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The Efficiency of Fertilisation in the Cultivation of High Oleic Sunflower on Typical Low Humus Chernozems

Abstract. The cultivation of high oleic sunflower hybrids is very promising as sunflower is highly competitive on the international market and has a growing demand for oil as the main product of its processing. Despite the significance of sunflower as one of Ukraine's traditional crops, its cultivation technology still has many unresolved issues. Among the elements of cultivation technology aimed at increasing crop yields, research with high-oleic hybrids is of particular importance, as it requires studying the level of mineral nutrition and the need for sulfur application, considering their impact on the oleic acid content. The purpose of the study is to determine the effect of sulfur at different rates of mineral fertilisers on the formation of productivity of high-oleic sunflower plants on typical low-humus chernozems of the Right-Bank Forest-Steppe of Ukraine. The research programme envisaged the establishment of a field trial in 2015-2017. The research was conducted in the form of a two-factor field experiment. The experimental program provides for the study of the following factors: factor A – mineral fertiliser application rates, factor B – sulfur application. The study was conducted using generally accepted methods for scientific research in crop production. The study revealed that the maximum amount of dry matter was accumulated in the variants with the introduction of $N_{90}R_{75}K_{135}+S_{30}$ and $N_{120}R_{100}K_{180}+S_{30}$. The addition of sulfur increases the dry matter yield from 5.69% to 9.27%. The highest yield of sunflower seeds is formed by applying $N_{90}R_{75}K_{135}+S_{30}$ -4.12 t/ha. A further increase in the rate of application of mineral fertilisers does not lead to a significant increase in yield. The introduction of S_{30} in combination with $N_{90}R_{75}K_{135}$ allows increasing the yield of sunflower seeds by 0.35 t/ha or 9.28%. The correlation and regression analysis of the obtained research results shows a close correlation between the accumulation of dry matter mass in BBCH55-57 and BBCH 65-67 and the level of yield (respectively $r = 0.917$ and $r = 0.972$). The highest fat content in seeds (49.7%) with the

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highest oleic acid content (88.5%) and the maximum oil yield (2.05 t/ha) is provided by the cultivation of the ES Romantic hybrid with the introduction of $N_{90}R_{75}K_{135}+S_{30}$

Keywords: oilseeds, hybrids, mineral nutrition, mineral fertiliser application rates, dry matter, yield

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The share of foreign-bred hybrids in Ukraine is 60-70%. In addition to high productivity, foreign hybrids also have high quality indices, which are best manifested in the environments where they were produced. In the harsh soil and climatic, agronomic, and extreme weather conditions of Ukraine, they may not have advantages over domestic varieties. Therefore, it is important to consider their bioadaptability and disease resistance. Adaptation of sunflower hybrids to different soil and climatic conditions in view of constant climate change should be based on a detailed analysis of the response to changing conditions and crop cultivation technology. Sunflower is a culture of moderate climate zone and is quite flexible to weather and soil changes (Yeremenko *et al.*, 2018; Chutamard *et al.*, 2011). The introduction of hybrids with high yield potential into production is complicated by the issue of ecological adaptation: the potential of the cultivation zone cannot rise in proportion to the growth of the genetic potential of hybrids (Calamai *et al*, 2018; Canavar *et al.*, 2010). The adaptability of hybrids is an extremely important feature due to variable abiotic and biotic environmental factors (Gonzáles *et al.*, 2013). Sunflower is characterised by high adaptability (Debaeke *et al.*, 2017).

Sunflower reacts intensively to changes in mineral nutrition, and therefore it is important to regulate it by applying mineral fertilisers. This agricultural measure maximises the impact on plant growth and development, which subsequently affects the yield (Kokovikhin *et al.*, 2015). An optimally formed sunflower agrocenosis contributes to the formation of high-quality seeds (Nel *et al.*, 2000) It is the formation of an agrocenosis with optimal plant density and optimal supply of nutrients that ensures the growth of its productivity (Gholinezhad *et al.*, 2009).

Morphological features of a plant are varietal characteristics, but they can change under the influence of environmental factors and growing technologies (Ion *et al.*, 2015). The application of nitrogen fertilisers increased the yield of sunflower hybrids and the diameter of the baskets (Ahmad *et al.*, 2017). The growth of leaf surface area and photosynthesis processes in them largely depend on the influence of different rates of mineral fertilisers (Yeremenko, 2017; Nizamov, 2018).

Sunflower responds positively to nutrients and soil cultivation. Thus, the efficiency of different tillage and fertilisation systems was studied in field experiments at the Institute of Oilseeds of the National Academy of Agrarian Sciences of Ukraine in Zaporizhzhia Oblast. The largest weight of 1000 seeds were formed under the classical tillage system and depended on fertiliser: control – 50.0-50.6, with N_{40} – 51.5-51.8, $N_{40}P_{60}$ – 51.9-52.3, $N_{60}P_{60}K_{60}$ – 52.4-52.7 g. The highest yield in the hybrid Ratnyk (3.34 t/ha) was observed when cultivated with the introduction of $N_{60}P_{60}K_{60}$ for pre-sowing cultivation and treatment of crops in the phase of 6-8 pairs of true leaves with a mixture of 'Rost-kontsentrat' and 'Khelatyn oliyni' (Polyakov *et al.*, 2017).

Sunflower is a highly sulfur-sensitive crop. A feature of the crop's mineral nutrition is its higher sulfur intake: three times higher than that of cereals, which make up almost 50% of rapeseed's needs. Sulphur plays an important role in plant nutrition and is one of the nine elements necessary for plant nutrition (Hayfa *et al.*, 2003). In cells, it performs the following biological functions: energetic, structural (as part of proteins, carbohydrates, lipids, etc.), catalytic (in the active centre of enzymes, a component of cofactors), redox (balance in the cell), initiating (during cell division), and growth (in the polypeptide chain during protein synthesis). Sulphur is actively consumed by cultivated plants in the biological cycle and is alienated from the harvest. Sufficient sulfur nutrition increases the resistance of plants to low temperatures, drought, diseases, and soil salinity. In old leaves, it is highly labile and is a source of a certain amount of mobile sulfur for the meristems of young leaves and roots, which are in greater need of it and actively dividing (Shevyakova, 1979). With sulfur starvation, the leaves do not die off, although their colour becomes paler.

Studies have also shown that sulfur-containing fertilisers contributed to a more intensive supply of nitrogen, phosphorus, potassium, calcium, magnesium, sulfur and a number of trace elements to corn, sugar beet, potato and rapeseed plants (Bloem *et al.*, 2002).

The purpose of the study is to determine the sulfur influence on the formation of high-oleic sunflower plant productivity on typical low-humus black soils of the Right-Bank Forest-Steppe of Ukraine at different rates of mineral fertiliser application.

MATERIALS AND METHODS

The study was conducted in an 8-seed stationary grain-tilled crop rotation of the Department of Plant Production at the Agronomic Research Station of the National University of Life and Environmental Sciences of Ukraine and in the analytical research laboratory of the Department of Plant Production in 2015-2017. The soils of the experimental field are typical low-humus medium loamy chernozems with a humus content of 4.38-4.53% in the topsoil and a pH of 6.9-7.3 in the salt extract.

The research station is located in the Kyiv Oblast. The annual precipitation is 543 mm. Their distribution by vegetation period and intensity is uneven. In 2015 and 2017, there were some deviations of the main weather indicators from the long-term average, while in 2016 they were close to the long-term average and the most favourable for crop growth and development. The weather conditions in 2015 showed certain unique characteristics: the amount of precipitation at the beginning of the growing season was below the long-term average. While the deficit was compensated for at the beginning of the growing season through soil moisture use, the June drought was complicated by high temperatures. The moisture deficit in the first half of the 2017 growing season was accompanied by severe frosts in the third decade of April.

The study programme envisaged a two-factor field experiment in 2015-2017. The following factors were to be studied: factor A – mineral fertiliser application rates, factor B – sulfur application (Table 1). Fertiliser application rates were calculated using the balance method for the planned yield, considering the content of the main mineral nutrients in the soil.

The subject of the study was a hybrid of high leucine sunflower ES Romantic (applicant

Euralis Semences Ukraine LLC), which is resistant to broomrape races A-G. Ripening group: mid-early. Development type: moderately intensive. Plant height: 165-175 cm, head diameter: 22-24 cm, head inclination: semi-raised. Fat content: 49-50%, oleic acid content: 88-89%.

Table 1. Efficiency of fertiliser application for sunflower cultivation (experimental scheme)

Fertiliser application rates (factor A) / variant designation	Fertiliser application rates (factor A) / variant indication
1. $N_{60}R_{50}K_{90}$ (control)	1. $N_{60}R_{50}K_{90}$ + S_{30}
2. $N_{90}R_{75}K_{135}$	2. $N_{90}R_{75}K_{135}$ + S_{30}
3. $N_{120}R_{100}K_{180}$	3. $N_{120}R_{100}K_{180}$ + S_{30}

The cultivation technology is standard for the Forest-Steppe zone, except for the elements under study. Phosphorus and potassium fertilisers were applied for basic tillage, nitrogen fertilisers were applied in fractions: part for basic tillage, the rest for pre-sowing cultivation; sulfur was applied in the form of ammonium sulfate ($(NH_4)_2SO_4$) for pre-sowing cultivation.

The area of the sample plot is 50 m^2, the repetition rate is four times, and the placement of variants is sequential. The research was conducted using generally accepted methods of scientific research in agronomy (Rozhkov, 2016).

RESULTS AND DISCUSSION

The study of the dynamics of dry matter accumulation depending on the mineral nutrition system of sunflowers is of considerable scientific and practical interest. Dry matter is closely related to varietal characteristics and mineral fertiliser application rates (Fig. 1). The dry matter content of plants was determined by the main stages of growth and development of sunflower plants.

The level of fulfilment of the biological potential of varieties and hybrids depends on the climatic conditions of a particular year, cultivation technology and their interaction (Kalenska *et al.*, 2010, Ion *et al.*, 2013; Mijic *et al.*, 2020), which is confirmed by the results of this research: the accumulation of dry matter is uneven and depends on the factors studied.

The dry matter content of microstages of BBCH 15-17 (rosette phase) ranged from 54.4 g/m^2 in the control variant to 62.9 g/m^2 when $N_{120}R_{100}K_{180}$+S_{30} was applied. At the beginning of the growing season, this indicator was significantly influenced by the rates of mineral fertilisers, while sulfur input had no significant effect. During the period BBCH 15-17-BBCH 55-57, due to the active growth and development of plants, the dry matter content increased by more than 4 times and was the highest in the variant with the introduction of $N_{120}R_{100}K_{180}$+S_{30}. In the microstages of BBCH 55-57 (budding phase), it is noted that sulfur affects the accumulation of dry matter in variants with increased rates of mineral fertilisers.

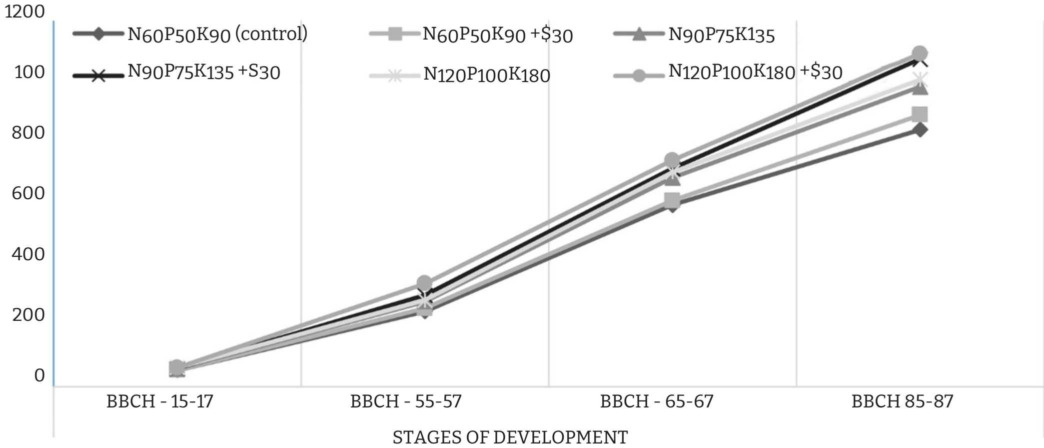

Figure 1. Dynamics of dry matter accumulation by sunflower plants, g/m2 (average for 2015-2017)
Note: LSD_{05} BBCH – 15–17=0,28; BBCH – 55–57=18.7; BBCH – 65–67=25.4; BBCH – 85–87=37.4

In the later phases (period of BBCH 65-67 – BBCH 85-88), more intensive accumulation of dry matter occurs in variants with the introduction of $N_{90}R_{75}K_{135}+S_{30}$ and $N_{120}R_{100}K_{180}+S_{30}$. In the microstages of BBCH 85-88 (ripening phase, seed moisture content of 15%), the difference between the variants with the maximum mineral fertilisation is not significant, which is explained by the extended performance of leaves when $N_{90}R_{75}K_{135}+S_{30}$ was applied, less affected by diseases.

Thus, the introduction of sulfur increases the accumulation of dry matter by sunflower crops from 5.69% in the control variant to 9.27% – with the introduction of $N_{90}R_{75}K_{135}$.

The yield level is determined by a set of zonal agrotechnological measures and weather conditions. A number of scientific studies have shown that the interaction of hybrid-fertiliser factors has the greatest impact on yields as new hybrids are introduced and put into production. Moreover, intensive hybrids require more nutrients to generate high yields, and in some years, especially with a water consumption factor of more than 1, the share of fertiliser influence increases to 60%. However, these studies were conducted with linoleic hybrids with a linoleic acid content of 55-60%. Therefore, research on high-oleic hybrids requires studying the level of mineral nutrition, the need for sulfur application, based on their impact on the content of oleic acid. The results of this study demonstrate that weather conditions have a significant impact on sunflower yields (Table 2). Thus, for all variants of the experiment, the highest yield was obtained in 2016, which was the most common in terms of multi-year indicators, and the lowest in 2017.

Table 2. Sunflower yield, t/ha

Fertilisation variants	Years			The average for 2015-2017
	2015	2016	2017	
$N_{60}R_{50}K_{90}$ (control)	3.15	3.45	3.11	3.24
$N_{60}R_{50}K_{90}+S_{30}$	3.38	3.73	3.31	3.47
$N_{90}R_{75}K_{135}$	3.69	4.11	3.52	3.77
$N_{90}R_{75}K_{135}+S_{30}$	4.03	4.55	3.79	4.12
$N_{120}R_{100}K_{180}$	3.81	4.38	3.64	3.94
$N_{120}R_{100}K_{180}+S_{30}$	4.04	4.7	3.83	4.19
$LSD_{0.05}$	0.16	0.18	0.15	

It was revealed that sunflower yield is determined by the level of mineral nutrition. On average, over 3 years of research, when $N_{60}P_{50}K_{90}$ (control) was applied, the seed yield was the lowest and amounted to 3.24 t/ha. The application of mineral fertilisers at the rate of $N_{90}P_{75}K_{135}$ increased the yield of sunflower compared to the control variant by 0.53 t/ha or 16.4%. With an increase in the application rate to $N_{120}P_{100}K_{180}$, the seed yield increases to 3.94 t/ha (+0.7 t/ha (+21.6%) compared to the control).

The highest seed yield was obtained by applying $N_{90}R_{75}K_{135}+S_{30}$ and amounted to 4.12 t/ha. A further increase in the rate of application of mineral fertilisers does not lead to a significant increase in yield. The introduction of S_{30} in combination with $N_{90}R_{75}K_{135}$ allows increasing the yield of sunflower seeds by 0.35 t/ha or 9.28%.

Thus, based on the findings, it can be argued that the introduction of S_{30} on the background of $N_{90}P_{75}K_{135}$ provides optimal conditions for the formation of the crop when growing a high-oleic sunflower hybrid ES Romantic. The correlation and regression analysis of the obtained research results shows a close correlation between the accumulation of dry matter in 55-57 BBCH and the level of yield (r = 0.917) (Fig. 2). A closer direct correlation between the mass of dry matter and yield was noted in BBCH 65-67 (r = 0,972).

The dependencies obtained can be described by regression equations: Yield, t/ha = .80370 + 0.01051 X dry matter weight, g/m^2 (BBCH – 55-57); yield, t/ha = -0.7319 + 0.00674 X dry matter weight, g/m^2 (BBCH – 65-67).

Various factors determine the fat content of seeds. The main ones are the genetic characteristics of hybrids and mineral application rates, which are confirmed by the findings of this study (Table 3). Analysis of the fertilisation rates' influence on the fat content of seeds, revealed that the highest values (49.7%) were in the variant with $N_{90}R_{75}K_{135}+S_{30}$. The minimum amount of fat (46.2%) was observed in the $N_{120}R_{100}K_{180}$ variant, which is associated with excess nitrogen, which leads to an increase in the protein content in the nucleus as there is an inverse correlation between the protein and fat content in the kernel.

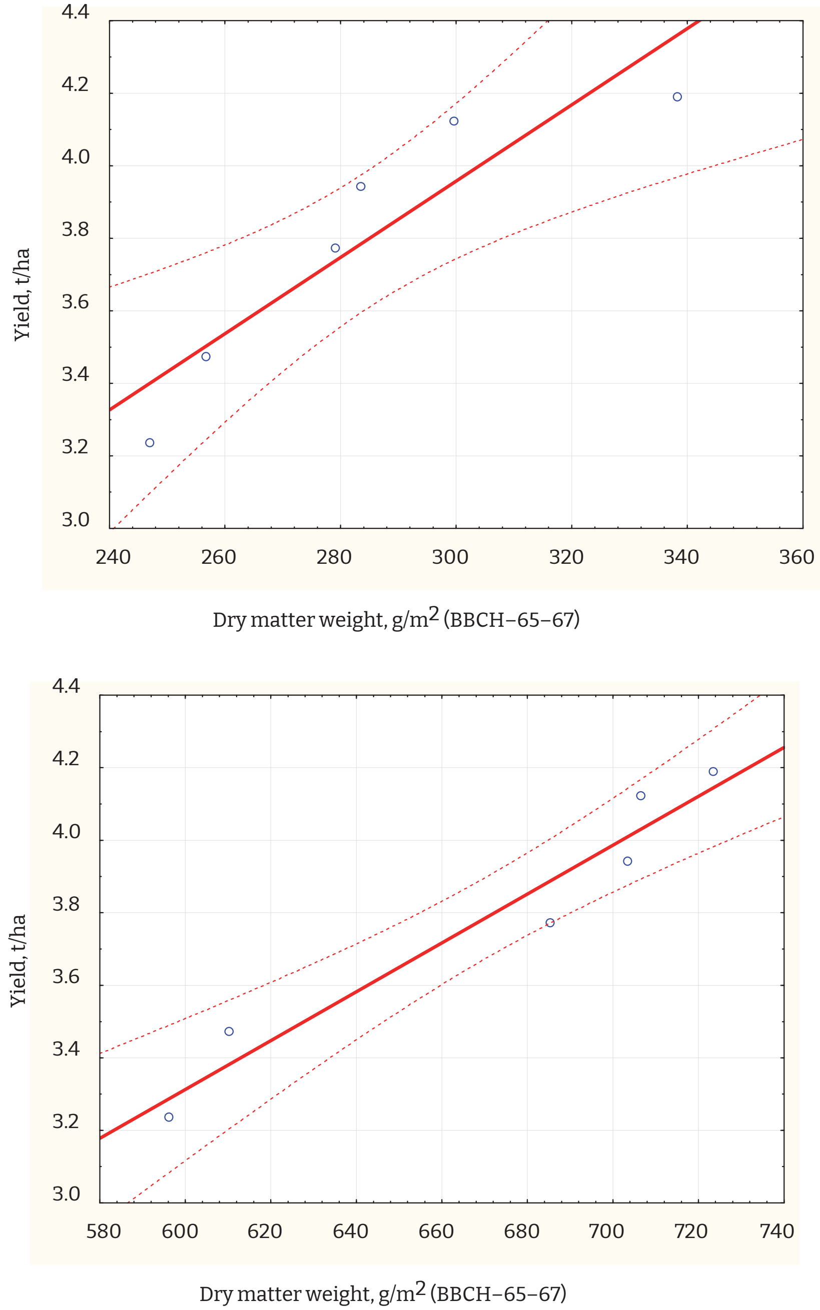

Figure 2. Correlation between yield (y) and dry matter weight (X) of sunflower seeds in microstages BBCH 55-57 and BBCH 65-67 (Average for 2015-2017)

Table 3. Oil quality indicators and yield (average for 2015-2017)

Fertiliser variant	Quality indicators		
	fat content, %	oleic acid content, %	oil yield, t/ha
$N_{60}R_{50}K_{90}$ (control)	47.3	85.6	1.53
$N_{60}R_{50}K_{90}+S_{30}$	48.8	86.7	1.69
$N_{90}R_{75}K_{135}$	48.1	87.3	1.81
$N_{90}R_{75}K_{135}+S_{30}$	49.7	88.5	2.05
$N_{120}R_{100}K_{180}$	46.2	83.4	1.82
$N_{120}R_{100}K_{180}+S_{30}$	47.2	85.1	1.98
$LSD_{0.05}$	1.4	3.3	

Excess nitrogen affects the content of oleic acid, leading to its reduction, which is undesirable for high-oleic hybrids. The lowest content of oleic acid was observed in the variant $N_{120}R_{100}K_{180}$ – 83.4% against 87.3% when $N_{90}R_{75}K_{135}$ was applied. All fertiliser variants with sulfur application showed a tendency to increase the content of oleic acid. However, on average over 3 years, this difference was within the margin of error.

The studies conducted show that, in general, the fertiliser variants under study provide a high yield of oil per unit area. However, the highest oil yield is provided by the cultivation of the ES Romantic hybrid with the introduction of $N_{90}R_{75}K_{135}+S_{30}$ and is 2.05 t/ha, which is more than 0.52 t/ha compared to the control variant.

CONCLUSIONS AND PROSPECTS

The study revealed that the maximum amount of dry matter was accumulated in the variants with the introduction of $N_{90}P_{75}K_{135}+S_{30}$ and $N_{120}P_{100}K_{180}+S_{30}$. The addition of sulfur contributes to an increase in dry matter weight from 5.69% to 9.27%.

The highest yield of sunflower seeds is formed by applying $N_{90}R_{75}K_{135}+S_{30}$ – 4.12 t/ha. A further increase in the rate of application of mineral fertilisers does not lead to a significant increase in yield. The introduction of S_{30} in combination with $N_{90}R_{75}K_{135}$ allows increasing the yield of sunflower seeds by 0.35 t/ha or 9.28%.

The correlation and regression analysis of the obtained research results shows a close correlation between the accumulation of dry matter mass in BBCH55-57 and BBCH 65-67 and the level of yield (respectively $r = 0.917$ and $r = 0.972$).

The highest fat content in seeds (49.7%) with the highest oleic acid content (88.5%) and the maximum oil yield (2.05 t/ha) is provided by the cultivation of the ES Romantic hybrid with the introduction of $N_{90}P_{75}K_{135}+S_{30}$.

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Ефективність добрив при вирощуванні високоолеїнового соняшнику на чорноземах типових малогумусних

Анотація. Вирощування високоолеїнових гібридів соняшнику є дуже перспективним, оскільки соняшник є висококонкурентним на міжнародному ринку та має зростаючий попит на олію як основний продукт його переробки. Незважаючи на важливість соняшнику як однієї з традиційних культур в Україні, технологія його вирощування все ще має багато невирішених питань. Серед елементів технології вирощування, спрямованих на підвищення врожайності культури, особливого значення набувають дослідження з високоолеїновими гібридами, оскільки вони потребують вивчення рівня мінерального живлення та потреби у внесенні сірки з урахуванням їх впливу на вміст олеїнової кислоти. Мета дослідження – визначити вплив сірки в різних нормах мінеральних добрив на формування продуктивності рослин високоолеїнового соняшнику на чорноземах типових малогумусних Правобережного Лісостепу України. Програма досліджень передбачала закладання польового досліду впродовж 2015-2017 років. Дослідження проводили у формі двофакторного польового досліду. Програмою досліду передбачено вивчення наступних факторів: фактор А – норми внесення мінеральних добрив, фактор В – внесення сірки. Дослідження проводили з використанням загальноприйнятих методів наукових досліджень у рослинництві. Дослідженнями встановлено, що максимальна кількість сухої речовини накопичувалася у варіантах із внесенням $N_{90}R_{75}K_{135}+S_{3}0$ та $N_{120}R_{100}K_{180}+S_{30}$. Внесення сірки збільшує вихід сухої речовини з 5,69% до 9,27%. Найвища врожайність насіння соняшнику формується при внесенні $N_{90}R_{75}K_{135}+S_{30}$ –4,12 т/га. Подальше збільшення норми внесення мінеральних добрив не призводить до суттєвого підвищення врожайності. Внесення S_{30} у поєднанні з $N_{90}R_{75}K_{135}$ дозволяє підвищити врожайність насіння соняшнику на 0,35 т/га або 9,28%. Кореляційно-регресійний аналіз отриманих результатів досліджень свідчить про тісний кореляційний зв'язок між накопиченням маси сухої речовини у ЧС 55-57 і ЧС 65-67 та рівнем урожайності (відповідно $r = 0,917$ і $r = 0,972$). Найвищий вміст жиру в насінні (49,7%) з найбільшим вмістом олеїнової кислоти (88,5%) та максимальним виходом олії (2,05 т/га) забезпечується за вирощування гібрида ЕС Романтик з внесенням $N_{90}R_{75}K_{135}+S_{30}$

Ключові слова: олійні культури, гібриди, мінеральне живлення, норми внесення мінеральних добрив, суха речовина, урожайність