THE EFFECT OF FOLIAR FERTILIZATION ON INCREASING YIELD AND OIL CONTENT IN SUNFLOWER (HELIANTHUS ANNUUS L.) CULTIVATION

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Abstract. *Foliar fertilization, which complements successful artificial fertilization, is becoming more and more widespread in Hungary as well, which provides the plant with a more reliable or additional supply of nutrients, especially in drier periods. In a year with a lack of rainfall - when the plant is not able to absorb the right amount of nutrients from the soil - the nutrient applied through the leaves can be a huge help, which can play an important role in its development, crop set, and content. Our research below serves to prove this, where in the case of sunflower we examined whether foliar fertilization results in an increase in yield and oil content in a year with a very low rainfall and atmospheric drought. The experiment was carried out in 2022 in Szarvas. In the experiment, in the case of 4 nutrient levels with different fertilizer doses, we also used additional foliar fertilization treatment, which was examined in 4 repetitions. The 4 different treatments were as follows: Control (without fertilization), Environmental protection level, Balance level, Genesis regional. In order to investigate the utilization of the applied nutrients, we carried out various yield tests and calculations, as well as internal content measurements. During the experiment, it was established that foliar fertilization resulted in a higher crop yield both in the case of no fertilization and in the case of the 3 nutrient levels, and it also increased the oil content of most treatments.*

Keywords: *sunflower, foliar fertilization, dry season, oil content*

INTRODUCTION

Today's increasingly extreme weather conditions increase the risk of sunflower cultivation (SZABÓ, 2013; NOVÁK, 2015), however, adverse weather effects can be mitigated with appropriate agrotechnical responses, which also contribute to improving sunflower yield and quality (SZABÓ, 2014; NOVÁK, 2015). Among other things, foliar fertilization, which complements successful artificial fertilization, is becoming more and more widespread in Hungary, which provides the plant with a more reliable or additional supply of nutrients, especially in drier periods. In a year with a lack of rainfall - when the plant is unable to absorb the required amount of nutrients from the soil - the nutrients applied through the leaves can be a huge help, which can play an important role in its development, crop set and content. Our research below serves to prove this, where in the case of sunflower we examined whether foliar fertilization results in an increase in yield and oil content in a year with a very low rainfall and atmospheric drought. The experiment was carried out in 2022 in Szarvas, on the School Field of the Department of Irrigation and Land Improvement of the Institute of Environmental Sciences of the Hungarian University of Agricultural and Life Sciences. In the experiment, in the case of 4 nutrient levels with different fertilizer doses, we also used additional foliar fertilization treatment, which was examined in 4 repetitions. The 4 different treatments were as follows: Control (without fertilization), Environmental protection level, Balance level, Genesis regional. During the experiment, we used fertilizers and foliar fertilizers from Genezis Nitrogénművek Zrt. In order to investigate the utilization of the applied nutrients, we carried out various yield tests and calculations, as well as internal content measurements.

The sunflower is a medium water-demanding plant, consuming approximately 500 mm of water during the growing season. Looking at its water demand, two critical stages can be observed. One is the period from the beginning of the plate to flowering (it requires 200 mm of water), where it requires 40% of its water needs. A significant lack of water occurring in this phenophase can reduce the yield. The other period is the period of seed formation and oil accumulation (it absorbs 120-150 mm of water), which is 30% of its water demand (PEPÓ, 2005). The lack of water occurring in this phenophase partially affects the yield, but mainly the oil content (GÖÇMEN, 2021). The success of sunflower cultivation is determined by the initial water supply of the given field (PEPÓ, 2005). Its transpiration coefficient can be characterized by a dry matter value of 470–765 l/1 kg. Watering the sunflower can result in the appearance of various fungal diseases, nonetheless - especially nowadays - essential for the safety of the sunflower crop (BICSKEI, 2010). Although it is usually grown as a no-irrigation plant, it responds well to irrigation. An experiment carried out in Turkey confirms this fact, because the sunflower treatment, during which the plant received an adequate amount of irrigation water in all critical stages of development, approx. 85.4% higher yield, or approx. it produced an 88% higher oil content compared to the control (treatment without irrigation) (GÖKSOY et al., 2004). With its extensive root system and powerful ability to extract nutrients, the sunflower is able to properly utilize the soil's nutrient reserves that are not or difficult to absorb for other plants. Sunflower needs 40 kg of nitrogen, 30 kg of phosphorus, 70 kg of potassium, 24 kg of lime and 12 kg of magnesium to produce one ton of crop. Nitrogen is a basic requirement for the vegetative growth of sunflower, and the vegetative zinc formed in the appropriate amount during the generative stage should enable the development of a large harvest. Phosphorus positively affects the plant's root development, dry matter formation, and increases the oil content. As a result of the optimal supply of potassium, its resistance to diseases increases, as well as the plant's drought tolerance and stem strength. Sunflower reacts sensitively to calcium and magnesium deficiency. On acidic, Ca- and Mg- deficient soils, the yield surplus obtained as a result of NPK fertilization can be significantly further increased by applying calcium- and magnesium-containing substances (PEPÓ, 2005). Sulfur plays an important role in the synthesis of fatty acids, as it increases the green mass, the chlorophyll content and stimulates growth, and increases the absorption of certain nutrients, especially nitrogen (https 4). Boron is the most essential of the microelements, which plays a major role in crop formation (RÁCZ, 2019). It supports the smooth development of dividing tissues and the growing tip, and plays an important role in the strength of cell walls (https 2). Its deficiency delays flowering, the plates are distorted and leech clusters develop in them (RÁCZ, 2019). In the case of a severe boron deficiency, the plate that develops on the thinned growing tip may break prematurely, and may even tear off the plant (https 2). Deficiencies of the other microelements occur only rarely in sunflower stands (Cu-deficiency: inhibited growth, Mn-deficiency: yellow spots on the leaves, Fe-deficiency: chlorotic leaves). The sunflower does not require, nor does it appreciate, barnyard manure. Its nutrient requirements are also covered by fertilizers. The lack of microelements can be partially eliminated by improving the soil condition, and partially by using appropriate foliar fertilizers (PEPÓ, 2005). Nutrient supply through the leaves is an excellent remedy for situations when the plant's root system is not functioning optimally, or nutrient supply through the soil proves to be unsuccessful. Foliar fertilization primarily provides plants with extra nutrients, which is especially important when nutrient absorption through the roots is inhibited for any reason. Secondly, it prevents and quickly eliminates nutrient deficiency conditions, and thirdly, it alleviates the stress caused by weather, the effects of pesticide scorch and the effects of stress caused by high crop yields (https 1). In the case of sunflower, boron foliar fertilization is justified, because in drier periods and on soils with poorer conditions, boron deficiency may occur in the plant. However, even in the case of more favorable soils, only a few kg of it can be found per hectare in the upper soil level, which is why boron foliar fertilization is practically a mandatory technological element in sunflower cultivation (https 2). The optimal time for foliar fertilization is the period from the star bud stage to the beginning of flowering (PEPÓ, 2005). However, an experiment carried out in the Czech Republic proved that even boron applied at the beginning of vegetation can increase the crop yield by 8.3% and the oil content by 10.2% (ŠKARPA, 2013). Due to its high boron demand, we can best help the plant with multiple foliar fertilizing. However, an overdose of boron preparations can have a scorching effect and can also cause crop depression (https 2). The sunflower can be classified as one of the world's most important arable oil crops, which serves as an important raw material for the production of high-quality cooking oil (BRANIMIR et al., 2008; SANDRA et al., 2008; SZABÓ, 2013). The oil content of current sunflower hybrids varies between 45-55% (https 5). However, this can be influenced by a number of factors, which we can improve with appropriate agrotechnics. Primarily, the right choice of sowing time has a significant effect on the oil content and oil yield (Petcu et al., 2000). Many years of experience favor early sowing, which has a positive effect on both yield and oil content (HARPER és FERGUSSON, 1979; NOVÁK, 2015). Delaying the sowing time will only reduce the yield and oil content (MILLER et al., 1984; BAGHDADI et al., 2014; NOVÁK, 2015). The other important factor affecting the oil content is the supply of nutrients and the nutrient supply of the soil. Sunflower practically does not require potassium fertilization on loamy and more compact soils, in fact, oil content decreases above 50 kg N and 50 kg P_2O_5. However, on nutrient-poor acidic sandy soil that has not been fertilized for many years, sunflower can also become a nutrient-demanding plant, and thus it can respond positively to a smaller supply of N, P, K, Ca, Mg, which can be seen in an increase in crop yield and oil content (KÁDÁR, 2011). In addition to these, the prolonged initial development of sunflower can result in a significant drop in oil content, while sunny weather can result in an increase in oil content (https 5). Genezis Nitrogénművek Zrt. prepares the nutrient treatments used during the experiment - during the consultation - for anyone based on a preliminary soil test. The *Environmental protection level* provides for the replacement of all three macroelements (N, P, K), but uses measures to improve the supply of nutrients that improve the quality of the soil (https 3). Environmental protection nutrient management strives to minimize the burden on the environment, unify production needs and environmental protection goals, and adapt to the conditions of the growing area. The essence of environmentally friendly nutrient management is that crop-enhancing materials and fertilizers are applied in the right time and in the right amount, so that the plants can utilize the nutrients as best as possible, as well as the nutrient losses that occur during farming and the associated load on environmental elements, primarily water should be avoided as far as possible. In addition to replacing the nutrients taken by the plant, the *Balance level* also incorporates a slow increase in nutrient supply into the system (https 3). The basis of the balancing principle is that the nutrient supply levels of the soil are determined based on the results of soil tests, taking into account the soil properties that affect the absorption of nutrients (pH-value, $CaCO_3$-content), as well as the dynamics of the mineralization (mineralization) of the soil's organic matter. In order to calculate the required amount of nutrients, the specific nutrient requirements of the culture to be grown must be known (how much nutrients are needed to produce 1 t/ha of grain yield and its vegetative parts), the amount of yield to be achieved and the nutrient response of the culture, and the effect of previous crops must also be taken into account (for example the N-effect of butterfly-flowered plants) and the after-effect of organic fertilizers broken down into 1-2-3 years. The advantages of the system are that we can plan according to the given supply levels and the characteristics of the production site, it takes into account correction factors, and it is cost-effective both from the point of view of testing and nutrient planning. On the other side of the balance, however, is the fact that the active substance calculation only focuses on the macroelements (N, P, K) and does not reveal the connections (DIRICZI and MAKRA, 2017). In addition to field and plant specificity, Genezis regional technology also takes into account modifying factors such as climatic factors typical of the given area, the known nutrient reactions and nutrient absorption dynamics of the variety or hybrids to be grown, as well as the machinery and technological equipment available to the producer who requires expert advice. fertilizer application and incorporation options provided by the facility (https 3).

MATERIAL AND METHODS

In the course of the research, we searched for the answer to whether foliar fertilization without artificial fertilization and foliar fertilization with 3 treatments with different nutrient levels would result in an increase in crop yield and oil content in the case of the P64LE25 sunflower hybrid, in the ecological conditions of the Szarvas area, under the typical weather conditions for the year 2022. during a drought year. The secret of P64LE25's popularity lies in its excellent adaptability to different soil conditions, diverse weather and diverse cultivation technologies. It is popular from Krasnodar in Russia through Bulgaria, Romania and of course Hungary to France and the Iberian Peninsula (https 6). The P64LE25 hybrid uniformly carries the herbicide tolerance required for the Express®** weed control technology, thus enabling safe weed control. An early hybrid with high productivity and high oil content. It has „Pioneer Protector Szádor" and „Pioneer Protector Peronoszpóra" certification, so it is resistant to the "E" race of the sunflower downy mildew and is tolerant to the "G" race, as well as resistant to the latest downy mildew races (Piukovics, 2019). The experiment was set up in Szarvas, on the School Field of the Department of Irrigation and Land Improvement of the Institute of Environmental Sciences of the Hungarian University of Agricultural and Life Sciences. During the experiment, we examined the P64LE25 hybrid in a random block arrangement. During the experiment, the following 4 treatments received additional foliar fertilizer treatment: Control, without artificial fertilization; Environmental protection level; Balance level; Genesis regional. The experiment took place in an area of approx. 2000m^2.

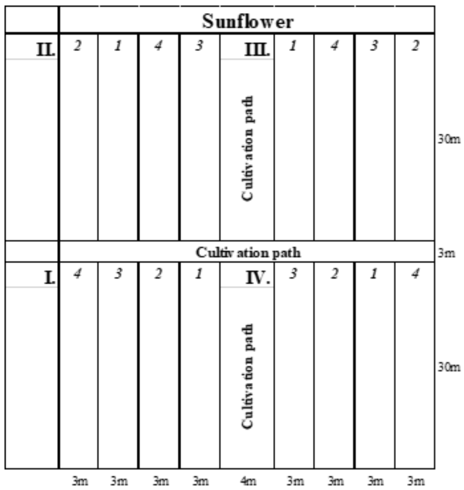

Figure 1: Diagram of the experimental area and the location of the treatments

The 4 different treatments mentioned above were tested in 4 repetitions. One repetition was located in an area of 360m^2. In one repetition, the size of a plot was 90m^2, half of which received additional foliar fertilization treatment, so the foliar fertilized part per plot was 45m^2. The entire experimental area and the location of the treatments are presented in *Figure 1.* The number of plants per hectare used was 50,000 plants/ha, and the row spacing was 75 cm.

Table 1 shows the fertilizers applied in the different treatments and their amounts of active ingredients. The table clearly shows that the smallest amount of nitrogen active ingredient was applied in the case of the Environmental protection treatments, while the most was applied in the Genesis regional. In the Genesis regional treatment, the same amount of active ingredients phosphorus and potassium was also applied.

Table 1

Fertilizers applied in different treatments and their amounts of active ingredients

Fertilizing treatment	N-dose kg ha^{-1}			P_2O_5 kg ha^{-1}	K_2O kg ha^{-1}	Fertilizer kind of
	In Autumn	In the Spring	Total	In Autumn		
1. Control	-	-	-	-	-	-
2. Environmental protection level	-	62.1	62.1	-	-	Pétisó
3. Balance level	-	75.06	75.06	-	-	Pétisó
4. Genesis regional	-	75.07	75.07	36	36	Pétisó+S Genezis 5-18-18

The pre-crop of sunflower in the experiment was corn, which is considered a moderately good pre-crop. Fertilizer was not applied in any of the treatments in autumn. Only the Genesis regional treatment received base fertilization, which took place in the spring, on 03.21, and the fertilizer was worked into the soil with a combiner on the same day. The starter fertilizer was applied to the treatments at the same time as the sunflower was sown, on 04.27. On 06.13, the sunflower was fertilized with a higher nitrogen dose, in proportion to the different treatments.

During the experiment, a total of 3 foliar fertilizer treatments took place, in the most suitable and most intensive phenological phases of the sunflower, when a nutrient deficiency may develop in the plant. However, properly timed application of nutrients through the leaves can mitigate or even cover the nutrient deficiency of the plant, especially in the case of a dry season, when nutrient uptake through the roots is inhibited due to minimal soil moisture. *Table 2* shows the dates of the foliar fertilizer treatments carried out during the experiment, the preparations applied in the different treatments, and their dosages and amounts of active ingredients.

„Nitrokén" is a complex preparation that, thanks to its high content of active ingredients, stimulates and strengthens the plant, and with its use, a higher yield and greater crop security can be achieved (https 7). *„Genezis Olajos BS"* has a favorable effect on the natural life process of the plant, promotes nutrient uptake from the soil during the period of intensive growth, flowering and fruit setting (https 8). *Mikromix Zn + Mikromix Mg* eliminates microelement deficiency diseases and increases the quantity of the crop and favorably improves its quality, as well as its resistance to diseases (https 9). *Pétibor Extra* is a state-of-the-art boron fertilizer that contains the nutrient boron in the form of a solution. Even when applied in low doses, it is very effective, which successfully takes up the fight in the prevention of boron deficiency diseases or when deficiency symptoms appear (https 10).

Table 2

The foliar fertilizer preparations used during the experiment, their dosage, amount of active ingredient, and the time of foliar fertilizer application

Date of treatment	Treatment	Name of preparation(s)	Dose (l/ha)	Amount of active ingredient (g/l)	Phenological phase of the plant
30.05.2022	Control	Nitrokén	3	150g N, 530g SO_3	6-8 leaf condition
	Environmental protection level	Nitrokén	3	150g N, 530g SO_3	
	Balance level	Nitrokén	3	150g N, 530g SO_3	
	Genesis regional	Genezis Olajos BS	5	150g N, 50g SO_3, 20g B	
15.06.2022	Control				8-10 leaf condition
	Environmental protection level				
	Balance level				
	Genesis regional	Mikromix Zn + Mikromix Mg	2+2	50g Zn + 50g MgO, 50g Fe	
28.06.2022	Control	Pétibór Extra	4	100g B	star bud state
	Environmental protection level	Pétibór Extra	4	100g B	
	Balance level	Pétibór Extra	4	100g B	
	Genesis regional	Pétibór Extra	4	100g B	

Table 3 summarizes the amounts of foliar fertilizer applied in the different treatments. It can be read from the table that the same foliar fertilizers were used in the Control, Environmental protection and Balance levels, in the same amount of active ingredients. However, the Genesis regional treatment was different from the others, here - excluding the Pétibór Extra preparation - different foliage fertilizers were applied. The total amount of active ingredients in the preparations was also smaller than in the case of the other 3 treatments, however, there was a more diverse supply of micronutrients compared to the other treatments.

Table 3

Amounts of active ingredients in foliar fertilizers applied in different treatments

Treatment		Control	Environmental protection level	Balance level	Genesis regional
Amount of active ingredient per treatment (g/ha)	N	450g	450g	450g	750g
	SO_3	1590g	1590g	1590g	250g
	B	400g	400g	400g	500g
	Zn	–	–	–	100g
	MgO	–	–	–	100g
	Fe	–	–	–	100g
Total amount of active ingredients		2440g	2440g	2440g	1800g

During the experiment, foliar fertilizers were applied per plot with a 5-liter hand sprayer. Due to the large lack of rainfall, in order to keep the experiment alive, the sunflower received two 30 mm irrigations using a reel-drum irrigation system with an irrigation console. During the experiment, in order to investigate the utilization of applied foliar fertilizers, we measured yield and oil content. During the yield test, 12 plants were randomly selected from each plot, and the plates were collected. Later, these were threshed by hand, and after cleaning the samples, their weight was weighed, converted to t/ha and corrected to 8% moisture content. The oil content was measured with a FOSS Infratec^{TM} NIR grain analyzer. During the application of the near infrared spectroscopy (NIR-spectroscopy) method, the device determines the oil content of the given sample using the near infrared range of the electromagnetic spectrum (800-2500 nm) (https 11).

RESULTS AND DISCUSSIONS

The results and data of the measurements and tests carried out during the experiment are presented in the form of tables and graphs. *Table 4* describes the crop yields of the treatments without foliar fertilizer and *Table 5* of the treatments with foliar fertilizer per plot, in the case of the 4 different nutrient supply technologies.

Table 4

Yield of treatments without foliar fertilizer

t/ha	Treatments without foliar fertiliser				
	Repetition I	Repetition II	Repetition III	Repetition IV	Average of repetitions
Control	2.8	2.75	2.65	3.07	**2.82**
Environmental protection level	2.5	2.82	1.37	3.68	**2.59**
Balance level	4.1	2.05	2.37	3.37	**2.97**
Genesis regional	3.93	2.47	3.03	2.8	**3.06**

Table 5

Yield of foliar fertilized treatments

t/ha	Foliar fertiliser treatments				
	Repetition I	Repetition II	Repetition III	Repetition IV	Average of repetitions
Control	4.24	2.36	2.55	4.68	**3.46**
Environmental protection level	4.07	2.19	2.89	4.08	**3.31**
Balance level	4.27	1.62	3.69	4.07	**3.41**
Genesis regional	4.41	2.98	1.7	3.31	**3.1**

Figure 2 shows the aggregated yield results of the different treatments, both in the case of treatments without foliar fertilizer and with foliar fertilizer. It can be seen from the figure that the highest yield among the foliar fertilizer treatments was achieved in the Control (without fertilization) treatment that only received foliar fertilizer. And the lowest yield results were produced by the combined treatment of the Genezis regional nutrient supply technology with foliar fertilization.

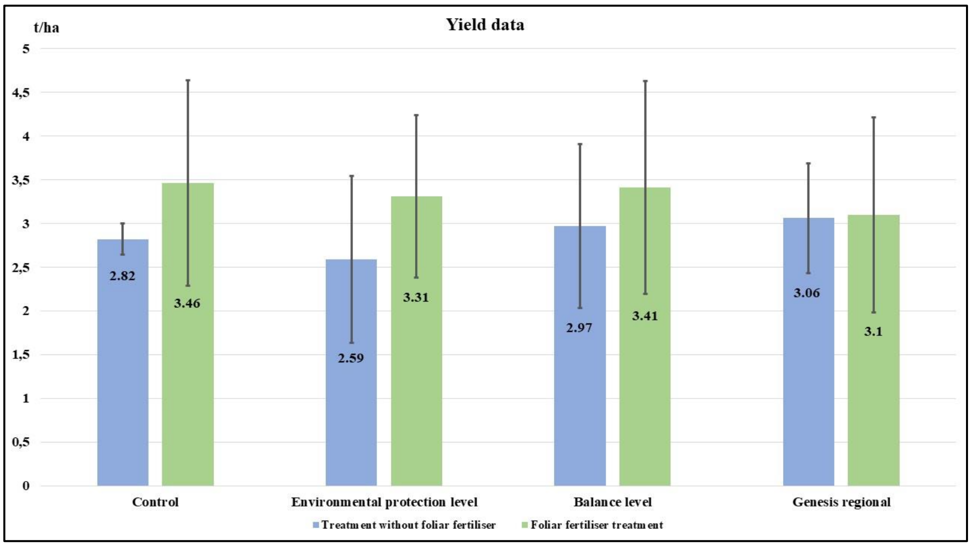

Figure 2*:* Aggregate yield data

Overall, however, it can be said that in the case of all treatments, the additional foliar fertilizer treatment increased crop yields. The largest yield increase occurred in the case of the Environmental protection level, where foliar fertilization resulted in a 27.8% higher harvested yield. In addition to these, what can also be observed in the figure is that the standard deviation of the yield results of treatments with foliar fertilization is greater than that of those without foliar fertilization.

Table 6 describes the oil content of the treatments without foliar fertilizer and *Table 7* of the treatments with foliar fertilizer per plot, in the case of the 4 different nutrient supply technologies.

Table 6

Oil content of treatments without foliar fertilizer

%	Treatments without foliar fertiliser				
	Repetition I	Repetition II	Repetition III	Repetition IV	Average of repetitions
Control	45.9	46.1	45.9	46.5	**46.1**
Environmental protection level	45.7	45.75	46.1	46.35	**46**
Balance level	45.9	46.05	46.15	46.15	**46.1**
Genesis regional	46.1	46.5	45.55	46.9	**46.3**

Table 7

Oil content of foliar fertilized treatments

%	Foliar fertiliser treatments				
	Repetition I	Repetition II	Repetition III	Repetition IV	Average of repetitions
Control	45.3	46.8	47.2	46.3	**46.4**
Environmental protection level	45.95	46.15	47.25	46.7	**46.5**
Balance level	46.05	45.5	46.65	46.05	**46.1**
Genesis regional	47.5	45.25	46.3	46.45	**46.4**

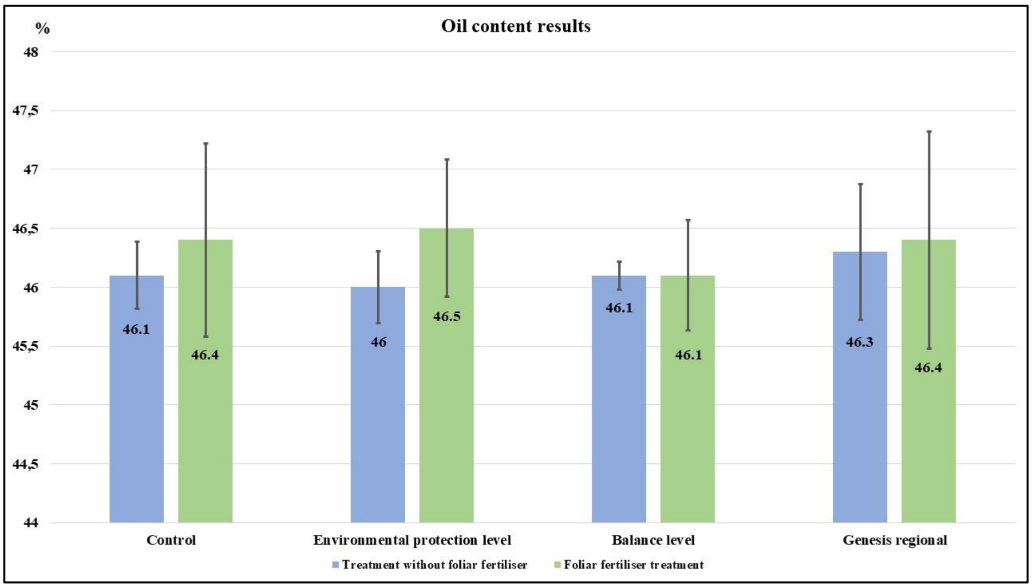

Figure 3: Aggregate oil content data

Figure 3 describes the results of the aggregated oil content analysis of the different treatments, both in the case of treatments without foliar fertilizer and with foliar fertilizer. It can be seen from the figure that among the treatments with foliar fertilization, the highest oil content crop could be harvested in the case of the Environmental protection level receiving additional foliar fertilization. The sunflower with the lowest oil content was produced by the Balance level treated with foliar fertilizer, in which case the foliar fertilizer did not improve, but fortunately did not worsen the oil content results. Overall, it can be said that in most of the treatments, additional foliar fertilization resulted in an increase in oil content. The largest increase in oil content occurred in the case of the Environmental protection level, but this was also minimal, as the oil content of the foliar-fertilized treatment was only 1.1% higher, compared to the treatment that did not receive foliar fertilization.

The sunflower in the Control plot, which had not received artificial fertilization for many years, required a great deal of nutrients, which it received during the growing season by applying foliar fertilizer. As a result, thanks to the diverse macro- and micronutrients found in the foliage fertilizer, we experienced a greater yield increase in this treatment. The yield-enhancing effect of supplementary foliar fertilization was the smallest in the Genesis regional treatment, and the increase in oil content was also minimal. This can be attributed to the fact that, in this treatment, the plant already had a higher level of nutrients that could be taken up through the roots, which is why additional foliar fertilization could not significantly increase the yield and oil content results. On the other hand, in this foliar fertilizer treatment, the plant received the smallest amount of active ingredients of all micronutrients, but at the same time, the most diverse micronutrient replenishment took place here.

Among all the nutrient levels, the Environmental protection responded best to the additional foliar fertilization treatment, both in terms of yield and oil content growth.

The yield data of the foliar-fertilized treatments show a larger standard deviation compared to those without foliar fertilizer. This can partly be attributed to the uneven scattering pattern of the hand sprayer, however, it does not show such a difference that would negatively affect the results of the experiment.

CONCLUSIONS

Overall, greater differences were observed between the results of the parts without foliar fertilizer and those with foliar fertilizer at the lower nutrient levels. This can be attributed to the fact that there were not enough nutrients for the sunflower to absorb from the soil, but this was replenished through the leaves, and it manifested itself in an increased yield and an increase in oil content. Therefore, it can be said that the additional foliar fertilizer treatment in order to increase yield can be useful in nutrient-poor farming, where fast and efficient nutrient replenishment is needed, and in such conditions it also has a greater effect on increasing the oil content than in the case of nutrient-rich farming.

The experiment also pointed to the fact that it is essential to apply foliar fertilization in sunflower cultivation in the event of a dry season, as all treatments resulted in an increase in yield, and in the case of most treatments it also had a positive effect on increasing the oil content.

Overall, it can be said that in the case of a dry season, the additional foliar fertilizer treatment has a much more positive effect on the increase in yield than on increasing the oil content of sunflower.

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