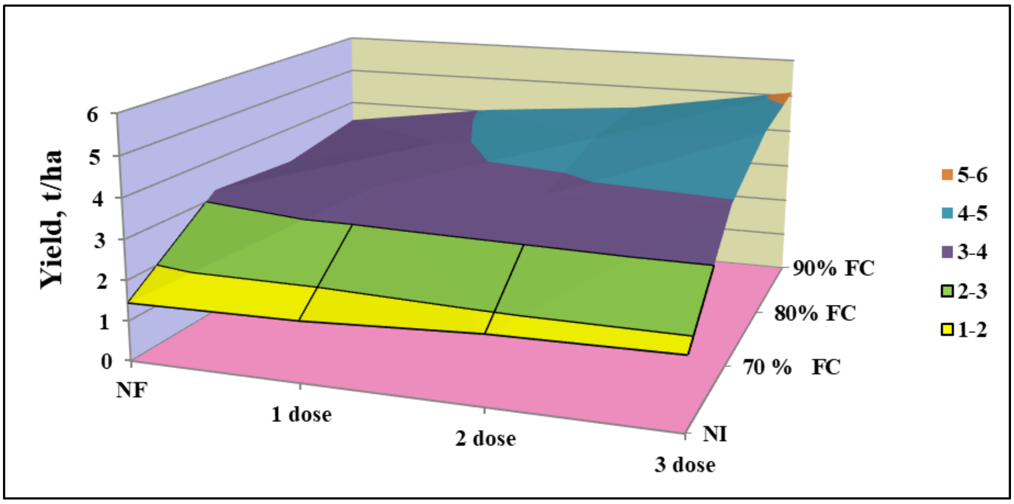


Figure 3.4.2. The combined effect of irrigation and fertilization on sunflower yield

For example, a yield of 1.0 to 2.0 t/ha can be obtained even without irrigation, whereas a yield of 3–4 t/ha can be achieved only with irrigation, maintaining the pre-irrigation soil moisture at 70% of field capacity, regardless of the fertilizer dose. A yield of 4–5 t/ha of sunflower seeds can be obtained under any irrigation regime, but only with the mandatory application of fertilizers, while yields exceeding 5 t/ha can be achieved only by maintaining the irrigation regime at 90% of field capacity and applying the maximum fertilizer dose – $N_{120}P_{90}K_{90}$ + N_{45}.

Thus, the optimal zone for sunflower cultivation under irrigated agriculture lies within the irrigation range of 80–90% of field capacity, with the application of mineral fertilizers at doses higher than $N_{60}P_{30}K_{30}$ + N_{15} kg a.i./ha.

Sunflower seeds are usually used for oil extraction, therefore their quality is evaluated by oil concentration. The value of this indicator depends on many factors—primarily the variety (hybrid) and weather conditions, but also, importantly, the cultivation technology used. In our experiments, the influence of irrigation and fertilizers on the oil concentration of the Aromatic hybrid was studied. During the years of research, the average values of this indicator ranged from 43.0% to 46.8% (Table 3.4.6).

Table 3.4.6. The influence of irrigation and fertilizers on the oil concentration of sunflower

Fertilization option, kg a.i./ha	Irrigation option				**Average**
	non-irrigated	70% FC	80% FC	90% FC	
NI	44,3	45,6	46,6	44,3	**45,2**
$N_{60}P_{30}K_{30}+N_{15}$	45,4	45,4	45,4	45,6	**45,4**
$N_{90}P_{60}K_{60}+N_{30}$	44,8	45,0	46,8	43,1	**44,9**
$N_{120}P_{90}K_{90}+N_{45}$	43,2	43,4	45,4	43,0	**43,8**
Media	**44,4**	**44,8**	**46,0**	**44,0**	**-**

LSD0,95 – for the irrigation factor – 1,1 %
for the fertilization factor – 1,3 %
for the interaction of factors – 2,3 %

It was found that the highest oil concentration was recorded in seeds grown under soil moisture maintained at 80% of field capacity, with the minimum fertilizer background – $N_{60}P_{30}K_{30}$ + N_{15}. However, the increases were insignificant and not always statistically justified (Figs. 3.4.3–3.4.4).

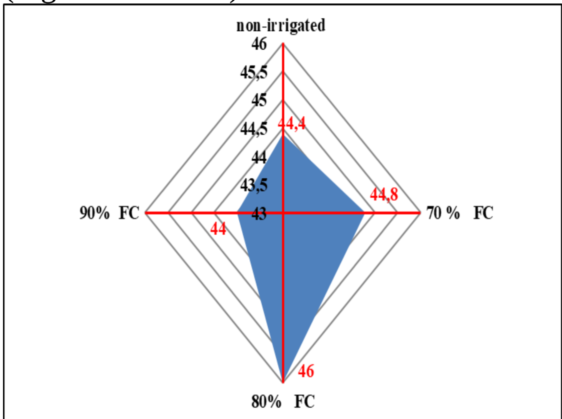


Figure 3.4.3. The influence of irrigation on the oil concentration of sunflower

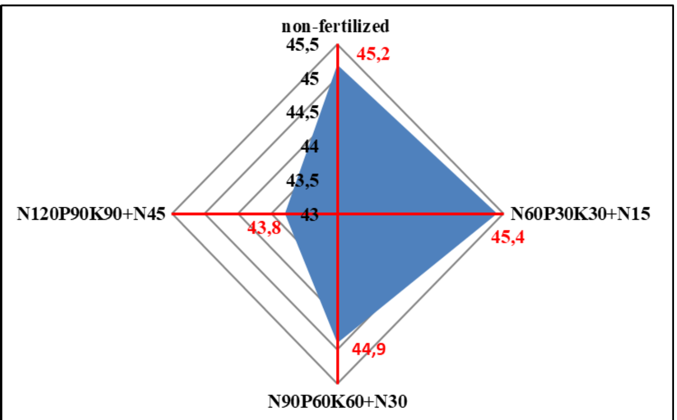


Figure 3.4.4. The influence of fertilizers on the oil concentration of sunflower

4. EFFICIENCY OF SUNFLOWER CULTIVATION

4.1. Efficiency of soil moisture and irrigation water use. In irrigated agriculture, a very important indicator is the coefficient of total water use efficiency, which shows how much water is consumed to produce one ton of yield.

On average, over the three-year period, in the non-irrigated plots, 1290 m³ of water were required to produce one ton of sunflower seeds. In the irrigated plots, soil moisture was used much more efficiently. This was probably the main reason for obtaining higher productivity in these plots. As the pre-irrigation soil moisture level increased from 70% to 90% of field capacity, the coefficient of total water use decreased to 895–1250 m³/t, i.e., by 3–31% (Table 4.1.1).

Table 4.1.1. The influence of irrigation on the efficiency of total water use and irrigation water use

Indicator	Irrigation option			
	Without irrigation	70% FC	80% FC	90% FC
Coefficient of total water use efficiency, m³/t	1290	1250	1120	895
Coefficient of irrigation water use efficiency, kg/m³	-	0,66	0,92	1,35
	Irrigation supplement, %			
Coefficient of total water use efficiency	-	+3	+13	+31
Coefficient of irrigation water use efficiency	-	-	+39	+105

A major importance for our region is the efficiency of irrigation water use. It is evaluated according to the coefficient of irrigation water use efficiency, i.e., by the amount of additional yield obtained per cubic meter of water used for irrigation, and the higher this value, the better. In the experiments conducted, as the pre-irrigation soil moisture level increased, the efficiency of irrigation water usage also increased. The maximum values of this indicator (1.35 kg/m³) were recorded in the variant with pre-irrigation soil moisture at 90% of field capacity, which is 105% higher compared with the 70% FC variant.

In the unfertilized variant, soil moisture was used with minimal efficiency—at least 1370 m³ of water were required to produce one ton of sunflower seeds. With increasing fertilizer doses, the efficiency of soil moisture use improved, increasing by 13–35% (Table 4.1.2).

At a plant density of 86 thousand plants/ha, both total water and irrigation water were used more efficiently than at a density of 57 thousand plants/ha—the coefficients of total water use efficiency and irrigation water use efficiency were 12% and 10% lower, respectively (Table 4.1.3).

Table 4.1.2. The influence of fertilizers on the efficiency of soil moisture and irrigation water use

Indicator	Fertilizer option			
	Without fertilizers	$N_{60}P_{30}K_{30}+N_{15}$	$N_{90}P_{60}K_{60}+N_{30}$	$N_{120}P_{90}K_{90}+N_{45}$
Coefficient of total water use efficiency, m³/t	1370	1190	1090	890
Coefficient of irrigation water use efficiency, kg/m³	0,81	0,86	1,01	1,18
	Fertilization supplement, %			
Coefficient of total water use efficiency	-	+13	+20	+35
Coefficient of irrigation water use efficiency	-	+6	+25	+46

Table 4.1.3. The influence of plant density on the efficiency of total soil water use and irrigation water use

Indicator	Densitatea plantelor	
	57 thousand plants/ha	86 thousand plants/ha
Coefficient of total water use efficiency, m^3/t	1220	1070
Coefficient of irrigation water use efficiency, kg/m^3	0,93	1,02
	Increase due to higher density, %	
Coefficient of total water use efficiency	-	+12
Coefficient of irrigation water use efficiency	-	+10

4.2. Recovery of fertilizers through yield. According to the Moldovan expert Iurie Rîja, in 2023–2024, fertilizer costs in Moldova accounted for 11% of the total annual technological costs for sunflower production [30]. For this reason, achieving maximum profitability of fertilizers through yield is a priority for both researchers and producers. It is well known that the application of fertilizers in years with precipitation deficits can have minimal or even negative effects [35].

Applying different types and rates of fertilizers on a typical chernozem soil, A.L. Toigildin and collaborators obtained yield increases between 5.2 and 8.1 kg per kg of fertilizer applied [26].

First, let us analyze the yield increase obtained per kilogram of active ingredient of fertilizers due to the factors studied. In the non-irrigated variant, fertilizer profitability through yield was minimal – 0.76 kg/kg a.i. Under irrigation, it increased significantly: in the 70% FC variant up to 2.79 kg/kg a.i., in the 90% FC variant up to 4.33 kg/kg a.i., while the maximum (5.67 kg/kg a.i.) was observed at 80% of field capacity (Fig. 4.2.1).

Fertilizer efficiency depended not only on irrigation but also on the fertilizer doses applied in the experiments (Fig. 4.2.2).

The most efficient application was the minimum fertilizer doses – $N_{60}P_{30}K_{30}$ + N_{15}, giving 3.7 kg/kg a.i. Although further increases in doses raised yield (not always statistically significant), this did not lead to higher efficiency, which decreased by approximately 13%.

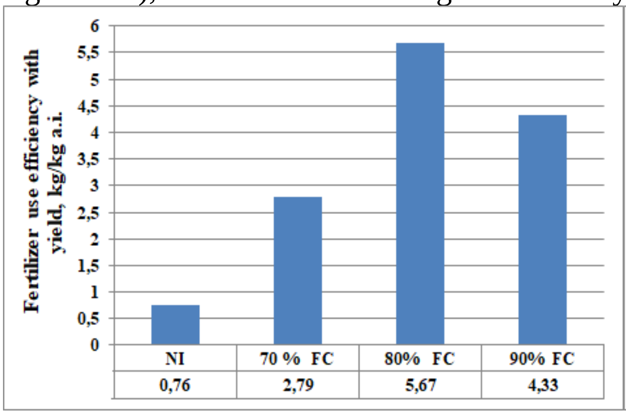


Figure 4.2.1. Fertilizer recovery through yield depending on the irrigation regime

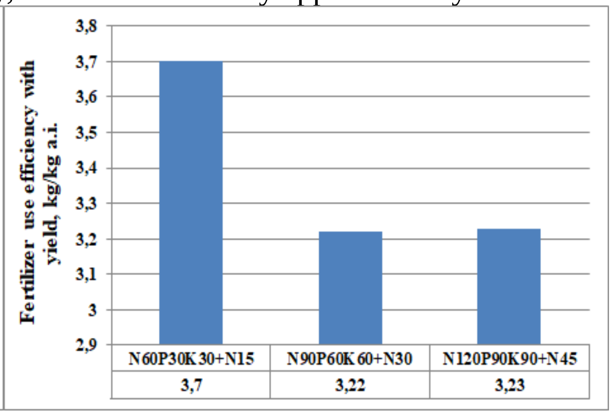


Figure 4.2.2. The influence of fertilizer doses on fertilizer recovery through yield

Fertilizer recovery through yield at a plant density of 86 thousand plants/ha was always 2–21% higher than at a density of 57 thousand plants/ha (Fig. 4.2.3).

The combined effect of irrigation and fertilizers consistently provided the highest yield gains per kilogram of active ingredient applied in the variant where pre-irrigation soil moisture was maintained at 80% of field capacity (Fig. 4.2.4).

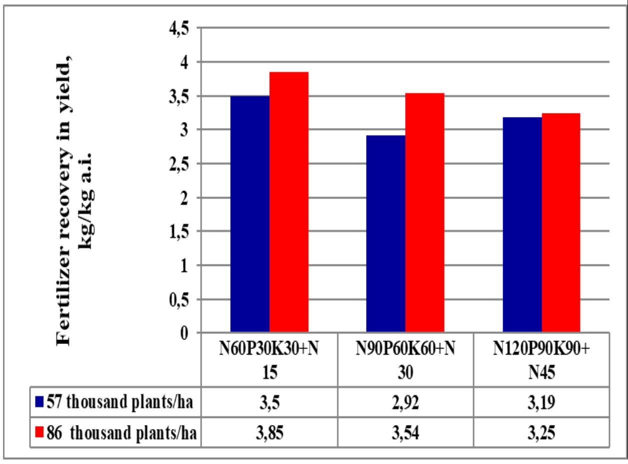


Figure 4.2.3. The influence of plant density on fertilizer recovery through yield

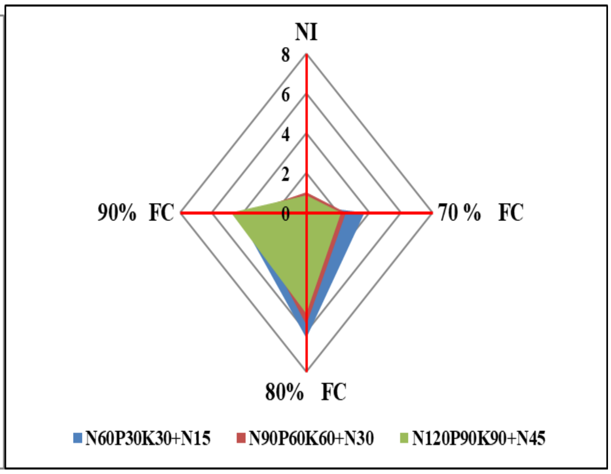


Figure 4.2.4. The combined effect of irrigation and fertilizers on their recovery through yield, kg/kg a.i.

Thus, fertilizers were recovered most efficiently when applied in small doses on an 80% FC irrigation background with increased plant densities.

4.3. Economic efficiency. The criterion for evaluating any technology is its economic efficiency. To determine this, we compared the cost of production with expenses, net profit, and profitability.

In calculating the economic efficiency of sunflower cultivation in Moldova, we based the calculations on the technology proposed by the expert from AGROEXPERT, Iurie Rîja [30]. The common expenses for all experimental variants per hectare were 11,336 lei. To calculate the total costs per variant, the following were added according to productivity: expenses for transport and seed cleaning, cost of fertilizers, and water used for irrigation.

According to Iurie Rîja, in 2024, the average selling price of sunflower seeds in Moldova was 9.52 lei/kg [31]. At this price, the sales value of production from our experiments ranged between 13.3 and 50.5 thousand lei/ha. The cost portion included all mechanized operations, seed cleaning, and the costs of fertilizers and irrigation water, which varied depending on the variant between 11.5 and 38.5 thousand lei/ha.

The application of fertilizers without irrigation was unprofitable; moreover, with increasing fertilizer doses, losses increased, while in the absence of fertilizers, net profit was 1.8–2.8 thousand lei/ha. Under irrigation, only two out of twenty-four variants were unprofitable, due to maximum fertilizer doses and high irrigation rates, even though productivity ranged between 3.6 and 3.8 t/ha.

Not all experimental variants were profitable, but in the best cases, profitability ranged between 53% and 60%. Increasing pre-irrigation soil moisture and plant density contributed not only to higher yields but also to greater technology profitability.

In the unfertilized variant, sunflower cultivation is profitable starting from a yield of 1.4 t/ha, both without irrigation and under any irrigation regime. The application of mineral fertilizers becomes profitable only with irrigation, with pre-irrigation soil moisture of at least 70% FC.

The minimum fertilizer dose ($N_{60}P_{30}K_{30}$+N_{15}) becomes profitable at a yield of at least 3.6 t/ha, the medium dose ($N_{90}P_{60}K_{60}$+N_{30}) at 4.0 t/ha, and the maximum dose ($N_{120}P_{90}K_{90}$ + N_{45}) at 4.1 t/ha.

On average, for the “irrigation” factor, the maximum profit was observed in the variant with pre-irrigation soil moisture at 90% FC (Fig. 4.3.1). Reducing pre-irrigation moisture to 80% FC decreased net profit by 40%, and to 70% FC by 89%. In the non-irrigated variant, there was no profit.

For the “fertilizer” factor, the maximum net profit (5.4 thousand lei/ha) was achieved with the minimum fertilizer dose – $N_{60}P_{30}K_{30}$ + N_{15} (Fig. 4.3.2). Increasing the doses reduced profit due to the high cost of fertilizers.

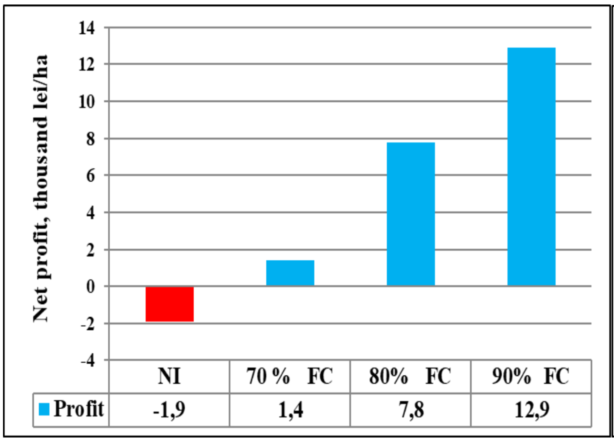


Figure 4.3.1. The influence of irrigation on net profit

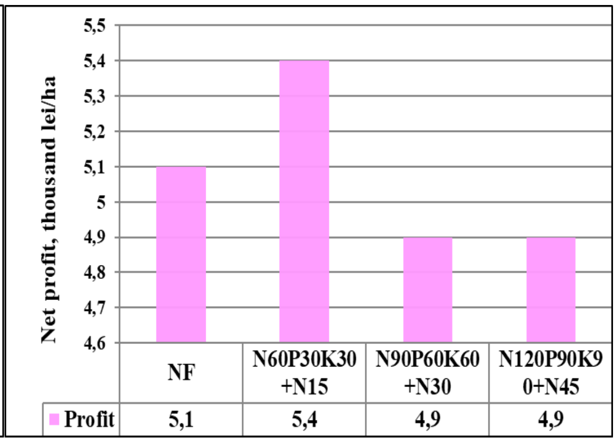


Figure 4.3.2. The influence of fertilizers on net profit

4.4. Energy Efficiency. Under current conditions, increasing the productivity of any agricultural crop requires an ever-greater consumption of energy in the form of fertilizers, water, pesticides, fuel, machinery, etc. For this reason, increasing the energy efficiency coefficient of technologies is an important task both for researchers and for agricultural producers.

The energy accumulated in the main product was calculated based on yield and the energy equivalent contained in 1 kg of seeds, which, according to Nekipelov T.S. and Pigorev

I.Ya., is 26.28 MJ/kg [28]. Depending on the variant, this indicator varied from 36.8 GJ/ha (in the variant without irrigation and without fertilizers) to 139.4 GJ/ha (under the irrigation regime of 90% of field capacity with the maximum fertilizer dose). With an increase in soil moisture level and fertilizer dose, the energy accumulated through the main yield generally increased.

For an objective assessment of biological energy efficiency, in addition to the energy accumulated through the yield, it is also necessary to consider the energy accumulated in the by-product, which is usually significantly higher. For example, in the experiments of Nekipelov T.S. and Pigorev I.Ya. in the Central Chernozem Zone of Russia, the energy accumulated in the sunflower by-product was 1.34–1.76 times higher than the energy accumulated in the harvested yield [28].

In our experiments, the energy accumulated in the by-product varied between 55 and 209 GJ/ha. Thus, together with the energy accumulated in the yield, the total energy, depending on the variant, ranged from 92 to 348 GJ/ha.

In the non-irrigated variant, fertilizers accounted for 27–48% of total energy costs, whereas under irrigation, depending on the pre-irrigation soil moisture level, their share ranged from 13 to 33%. The largest share of energy consumption was represented by irrigation water. At 70% of field capacity, it accounted for 41–58%, at 80% – 37–53%, and at 90% – 31–46%.

Increasing the pre-irrigation soil moisture level from 70% to 90% of field capacity increased the accumulated energy and reduced its consumption, thus increasing the energy efficiency coefficient from 1.81 to 2.56 (Fig. 4.4.1).

The technology of sunflower cultivation under non-irrigated conditions was also energy-efficient—the energy efficiency coefficient was 1.54, although the yields obtained in this variant were unprofitable and economically inefficient.

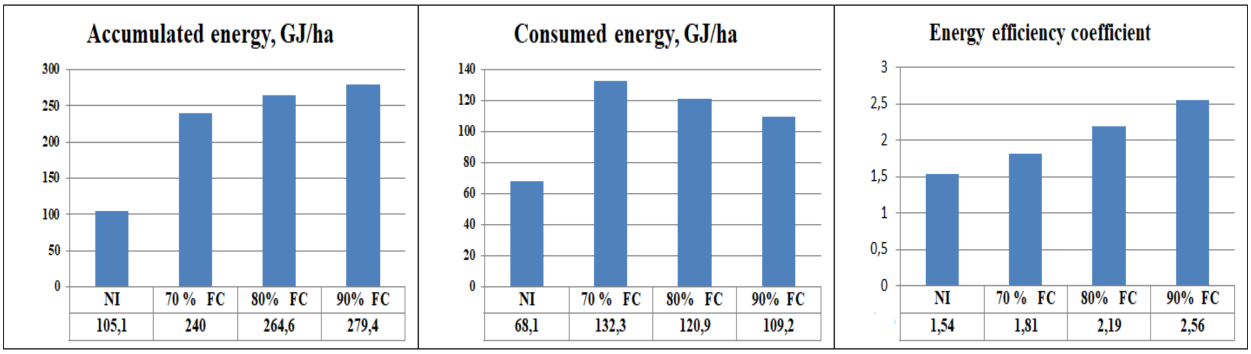


Figure 4.4.1. Effect of irrigation on the energy efficiency of sunflower cultivation

If the irrigation regimes increased the energy output and reduced its consumption, fertilizers increased both indicators. Therefore, the energy efficiency coefficient, although slightly, decreased from 2.16 to 2.00 (Fig. 4.4.2).

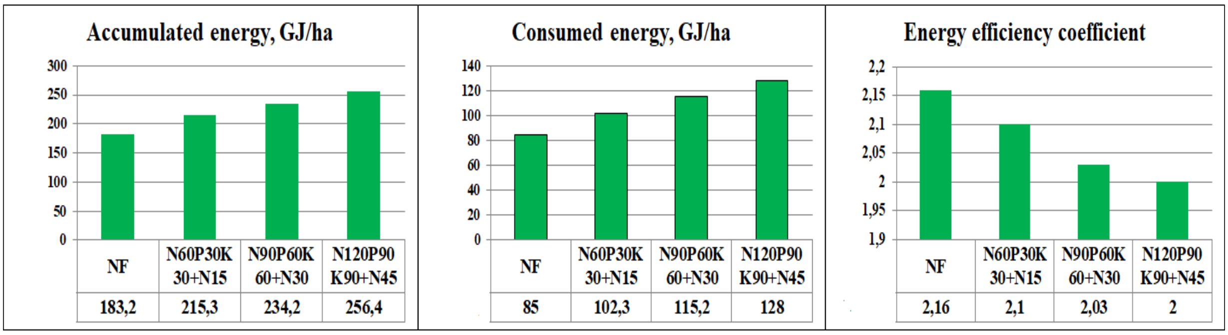


Figure 4.4.2. Effect of fertilizers on the energy efficiency of sunflower cultivation

This is due to the fact that the effect of irrigation on sunflower productivity was much more significant than the effect of fertilizers.

5. DEPENDENCE OF SUNFLOWER CROP YIELD ON THE STUDIED FACTORS AND THEIR USE FOR ACHIEVING DIFFERENT PRODUCTIVITY LEVELS

5.1. Dependence "Yield – Irrigation Regime". To evaluate the efficiency of irrigation regimes and fertilizers, agricultural specialists use various statistical correlations between water consumption and yield, as well as between yield and fertilizer doses.

American researchers have concluded that there are no universal correlation relationships valid for all regions of the country [2].

For our region, Alexei Gumanuk established that the "water – yield" relationships are best described by a second-degree polynomial equation, with high and very high approximation coefficients. This means that they can be widely used to determine the efficiency of irrigation regimes and to plan irrigation schedules for obtaining the planned yields [3].

The experimental data obtained allowed us to calculate the relationships "yield – irrigation regime" (Fig. 5.1.1a) and their components – "yield – irrigation rate" (Fig. 5.1.1c) and "yield – total water consumption" (Fig. 5.1.1d). These relationships are described by a second-degree polynomial equation, with high values of approximation coefficients ranging from 0.964 to 0.9982.

Analyzing these relationships, we can conclude that yields above 4.0 t/ha can be obtained both by maintaining the pre-irrigation soil moisture at 80% FC and at 90% FC. From the point of view of saving irrigation water and the total use of soil moisture reserves, the preferable option is 90% of field capacity, where irrigations are carried out more frequently but with smaller irrigation rates.

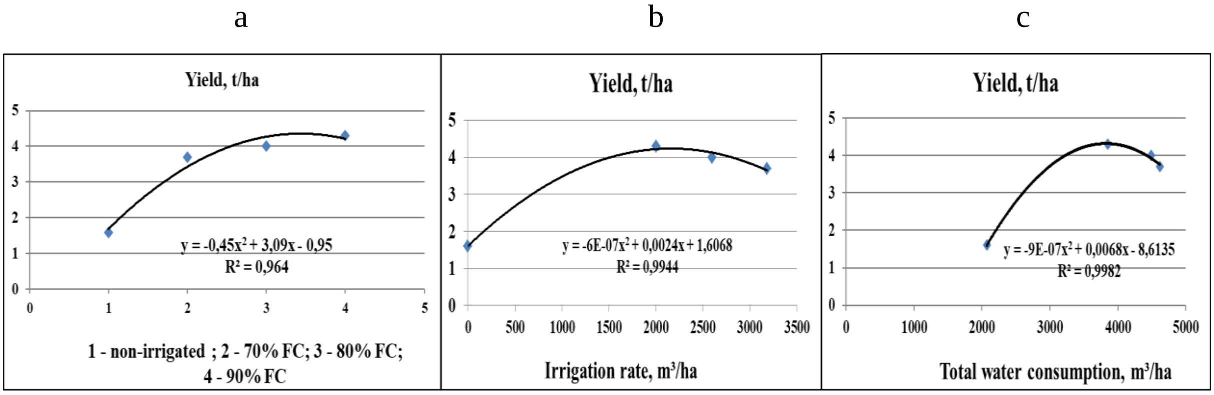


Figure 5.1.1. Sunflower yield dependence on irrigation regimes (a) and its components (b, c).

Thus, the water consumption deficit for the south-eastern zone of Moldova in dry years with low precipitation is 1800–2000 m³/ha, which must be compensated either by precipitation or by irrigation.

5.2. Dependence “Yield – Fertilizer Dose”. In the previous sections of this study, we established that the optimal irrigation regime for sunflower lies within the range of pre-irrigation soil moisture from 80% to 90% of field capacity, with a plant density of 86 thousand plants/ha.

To determine the optimal fertilizer dose, we calculated three additional relationships between yield and fertilizer dose, but at different levels of pre-irrigation soil moisture and with the optimal plant density.

Considering that at 70% of field capacity the irrigation rate and the total soil evaporation were maximal, it can be assumed that the plants lacked fertilizers, meaning that the nutrient regime was not fully optimized (Fig. 5.2.1). This phenomenon was caused by more abundant irrigations, which led to losses of water and nutrients from the wetted soil layer.

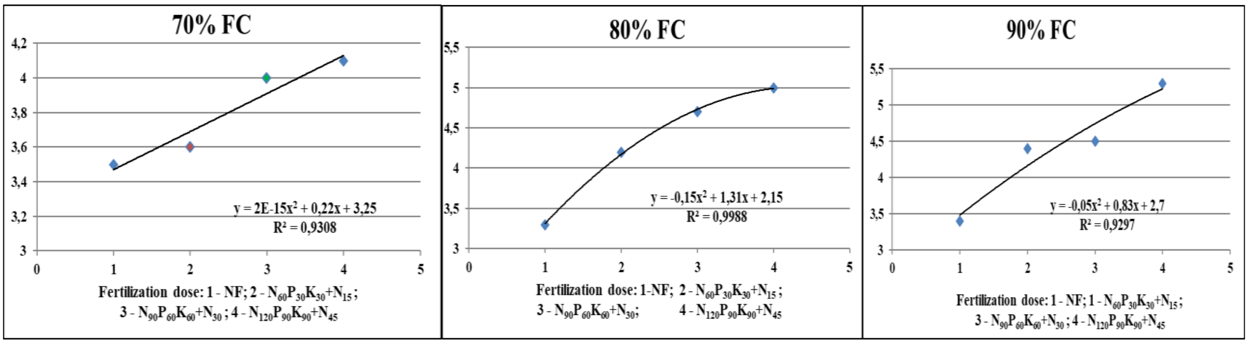


Figure 5.2.1. Yield–Fertilizer Dose Relationships for Different Pre-Irrigation Moisture Contents

The nutrient regime was best optimized in the variants where irrigation was carried out at 80% and 90% of field capacity. Considering that in the variant with 80% of field capacity the fertilizer efficiency (yield per kg of applied fertilizer active ingredient) was the highest (Fig. 4.2.1), and **the** approximation coefficient of the relationship was also the highest, this regime is considered preferable.

GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR PRODUCERS

1. The precipitation conditions during the years of study differed: 2022 was dry, 2023 – semi-dry, and 2024 – average. The total precipitation from April to September amounted to 178 mm in 2022, 266 mm in 2023, and 314 mm in 2024, compared to the long-term average (78 years of observations) of 299 mm.

2. The analysis of the correlation between sunflower yield and natural moisture reserves indicates that the meteorological conditions in our region limit sunflower productivity to 2.0–2.2 t/ha, and the only condition for increasing it is irrigation.

3. On average, over a three-year period, the total evaporation from the 0–50 cm soil layer **was** 1630–1690 m³/ha on non-irrigated land and 3560–4580 m³/ha on irrigated land. The crop root system primarily used moisture from the 0–50 cm soil layer. The share of evapotranspiration from the 50–100 cm layer was 25% on non-irrigated land and only 6% on irrigated land.

4. The soil nutrient regime was influenced not only by the studied factors (irrigation, fertilization, plant density), but also by the annual amount of precipitation. Even though fertilizer doses were the same each year, the nitrate concentration clearly depended on precipitation levels.

5. The applied fertilizers significantly increased the phosphorus supply capacity of plants, but had minimal effect on the concentration of exchangeable potassium in the soil. Plant density had little influence on the phosphorus nutrient regime.

6. The influence of the studied factors on plant growth and development was evaluated using biometric indicators measured at the flowering stage. In the non-irrigated variant, the average plant height was 140 cm, the head diameter was 17 cm, and leaf surface area was 32.4 thousand m²/ha. Irrigation increased plant height by 23–25%, head diameter by 24–25%, and leaf surface area by 104–134%. Fertilization had a smaller effect than irrigation.

7. In the non-irrigated variant, the average yield was 1.6 t/ha. Maintaining pre-irrigation soil moisture in the 0–50 cm layer at 70% of field capacity increased yield by 131%. Increasing moisture to 80% and 90% resulted in yield increases of 150% and 169%, respectively. In the non-fertilized variant, the average yield was 2.8 t/ha. The minimum fertilizer dose increased productivity by 18%, the medium dose by 29%, and the maximum dose by 39%. Increasing plant density from 57 to 86 thousand plants/ha increased yield from 3.2 to 3.55 t/ha (by 11%).

8. On non-irrigated land, the production of one ton of sunflower seeds required 1290 m^3 of water. Increasing the pre-irrigation soil moisture from 70% to 90% of field capacity reduced the total evapotranspiration coefficient to 895–1250 m^3/t, i.e., by 3–31%.

9. The maximum efficiency of irrigation water use (1.35 kg/m^3) was observed at a pre-irrigation soil moisture of 90% of field capacity, which was 105% higher than at 70%. Without fertilization, at least 1370 m^3 of water were required to produce one ton of seeds. Fertilization improved the efficiency of soil moisture use, increasing it by 13–35% as fertilizer doses increased. Increasing crop density from 57 to 86 thousand plants/ha improved the efficiency of water and soil moisture use by 10–12%.

10. The application of the minimum fertilizer dose ($N_{60}P_{30}K_{30}$+N_{15}) becomes profitable at a yield of at least 3.6 t/ha, the medium dose ($N_{90}P_{60}K_{60}$+N_{30}) at 4.0 t/ha, and the maximum dose ($N_{120}P_{90}K_{90}$+N_{45}) at 4.1 t/ha.

11. The maximum profit for the irrigation factor was obtained in the variant with pre-irrigation soil moisture of 90% of field capacity. Reducing soil moisture to 80% decreased net income by 40%, and to 70% by 89%. Without irrigation, no profit was recorded.

12. In the non-irrigated variant, fertilizers accounted for 27–48% of the total energy costs, while under irrigation, depending on pre-irrigation moisture, they accounted for 13–33%. The largest share of energy costs was associated with irrigation water: 41–58% at 70% FC, 37–53% at 80%, and 31–46% at 90% FC. Fertilization reduced the energy efficiency coefficient by 3–7%, whereas irrigation increased it by 18–66% compared with the non-irrigated variant.

13. The relationships “Yield – irrigation regime” and “Yield – fertilizer dose” show that productivity above 5.0 t/ha can be achieved only by combining irrigation at a pre-irrigation soil moisture level of at least 80% of field capacity with the application of the maximum fertilizer dose $N_{120}P_{90}K_{90}$+N_{45}.

Recommendations for Producers

1. Yields of 1.0–2.0 t/ha can be obtained without irrigation, with the application of fertilizers at $N_{60}P_{30}K_{30}$+N_{15} kg a.i./ha, while yields of 3–4 t/ha can be achieved only under irrigation, maintaining pre-irrigation soil moisture at 70% of field capacity, regardless of the fertilizer dose.

2. Yields of 4–5 t/ha can be obtained under any irrigation regime, but with the mandatory application of fertilizers, while yields above 5 t/ha can be achieved only by maintaining irrigation at 90% of field capacity and applying the maximum fertilizer dose $N_{120}P_{90}K_{90}$+N_{45}. However, this option is not always economically justified and may

contribute to the intensification of organic matter mineralization in the soil and a decline in soil fertility.

3. The optimal range for sunflower cultivation under irrigated agriculture is 70–90% of field capacity, with fertilizer application greater than $N_{60}P_{30}K_{30}+N_{15}$ kg a.i./ha.

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SELECTED BIBLIOGRAPHY

1. Соняшник - Основні Чинники Успішного Вирощування.” 2017. https://agro-liga.com/podsolnechnik-osnovnye-faktory-obespechivayushhie-uspeh-vyrashhivaniya/.
2. CHVAN, S.A., S.V. BHOITE, AND S.A. KHANVILKAR. “Effect Aflimited Irrigation on Performance of Different Rabi Crops Grown under Lateritic Soils.” J. Maharashtra Agr. Univ. 1989. p.p.301-303. https://scholar.google.co.in/citations?view_op=view_citation&hl=en&user=XkghNZ4AAAAJ&citation_for_view=XkghNZ4AAAAJ:Zph67rFs4hoC.
3. GUMANIUC A. “Eficienţa Regimurilor de Irigare .” Agricultura Moldovei. Вып 4. 2005, p.p. 15–17.
4. ROUPHAEL, Y., COLLA, G., FANASCA, S., KARAM, F. “leaf surface area Estimation of Sunflower Leaves from Simple Linear Measurements.” Photosynthetica 45 (2). 2007. pp.306–308. https://doi.org/10.1007/s11099-007-0051-z.
5. UWE MEIER. 2001. “BBCH Monograph.” https://www.openagrar.de/servlets/MCRFileNodeServlet/openagrar_derivate_00010428/BBCH-Skala_en.pdf.
6. БЕССМОЛЬНАЯ, Е. Н. “Режим орошения подсолнечника в засушливой черноземной степи Поволжья” Автореферат диссертации на соискание ученой степени кандидата технических наук. 2011. https://earthpapers.net/rezhim-orosheniya-podsolnechnika-v-zasushlivoy-chernozemnoy-stepi-povolzhya.
7. БОЧКОВОЙ, А.Д., Е.А. ПЕРЕТЯГИН, В.И. ХАТНЯНСКИЙ, В.А. КАМАРДИН, К.М. КРИВОШЛЫКОВ. “Подсолнечник: особенности сортовой политики в зависимости от почвенно-климатических, технологических и социально-экономических условий (Обзор).” Научно-технический бюллетень Всероссийского НИИ масличных культур 2 (174). 2018, p.p.120–134. https://doi.org/10.25230/2412-608X-2018-2-174-120-134.
8. ВАСИЛИОГЛО, Н., ГУМАНЮК, А., МАЙКА, Л. “Влияние минеральных удобрений на урожайность подсолнечника. Conferinţa naţională cu participare internaţională „Ştiinţa în Nordul Republicii Moldova: realizări, probleme, perspective” (ediţia a treia) - Bălţi, 21-22 iunie 2019, p. 203-207. ISBN: 978-9975-3316-1-6
9. ГАМАЮН, И.М., ГУМАНЮК, А.В., КОРОВАЙ В.И. и др.. “Орошение сельскохозяйственных культур придефиците водных и материально-технических ресурсов. Тирасполь: Литера, 2005, p.46 c
10. ГАРБАР, Л.А, КОВТУН, Т.В. “Формирование площади листовой поверхности гибридов подсолнечника под влиянием минерального удобрения.” *В*естник

алтайского государственного аграрного университета, № 11 (169). 2018, p.p.19-24. ISSN:1996-4277. https://cyberleninka.ru/article/n/formirovanie-ploschadi-listovoy-poverhnosti-gibridov-podsolnechnika-pod-vliyaniem-mineralnogo-udobreniya.

11. ГОСТ 18164-72. "Вода питьевая. метод определения сухого остатка." Межгосударственный стандарт вода питьевая метод определения содержания сухого остатка" издание официальное издательство стандартов Москва. 2003. https://files.stroyinf.ru/Data2/1/4294850/4294850719.pdf..
12. ГОСТ 23268.3-78. "Вода. методы определения гидрокарбонат - ионов." Воды минеральные питьевые лечебные, лечебно-столовые и природные столовые правила приемкии методы анализа. 1983. https://meganorm.ru/Data2/1/4294830/4294830762.pdf.
13. ГОСТ 23268.6-78. "Вода. методы определения ионов натрия." Воды минеральные питьевые лечебные, лечебно-столовые и природные столовые. Методы определения ионов натрия. September 1983. https://files.stroyinf.ru/Index2/1/4294830/4294830759.htm.
14. ГОСТ 23268.7-78. "Вода. Методы определения ионов калия." Воды минеральные питьевые лечебные, лечебно-столовые и природные столовые. Методы Определения ионов калия. 1983. https://meganorm.ru/Index2/1/4294830/4294830758.htm
15. ГОСТ 26951-86 Почвы. Определение нитратов ионометрическим методом". Accessed March 23, 2025. https://normadocs.ru/gost_26951-86.
16. ГОСТ 26205-91 Почвы. Определение подвижных соединений фосфора и калия по методу Мачигина в модификации ЦИНАО/26205 91." 1993. July 1, 1993. https://files.stroyinf.ru/Data2/1/4294828/4294828275.htm.
17. ГОСТ 26205-91 Почвы. Определение подвижных соединений фосфора и калия по методу мачигина в модификации ЦИНАО/26205 91." 1993. July 1, 1993. https://files.stroyinf.ru/Data2/1/4294828/4294828275.htm.
18. ГОСТ 26423-85. Почвы. Методы определения удельной электрической проводимости, PH и плотного остатка водной вытяжки. May 2011. https://files.stroyinf.ru/Data2/1/4294828/4294828015.htm
19. ГОСТ 4151-72. "Вода питьевая. методы определения общей жесткости." 1994. https://internet-law.ru/gosts/gost/46251/.
20. ГОСТ 4545-72. "Вода питьевая. методы определения содержания хлоридов." Межгосударственный стандарт вода питьевая Методы определения содержания хлоридов. Drinking Water. Methods for Determination of Chloride Content. 1974.

https://files.stroyinf.ru/Data2/1/4294850/4294850721.pdf.

21. ДОСПЕХОВ, Б.А. “Методика полевого опыта (с основами статистической обработки результатов исследований).” Агропромиздат. 2011. https://drive.google.com/file/d/0B5KiBwgHRtwjekJrRjdZcnJuNEk/view?resourcekey=0-T95jYNweQc3qAO6mEEbnfg.
22. КОЛОСОВ, Т.А. “Формирование урожайности и масличности семян гибридов подсолнечника, возделываемых по системе Clearfield, в условиях Предуральской Степи Республики Башкортостан.” Автореферат диссертации на соискание ученой степени кандидата сельскохозяйственных наук. Уфа. 2016. https://rusneb.ru/catalog/000199_000009_008536459/.
23. КРАВЧЕНКО, В.А., МАЛАЙ, Н.Ф., ШУРУПОВ, В.Г. “Продуктивность подсолнечника в зависимости от норм минерального питания.” Известия высших учебных заведений. Северо-Кавказский Регион. Естественные науки, Вып.4 (188), 2015. pp. 96–100. DOI:10.18522/0321-3005-2015-4-96-100. https://doi.org/10.18522/0321-3005-2015-4-96-100.
24. ЛУКОМЕЦ, В.М., КРИВОШЛЫКОВ, К.М. “Производство подсолнечника в Российской Федерации: состояние и перспективы.” “Земледелие” Вып.8. 2009, p.p.3-6. ISSN: 0130-9081 https://cyberleninka.ru/article/n/proizvodstvo-podsolnechnika-v-rossiyskoy-federatsii-sostoyanie-i-perspektivy/viewer.
25. 105. МАЦКОВА, С., ГУМАНЮК, А., ПАЗЯЕВА, Т. “Запасы продуктивной влажности почвы - залог высокой урожайности подсолнечника.” Agricultural science, no. 2 (January)/ 2023. pp. 24–29. ISSN 1857-0003 E-ISSN 2587-3202. https://doi.org/10.55505/sa.2023.2.03.
26. “Межгосударственный совет по стандартизации, метрологии и сертификации (МГС).” 2020. https://meganorm.ru/Data/521/52189.pdf.
27. “Методика определения густоты стояния растений.” 2020. November 14, 2020. https://floramir.ru/metodika-opredeleniya-gustoty-stoyaniya-rasteniy/.
28. НЕКИПЕЛОВ, Т.С., ПИГОРЕВ, И.Я. “Энергетическая оценка агроценозов подсолнечника масличного масличного (*Helianthus annuus l.*) в Условиях ЦЧР.” Вестник Курской государственной сельскохозяйственной академии, Вып. № 1. 2025, pp.6-12.. https://cyberleninka.ru/article/n/energeticheskaya-otsenka-agrotsenozov-podsolnechnika-maslichnogo-helianthus-annuus-l-v-usloviyah-tschr.
29. ПАЗЯЕВА, Т.В., СТОЯНОВА, Е.М.,. МАЦКОВА, С.И., ДОРОШЕНКО, А.В. 2022. “Значение и развитие орошаемого земледелия.” 236:184–90. ISSN 1857-4246 http://spsu.ru/images/files/science/Vestnik_2_2022.pdf.

30. РИЖА, Ю. “Анализ: затраты на производство подсолнечника и масла.” 2023. https://agroexpert.md/rus/tseny-i-trendy/analiz-zatraty-na-proizvodstvo-podsolnechnika-i-masla.

31. РИЖА, Ю. “S-au scumpit semințele de floarea-soarelui. La cât ajung prețurile.” Agroexpert.Md. October 25, 2024. https://agroexpert.md/rus/novosti/s-au-scumpit-semintele-de-floarea-soarelui-la-cat-ajung-

32. СТОЛЯРОВ, О.В., КОЛОДЯЖНЫЙ, С.В. “Влияние обработки почвы и норм высева на урожайность подсолнечника, выращиваемого по системе Express Suntm. .”Вестник Воронежского Государственного Аграрного Университета, №2 (57), 2018, p.p. 13–19/. https://doi.org/10.17238/issn2071-2243.2018.2.13.

33. ТОЙГИЛЬДИН, А.Л., ТОЙГИЛЬДИНА, И.А., ХАЗОВ, М.М. “Эффективность внесения минеральных удобрений при возделывании подсолнечника в условиях чернозема типичного.” Агрономия, Агрохимия и Агроэкология. 2020, p.p.39-43. ISSN: 0002-1881. http://lib.ugsha.ru:8080/bitstream/123456789/23929/1/2020-02-39-43.pdf

34. УШУРЕЛУ, Ю. 2017. “Итоги сельхозсезона-2017 в Молдове.”. https://agroexpert.md/rus/agrarnaya-politika/itogi-selihozsezona-2017-v-moldove.

35. ХВОСТИКОВ, Ю.А. “Влияние минеральных удобрений на урожайность подсолнечника.” Известия Вузов. Северо-Кавказский регион. естественные науки. Вып.11. 2006, pp.83-85. ISSN: 1026 2237. https://cyberleninka.ru/article/n/vliyanie-mineralnyh-udobreniy-na-urozhaynost-podsolnechnika/viewer.

36. ЧЕРЕМИСИНОВ, А. А., ЧЕРЕМИСИНОВ, А. Ю. “Обзор расчетных методов определения суммарного испарения орошаемых сельскохозяйственных полей.” Научный журнал Российского НИИ проблем Мелиорации, № 1(21). 2016, p.p. 113–133. ISSN: 2222-1816. https://cyberleninka.ru/article/n/obzor-raschetnyh-metodov-opredeleniya-summarnogo-ispareniya-oroshaemyh-selskohozyaystvennyh-poley.

37. ШТОЙКО Д, А. “Орошаемое земледелие на украине : Пособие для руководителей и специалистов сел. хоз-ва / [Ред.-Сост. Д. А. Иваненко и В. М. Ралле]. Киев : Урожай, 1968.

LIST OF PUBLICATIONS ON THE TOPIC OF THE THESIS

• **Статьи в международных журналах**

1. MATSKOVA, S.I., GUMANYUK, A.V. ‘Reserves of soil productive humidity are the key to high yield of sunflower’, Research Journal of Agricultural Science, 57 (1). (2025). ISSN:2668-926X. http://doi.org/10.59463/RJAS.2025.1.19. Available at: https://rjas.ro/paper_detail/4204 (Accessed: 5 August 2025).

• **Статьи в профильных журналах Национального Регистра, категория В**

1. МАЦКОВА, С., ГУМАНЮК, А., ПАЗЯЕВА, Т. ‘Запасы продуктивной влажности почвы-залог высокой урожайности подсолнечника’, Agricultural Sciences, (2), pp. 24–29. (2023). ISSN 1857-0003 E-ISSN 2587-3202 Available at: https://doi.org/10.55505/sa.2023.2.03.
2. МАЦКОВА, С., ГУМАНЮК, А., СТОЯНОВА, Е. ‘Влияние минерального питания подсолнечника на урожайность при капельном орошении’. Agricultural Sciences, (1), (2025). pp. 52-61. ISSN 1857-0003 E-ISSN 2587-3202.

• **Статьи в национальных и международных сборниках**

1. МАЦКОВА, С.И., ГУМАНЮК, А.В. ‘Влияние метеоусловий на урожайность подсолнечника’, Аграрна наука і освіта: історичний екскурс, сучасна парадигма, стратегія розвитку: Матеріали V Міжнародної науково-практичної конференції (у рамках VIII наукового форуму «Науковий тиждень у Крутах – 2022», 4 березня 2022 р., с. Крути, Чернігівська обл.)., pp. 52. https://ovoch.com/assets/files/conference/tezu/agrarna-04-03-2022.pdf?utm_source.
2. МАЦКОВА, С.И., ГУМАНЮК, А.В. ‘Взаимосвязь урожайности подсолнечника с биометрическими показателями роста и развития растений при различных дозах удобрений’, Аграрна наука і освіта: історичний екскурс, сучасна парадигма, стратегія розвитку: Матеріали V Міжнародної науково-практичної конференції (у рамках VIII наукового форуму «Науковий тиждень у Крутах – 2023», 3 березня 2023 р., с. Крути, Чернігівська обл.)., pp. 160–165. (2023). https://ibn.idsi.md/ro/vizualizare_articol/179699/gscholar.
3. МАЦКОВА, С.И., ПАЗЯЕВА, Т.В, ГУМАНЮК, А.В. Влияние орошения на рост, развитие и продуктивность подсолнечника. Материалы IV Международной научно-практической конференции. «Продовольственная безопасность в АПК», г. Тирасполь, 23 ноября 2023 г., секция «Сельскохозяйственные науки». pp. 26-34. 2024. ISBN 978-5-6051575-6-4.
4. МАЦКОВА, С.И. ‘Изучение роста и развития растений подсолнечника в севообороте на орошении’, Conferinţa Tehnico-Ştiinţifică a Studenţilor,

Masteranzilor şi Doctoranzilor, Universitatea Tehnică a Moldovei, 27-29 martie 2024, VOL. IV, p. 2358-2363.. https://ibn.idsi.md/sites/default/files/imag_file/2358-2363.pdf.

5. МАЦКОВА, С.И., ГУМАНЮК, А.В., ПАЗЯЕВА, Т.В. ‘Влияние агроприемов в севообороте на продуктивность культур и почву при традиционной и альтернативной системах земледелия’, Вестник приднестровского университета Серия: Медико-биологические и химические науки. – Тирасполь. – 2024, №2 (77), pp. 92–99. ISSN:1857-4246. Available at: http://spsu.ru/science/nauchno-izdatelskaya-deyatelnost/vestnik-pgu. (Accessed: 22 December 2024).
6. МАЦКОВА, С.И., ГУМАНЮК, А.В. ‘Зависимость продуктивности подсолнечника от уровня минерального питания при капельном орошении. ’ Материалы IV Международного форума молодых исследователей: Международный форум молодых исследователей, Петрозаводск, секция «Сельскохозяйственные науки», Москва: МЦНП «Новая наука», 2025 г, с. 256-266.. ISBN: 9785002157280. https://m.sciencen.org/assets/Kontent/Konferencii/Arhiv-konferencij/KOF-1279.pdf?utm_source.
7. МАЦКОВА, С.И. Масличность подсолнечника в зависимости от орошения и удобрения. «Селекция, семеноводство и технологии возделывания сельскохозяйственных культур» : Материалы международной научно-практической конференции, Тирасполь, 7–8 июля 2025 г. – pp.223-227- ISBN 978-9975-89-329-9. https://doi.org/10.70739/sstac2025.50.

АННОТАЦИЯ

Мацкова Светлана, «Совершенствование элементов технологии возделывания подсолнечника путем регулирования густоты стояния, водного и пищевого режимов при капельном орошении в Молдове», диссертация доктора сельскохозяйственных наук, Кишинэу, 2026

Структура диссертации: введение, 5 глав, общие выводы и рекомендации, 119 страницы основного текста, список литературы из 164 источников, 30 таблиц, 40 рисунков, 27 приложений. Полученные результаты опубликованы в 10 научных работах.

Ключевые слова: подсолнечник, орошение, удобрение, густота стояния растений, урожайность, климатические условия, суммарное испарение, экономическая и энергетическая эффективность.

Цель работы. Разработать некоторые элементы технологии возделывания подсолнечника при капельном орошении с помощью регулирования водного и пищевого режимов почвы, а также густоты стояния, которые обеспечивают получение экономически обоснованных урожаев.

Задачи исследования: установить оптимальные поливные режимы при поливе капельным способом; изучить водный режим почвы при различных режимах капельного орошения; установить взаимовлияние орошения, различных доз минеральных удобрений и загущенных посевов на урожайность и качество продукции; дать экономическую и энергетическую оценку исследуемых приемов; установить зависимости «урожайность – режим орошения», «урожайность – удобрение» для их использования в производстве.

Научная новизна и оригинальность проведенных исследований состоит в том, что в Республике Молдова впервые разработан и рекомендован производству режим капельного орошения, оптимальная доза удобрений и густота стояния растений, которые обеспечивают высокую урожайность с хорошим качеством продукции.

Решение важной научной проблемы состоит в *научном обосновании* водного, пищевого режима и густоты стояния, *что позволило* усовершенствовать технологию возделывания подсолнечника, *способствуя тем самым* получению высокой урожайности.

Теоретическая значимость. Установлены зависимости «урожайность – режим орошения», «урожайность – удобрение», для их использования в производстве.

Практическая значимость. Разработаны оптимальные режимы капельного орошения подсолнечника и соответствующие им дозы удобрений и густоты стояния растений обеспечивающие высокую урожайность с хорошим качеством, эффективность использования оросительной воды, прибыль и рентабельность.

Внедрение результатов исследований проходило в двух хозяйствах Сдободзейского района на площади 10 га – в ООО «Экспедиция Агро» и ООО «Плантатор».

ADNOTARE

Maţcova Svetlana, ”Perfecționarea elementelor tehnologice de cultivare a florii-soarelui sub influența regimului hidric, nutritiv și a densității plantelor în condiții de irigare prin picurare în Moldova”, teză de doctor în științe agricole, Chișinău, 2026.

Structura tezei: întroducere, 5 capitole, concluzii generale şi recomandări, 119 pagini de text de bază, bibliografie din 164 surse, 30 tabele, 40 figuri, 27 anexe. Rezultatele obținute au fost publicate în 10 lucrări științifice.

Cuvinte-cheie: floarea soarelui, irigare, fertilizare, densitate de plantare, productivitate, condiţii climaterice, consumul total de apă, eficienţa economică şi energetică.

Scopul lucrării: Elaborarea unor elemente ale tehnologiei de cultivare a florii-soarelui prin irigare prin picurare cu ajutorul reglării regimului de apă și nutriție a solului, precum și a densității de plantare, care asigură obținerea unor recolte economic justificate.

Obiectivele studiului sunt: stabilirea unor regimuri optime de irigare la aplicarea udărilor prin picurare; studierea regimului apei din sol sub diferite regimuri de irigare prin picurare; stabilirea influenţei reciproce a irigaţiilor, a diferitelor doze de îngrăşăminte minerale şi a densităţii de plantare asupra productivităţii şi a calităţii producţiei; evaluarea economică şi energetică a metodelor studiate; stabilirea dependenţei "recoltă - regim de irigare," "recoltă - îngrăşământ" pentru utilizarea lor în producţie.

Noutatea științifică și originalitatea cercetărilor efectuate constau în faptul că în Republica Moldova pentru prima dată a fost elaborat și recomandat producătorilor un regim de irigare prin picurare, doza optimă de îngrășăminte și densitatea de plantare, care asigură o productivitate ridicată cu o calitate bună a producției.

Rezolvarea unei probleme științifice importante constă în *justificarea științifică* a regimului de apă, regimului alimentar și a densității de plantare, *ceea ce a permis* perfecționarea tehnologiei de cultivare a floarea-soarelui, *contribuind astfel* la obținerea unor producții ridicate.

Importanța teoretică. Au fost stabilite dependențele „productivitate – regim de irigare", „productivitate – îngrășământ", pentru utilizarea lor în producție.

Semnificaţia practică. Au fost elaborate regimuri optime de irigare prin picurare a florii-soarelui, dozele corespunzătoare de îngrășăminte și densitatea plantelor care asigură o productivitate ridicată cu o calitate bună, eficiența utilizării apei de irigație, profit și rentabilitate.

Implementarea rezultatelor cercetărilor a avut loc în două gospodării din raionul Slobozia, pe o suprafață de 10 hectare – în SRL «Expediția Agro», SRL « Plantator».

ABSTRACT

Matskova Svetlana « Improvement of technological elements of sunflower cultivation under the influence of water and nutrient regimes and plant density under drip irrigation conditions in Moldova» Doctoral Dissertation in Agricultural Sciences, Chișinău, 2026

Structure of the dissertation: introduction, 5 chapters, general conclusions and recommendations, 119 pages of main text, a bibliography comprising 164 sources, 30 tables, 40 figures, and 27 appendices. The obtained results have been published in 10 scientific papers. **Keywords:** sunflower, irrigation, fertilization, plant density, yield, climatic conditions, total evapotranspiration, economic and energy efficiency.

Aim of the study. To develop specific technological elements for sunflower cultivation under drip irrigation by regulating the soil water and nutrient regimes, as well as plant density, in order to obtain economically justified yields.

Objectives of the study:

- to determine optimal irrigation regimes under drip irrigation;
- to study the soil water regime under different drip irrigation conditions;
- to establish the interaction between irrigation, various doses of mineral fertilizers, and denser sowing on yield and product quality;
- to provide an economic and energy evaluation of the tested practices;
- to establish the relationships between "yield – irrigation regime" and "yield – fertilization" for practical application.

Scientific novelty and originality of the research lie in the fact that for the first time in the Republic of Moldova, a drip irrigation regime, optimal fertilizer dose, and plant density have been developed and recommended for production, ensuring high yields and good product quality.

The solution to a significant scientific problem lies in the scientific justification of water and nutrient regimes and plant density, which has improved sunflower cultivation technology, thereby contributing to higher yields.

Theoretical significance. The relationships "yield – irrigation regime" and "yield – fertilization" were established for application in agricultural production.

Practical significance. Optimal drip irrigation regimes for sunflower, along with corresponding fertilizer doses and plant densities, were developed to ensure high yields with good quality, efficient use of irrigation water, increased profitability, and cost-effectiveness.

Implementation of the research results was carried out on 50 hectares in two farms located in the Slobozia district - – LLC « Expedition Agro», LLC« Plantator».

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411.08 – Crop Production

Abstract of the PhD Thesis in Agricultural Sciences