agronomy

MDPI

Article

Effect of Varying Nitrogen and Micronutrient Fertilization on Yield Quantity and Quality of Sunflower (*Helianthus annuus* L.) Achenes

Wacław Jarecki

Department of Crop Production, University of Rzeszów, Zelwerowicza 4 St., 35-601 Rzeszów, Poland; wjarecki@ur.edu.pl

Abstract: Sunflower is a good alternative crop in rotation, even in light soils. This is due to the changing climate, economic factors and the need to reduce agriculture pressure on the environment. In this field experiment, the effect of soil nitrogen doses (60 and 90 kg ha^{-1}) and additional foliar fertilization (B, Cu, Fe, Mn, Mo, Zn) on selected plant characteristics, yield and quality of sunflower achenes was assessed. The single-factor experiment was conducted in 2020 and 2021 on Luvisol soil. It was shown that a higher nitrogen dose had a positive effect on plant biometric features, protein content in achenes, as well as LAI (leaf area index) and SPAD (soil plant analysis development) indices. Additionally, the applied double foliar spraying resulted in an increase in yield components and quality of achenes. Sunflower yielding depended on the interaction of weather conditions with fertilization. In the first year of the research, high yields were obtained after applying 60 or 90 kg N ha^{-1} in combination with double foliar fertilization (3.68 and 3.65 t ha^{-1}, respectively). A significantly lower yield was recorded after applying only the 60 kg N ha^{-1} dose. This was not statistically confirmed in the second year of the study, with a higher average yield of 3.79 t ha^{-1}. Economic calculations showed that the optimal option was to use 60 kg N ha^{-1} together with single or double foliar fertilization. Fertilizing with 90 kg N ha^{-1} in combination with micronutrient spraying was the least profitable.

Keywords: *Helianthus annuus* L.; fertilization; foliar fertilization; nitrogen; microelements; plant nutrition; plant architecture; yield; chemical composition

Citation: Jarecki, W. Effect of Varying Nitrogen and Micronutrient Fertilization on Yield Quantity and Quality of Sunflower (*Helianthus annuus* L.) Achenes. *Agronomy* **2022**, *12*, 2352. https://doi.org/10.3390/agronomy12102352

Academic Editor: Antonios Chrysargyris

Received: 8 September 2022
Accepted: 27 September 2022
Published: 29 September 2022

1. Introduction

Sunflower (*Helianthus annuus* L. 2n = 34) belongs to the family Asteraceae and is one of the most important oil plants in the world [1,2]. Oil is obtained from achenes of this species, and the residues are used for fodder. There is also great interest in sunflower edible products as an alternative food [3]. Sunflower preparations are known in traditional medicine [4], and flowers in floriculture. According to many authors [1,2,5], the increase in sunflower acreage results from the transfer of new, better varieties, including hybrid ones, to agricultural practice. In many regions, it is the result of climate change, the economic situation and the need to search for species that require less intensive agricultural technology [6]. Sunflower is increasingly being grown by farmers also in Poland. However, there is a lack of new agriculture information regarding the optimal fertilization and production profitability. Sher et al. [7] concluded that field experiments with sunflower should be carried out in various habitat conditions. This would allow the development of cultivation technology recommendations for local environmental conditions and legal regulations. Li et al. [8] have noted that sunflower has moderate water and fertilization needs; however, they are not low. The best results were obtained with an average level of irrigation and mineral fertilization. Watanabe et al. [9] showed that a deficiency of nitrogen, phosphorus or potassium resulted in changes in the chemical composition of sunflower leaves. Hammad et al. [10] have concluded that sunflower requires moderate doses of

NPK and reacts favorably to organic fertilizers (straw). The obtained effects, however, depended on the variety. Kováčik et al. [11] and Mokgolo et al. [12] confirmed that various organic fertilizers could be used in sunflower cultivation. These authors obtained the best yields after manure application. Sharma et al. [13] and Soleymani et al. [14] concluded that organic fertilizers allowed one to reduce the doses of mineral fertilizers. Oshundiya et al. [15] proved that the advantage of organic fertilizers was a beneficial effect on the chemical composition of sunflower achenes. Oil and protein contents of seeds from early and late sown sunflower plants were significantly increased by organic fertilizer application, except the protein content of late sown sunflower. Sefaoglu et al. [16] obtained the highest yields of achenes (4.854 kg ha^{-1}) and fat (2.114 kg ha^{-1}) with the combined use of nitrogen and vermicompost. Interestingly, the use of vermicompost alone resulted in the highest fat content in achenes (46.8%). Rocha et al. [17] indicated that a dose of 30 to 50 kg N ha^{-1} was sufficient to obtain a high fat yield. Oyinlola et al. [18] showed that excess nitrogen decreased achene yield and oil content and delayed sunflower blooming. The optimal nitrogen dose according to the latter authors ranged from 90 to 100 kg·ha^{-1}. Ahmad et al. [19] confirmed that nitrogen fertilization exerted a positive effect on the growth and development of sunflower, but could worsen the quality parameters of achenes, which was due to the reduction of the oil content. Sincik et al. [20] indicated that the economically optimal dose of nitrogen for sunflower was 145–150 kg ha^{-1} under conditions without irrigation and 177–190 kg ha^{-1} with watering. Kandil et al. [21] proved that a high dose of nitrogen (168 kg ha^{-1}) increased plant height, stem thickness, number of leaves per plant, leaf area, number of achenes per head, head diameter and 1000 achenes weight (TAW), which was reproducible over the years. They proved that a high nitrogen dose (168 kg ha^{-1}) compared to a low dose (72 kg ha^{-1}) significantly increased achene yield (by 12.0 and 11.6%, respectively), in the first and second year of the study. Zeng et al. [22,23] concluded that high nitrogen fertilization was justified on soil with low or medium salinity or soil with high salinity but irrigated. Ozturk et al. [24] stated that nitrogen form in the fertilizer was of great importance in shaping the yield of achenes and sunflower fat. They showed that urea was better compared to ammonium sulfate or ammonium nitrate. Souza et al. [25] reported that higher nitrogen doses were economically justified in sunflower cultivation. However, the tested varieties showed differentiated nitrogen demand, from 80 to 120 kg ha^{-1}. Eltarabily et al. [26] indicated that nitrogen constituted over 80% of all minerals absorbed by plants and significantly limited plant yields, especially under conditions of water deficit, 65% evapotranspiration (ET_C). Ahmad et al. [19] proved that optimal nitrogen fertilization of sunflower plants significantly increased the yield and its components, but reduced the fat content in achenes. Soleymani [27] showed that sunflower required from 100 to 150 kg ha^{-1} nitrogen. Qadeer et al. [28] reported that the nitrogen dose of 150 kg ha^{-1} significantly increased the diameter of the sunflower head by 8.45 cm compared to control. Travlos et al. [29] applied high nitrogen doses (150 and 300 kg ha^{-1}) in sunflower cultivation. Hajduk et al. [30] proved that increased mineral fertilization with nitrogen decreased the boron content of sunflower biomass. Therefore, Alves et al. [31] concluded that higher nitrogen doses should be combined with boron fertilization, as they allowed one to obtain significantly higher sunflower yields. Alipatra et al. [32] indicated that the optimal dose of nitrogen was 80 kg ha^{-1}, but in combination with P, K, S and B fertilization and irrigation of sunflower plantations. Gomes et al. [33] confirmed that the efficiency of minimal and organic fertilization was higher when sunflower plantation was irrigated. In turn, Milev [34] proved that sunflower reacted to multicomponent mineral fertilizers with increased yield and its quality. El-Din Mekki [35] believed that boron was important in fertilizing sunflower seeds. In a greenhouse experiment, he showed that the deficiency of this micronutrient in the soil reduced both the size and quality of the crop. Shehzad et al. [36,37] and Alves et al. [31] also showed that sunflower response to B fertilization varied, especially at higher nitrogen doses. Bozca and Leblebici [38] reported that boron fertilization reduced plant stress at a low temperature. On the other hand, the application of boron at high temperatures worsened the development of the sunflower root system.

Al-Amery et al. [39] proved that boron fertilization reduced the number of empty achenes, which resulted in a significant increase in yield. Khalid et al. [40] showed that fertilization with boron did not provide the expected results, even in the soil poorer in nutrients. The study of Asad et al. [41] showed that the highest level of foliar B fertilization caused leaf burn, but plant growth was not affected. Ekmekçi et al. [42] confirmed that excess boron was toxic to sunflower plants. Therefore, it was necessary to perform soil analyses to determine the equivalent doses of macro- and micronutrients.

Fernández and Brown [43] reported that the application of agrochemical sprays to the aerial parts of crop plants was an important agricultural practice worldwide. While variable effectiveness is often observed in response to foliar treatments, there is ample evidence indicating the beneficial effects of foliar fertilizers in improving crop metabolism, quality and yield. Brown and Shelp [44] have reported that boron is unique among the essential plant nutrients because it has limited mobility in many plant species, while it is freely mobile in others. No other element is known to have such a wide variation in mobility. Baraich et al. [45] showed that foliar fertilization (8 Zn + 0.75 B + 0.30 Fe kg ha^{-1}) significantly improved the sunflower yield and its components. In turn, Hlisnikovský et al. [6] showed that micronutrient spraying (B, Zn, Mo) exerted no significant effect on sunflower biomass yield. Bhattacharyya et al. [46] proved that foliar boron fertilization was more effective than soil fertilization. Andrade et al. [47] reported that boron fertilization had a positive effect on plant growth and sunflower yield, and this effect was observed in soil with a low boron content. Singh et al. [48], after foliar fertilization with boron, achieved an increase in protein content in achenes and a higher fat yield. Khan et al. [49] proved that sunflower reacted differently to soil and foliar boron fertilization. The foliar spraying had a better effect on the yield and its components. Pattanayak et al. [50] showed that sunflower positively responded to combined NPK, zinc and boron fertilization. As a result of such fertilization, they obtained the highest oil yield (>1000 kg ha^{-1}). Kumar et al. [51] indicated that copper was an important element, but its excess caused a detrimental effect on sunflower plants. Hajduk et al. [52] showed that the molybdenum content in sunflower green mass depended on the dose of NPK and Ca. Steiner and Zoz [53] reported that foliar fertilization with molybdenum resulted in an increase in thousand achene weight (40%) and yield (27%) compared to control. This was due to the influence of molybdenum on nitrogen metabolism in sunflower plants. Škarpa et al. [54] proved that double foliar fertilization with Mo increased the yield of achenes and fat yield. Li et al. [55] reported that the foliar application of Zn caused short-term stress, but it did not adversely affect the absorption of this micronutrient in the leaves. Kandhro et al. [56] proved the beneficial interaction of Zn fertilization and plant irrigation on sunflower yielding. In addition, they indicated the need to select an appropriate variety for the habitat conditions. Li et al. [57] reported that the efficiency of foliar fertilization with Zn, Mn and Fe depended on the plant species (sunflower, tomato, soybean) and the morphological and anatomical structure of the leaf. Li et al. [58] demonstrated that foliar zinc fertilization had a positive effect on the yielding of sunflower, even when the content of this element in the soil was sufficient. Therefore, it should be stated that research in the field of sunflower plant fertilization is cognitively important for science and agricultural practice.

The aim of the experiment was to evaluate the effect of two nitrogen doses and an additional single and double foliar fertilization with micronutrients on the size and quality of the sunflower achene yield. The research hypothesis assumed that the applied fertilization variants would significantly modify the assessed characteristics and parameters of plants, as well as the economic result of sunflower cultivation.

2. Materials and Methods

2.1. Field Conditions

The field experiment was carried out in 2020 and 2021, in the field of a private farm in the town of Szówsko (50°03′ N, 22°42′ E), Podkarpackie Voivodeship, Poland. The single-factor experiment was conducted in four replicates in a random block design. The tested factor were different variants of nitrogen (in-soil) and micronutrient (foliar) fertilization:

1. A—60 kg N ha^{-1}
2. B—90 kg N ha^{-1}
3. C—60 kg N ha^{-1} and foliar fertilization
4. D—90 kg N ha^{-1} and foliar fertilization
5. E—60 kg N ha^{-1} and double foliar fertilization
6. F—90 kg N ha^{-1} and double foliar fertilization

The weather conditions were provided according to the records of the Meteorological Station in Skołoszów, located approximately 18 km from the experimental field. Soil chemical analysis was performed in the accredited laboratory of the Regional Chemical and Agricultural Station in Rzeszów, according to Polish standards. The experiment was established on Luvisol soil [59]. The soil was characterized by a slightly acidic pH (Table 1). The content of available phosphorus and potassium was high, while that of magnesium was medium (2020) or high (2021); the content of micronutrients was average.

Table 1. Soil analysis under field experiment (0–30 cm).

Parameter	Unit	2020	2021
pH in KCl	-	6.5	6.3
Humus	%	1.3	1.2
N_{min}	kg·ha^{-1}	56	52
P_2O_5	mg·100 g^{-1} gleby/soil	18.4	17.5
K_2O		21.2	22.4
Mg		6.4	7.2
Fe	mg·1000 g^{-1} gleby/soil	2352.6	2289.3
Zn		12.9	14.4
Mn		251.3	389.6
Cu		6.4	6.1
B		1.5	1.7

Sunflower (cv. MAS 81.K) cultivation was carried out in accordance with the available agriculture knowledge. In Poland, an increase in the acreage of this species has only been recorded for several years. The forecrop each year was maize for grain, followed by pre-winter tillage. In the spring, harrowing was applied and a combined cultivator was used before sowing. Achene sowing was performed in the third decade of April (23 April 2020 and 26 April 2021) using a precision seeder. Fluarto 50 FS (fludioxonil) was used for dressing, in accordance with the manufacturer's instructions. Row spacing was 50 cm and sowing depth was 4 cm. Eight germinable achenes were sown per 1 m^2. The area of a single plot was 20 m^2 (4 m × 5 m). The isolation strips between the plots were 1 m^2. The values of biotic indices are shown in Table 2.

Table 2. Chemical plant protection.

Preparation	Active Substance	Dose (L/ha)
Activus 400 S.C. (herbicide)	pendimetalina	4.0
Bandur 600 S.C. (herbicide)	aklonifen	3.0
Efica 960 EC (herbicide)	metolachlor-S	1.25
Amistar Gold Max (fungicide)	azoksystrobina, difenokonazol	1.0
Trico (repellant)	sheep fat	15.0

The timing and dosages of the applied products (herbicides, fungicide, repellant) were in accordance with the manufacturer's recommendations. Urea with a urease inhibitor (46%) was used for nitrogen fertilization in one spring dose. Phosphorus-potassium fertilization was carried out in autumn in the following doses: 60 kg ha^{-1} P_2O_5 (simple superphosphate) and 90 kg ha^{-1} K_2O (potassium salt). Foliar fertilization was performed with MIKRO PLUS™ (Intermag Sp. z o.o., Poland), single (1.5 L ha^{-1} in the 12-leaf phase) or double spraying (1.5 L ha^{-1} in the 12-leaf stage and 1.5 L ha^{-1} in the end-of-budding phase), according to the experimental design. Composition of foliar fertilizer was as follows (g/L): boron—2.3, copper—1.2, iron—23.2, manganese—9.3, molybdenum—0.58, zinc—3.5. The volume of the working solution was 300 L ha^{-1}.

Plant density per 1 m^2 was counted before harvest on each plot. Subsequently, the height of 20 plants was measured and heads were collected for biometric measurements (diameter, number of achenes, thousand achene weight). Thousand achene weight (TAW) was converted to a constant moisture of 9%. Harvest was carried out using a harvester in the first decade of October (9 October 2020 and 7 October 2021). Achene yield was calculated per 1 ha taking into account a constant moisture content of 9%.

2.2. Chemical Composition

Achenes for chemical analyses were obtained during harvesting from each plot, a total of 24 samples weighing 0.5 kg each. The chemical composition of achenes whole (fat, protein, ash, fiber) was determined by the near infrared method using a FT-LSD MPA spectrometer (Bruker, Germany) in the laboratory of the Department of Plant Production, University of Rzeszów.

The biological yield of both components (fat and protein) was calculated based on the yield of achenes and their percentages of crude fat and total protein.

Yield of protein or oil = (Yield of achenes (t ha^{-1}) $\times$ content of a given component in achenes (%)): 100.

2.3. Economic Analysis

Prices for economic calculations are given for 2022, in line with the offer of commercial companies and available data from the agricultural market. Achene yield was taken as the average of the study years. Exchange rate: 1 EUR = 4.75 PLN. The purchase price of achenes was 547.37 EUR per ton. The cost of fertilizers was: 1 kg of nitrogen—2.23 EUR, MIKRO PLUS™—4.39 EUR/liter. Cost of spraying—9.3 EUR per 1 ha.

2.4. Statistical Analyses

The results of the study were statistically analyzed using analysis of variance (ANOVA), implemented in Statistica 13.3.0 (TIBCO Software Inc., Palo Alto, CA, USA). Significance of differences between treatments was verified by the Tukey test.

3. Results

3.1. Weather Conditions

The weather conditions varied in the years of the study, which modified the obtained results (Figure 1). Heavy rainfall was recorded in June 2020 and August 2021. Low rainfall compared to multi-year data occurred in July and August 2020. This coincided with the flowering phase of sunflowers. October 2021 was also dry, which had a positive effect on the harvest. Air temperature varied over the years and generally differed from the long-term average. The warmest month was July 2021 (Table 3).

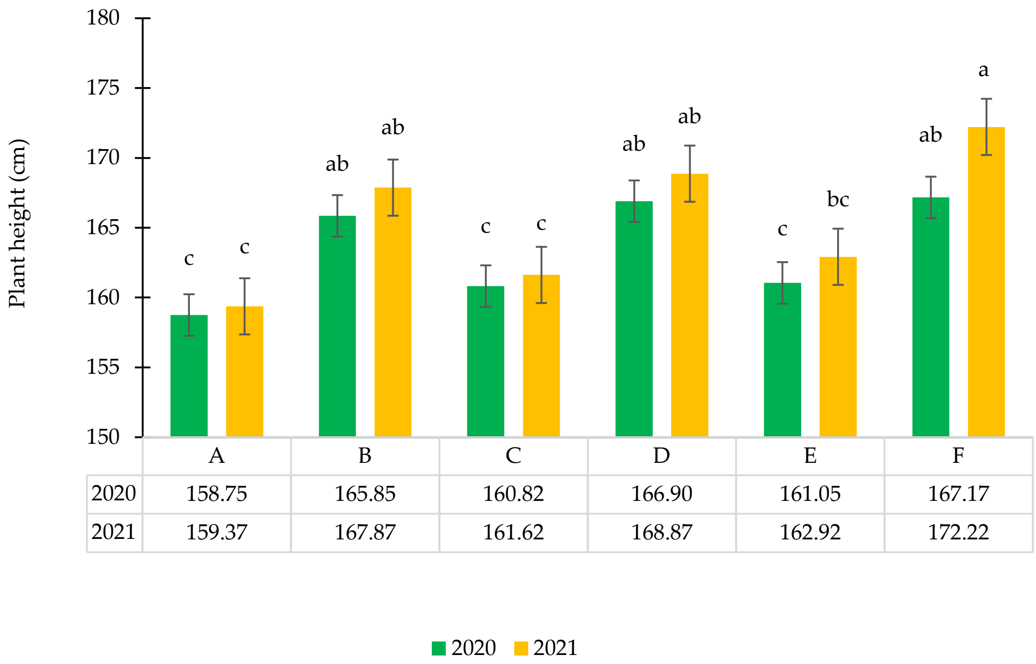


Figure 1. Plant height (cm). A–F—variants of fertilization. Different lowercase letters indicate significant differences ($p < 0.05$) according to the analysis of variance (ANOVA).

Table 3. Weather conditions.

Month	Sum of Precipitation (mm)			Mean Temperature (°C)		
	2020	2021	Multi-Years	2020	2021	Multi-Years
III	19.8	17.5	37.0	5.1	3.2	2.8
IV	10.0	49.4	46.0	9.2	6.5	8.7
V	83.3	63.9	77.1	11.3	12.8	13.7
VI	162.9	47.3	80.2	18.1	18.8	17.1
VII	18.9	55.0	95.4	18.8	21.6	19.0
VIII	7.3	107.4	65.0	19.9	17.5	18.4
IX	43.5	85.8	62.5	15.0	13.1	13.6
X	54.3	2.5	46.4	11.1	9.1	8.8

3.2. Field and Biometric Measurements

The highest plants were obtained after fertilization with a dose of 90 kg N ha^{-1}, while significantly lower plants developed after applying 60 kg N ha^{-1}. Foliar fertilization did not affect the discussed parameter. On average, in the experiment, the plants were higher in 2021 compared to 2020 (Figure 1).

Plant density before harvest was not modified by the tested factor. On average, it amounted to 7 individuals per m^2. It was shown that foliar fertilization in variants C, D, E and F significantly increased head diameter compared to the 60 kg N ha^{-1} dose. The LAI index was modified by both fertilization and years of study. The higher dose of nitrogen significantly increased this parameter. In 2020, the LAI index values were higher than in 2021 (Table 4).

Table 4. Measurement of selected sunflower parameters.

Factor	Number of Plants before Harvest (pcs·m^{-2})	Head Diameter (cm)	LAI (m^2/m^2)
	Fertilization		
A	6.99 ± 0.10	16.26 ± 0.79 ^{b}	3.96 ± 0.17 ^{b}
B	6.95 ± 0.07	16.76 ± 0.56 ^{ab}	4.10 ± 0.19 ^{a}
C	6.95 ± 0.09	16.95 ± 0.54 ^{a}	3.98 ± 0.17 ^{b}
D	7.00 ± 0.08	16.93 ± 0.56 ^{a}	4.13 ± 0.19 ^{a}
E	7.02 ± 0.06	17.01 ± 0.52 ^{a}	3.99 ± 0.17 ^{b}
F	7.01 ± 0.11	17.11 ± 0.55 ^{a}	4.14 ± 0.19 ^{a}
	Years		
2020	7.00 ± 0.09	17.00 ± 0.62	4.11 ± 0.19 ^{a}
2021	6.98 ± 0.07	16.67 ± 0.60	4.00 ± 0.17 ^{b}

A–F—variants of fertilization. Results are expressed as mean value ± standard deviations. Different letters in the same column indicate significant differences ($p < 0.05$) according to the analysis of variance (ANOVA).

In 2020, the measurement of the SPAD index showed that the 90 kg N ha^{-1} dose together with double foliar fertilization (variant F) resulted in better plant nutrition compared to the lower nitrogen dose (60 kg ha^{-1}). In 2021, the SPAD index was lower and varied less between the treatments (Figure 2). However, it could be noticed that the more intensive fertilization variants (D and F) had a better effect on the discussed parameter compared to variant A.

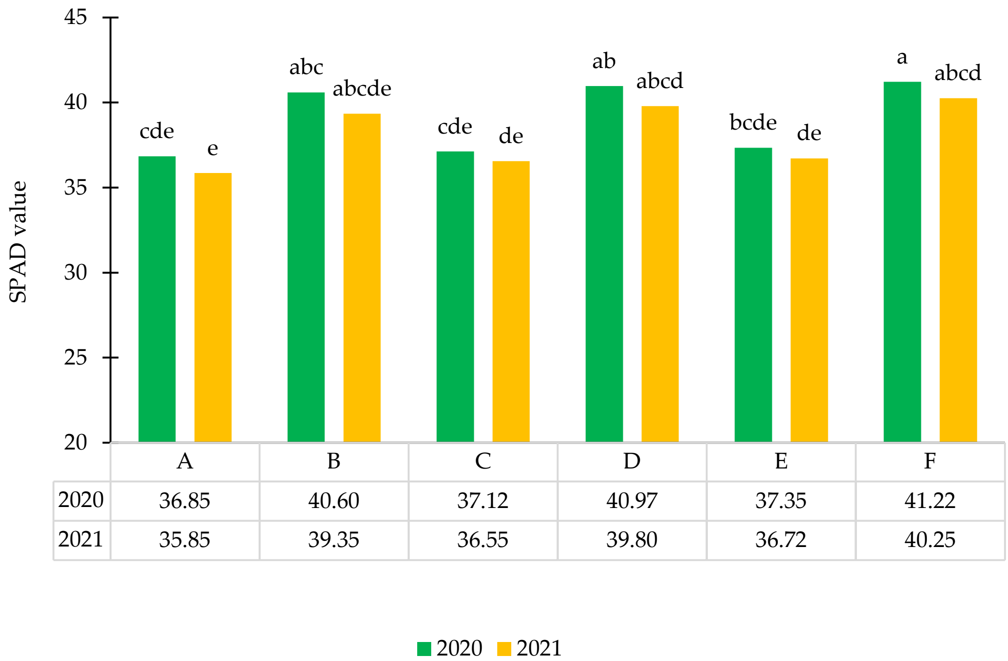


Figure 2. SPAD value. A–F—variants of fertilization. Different lowercase letters indicate significant differences ($p < 0.05$) according to the analysis of variance (ANOVA).

The number of achenes in the head was dependent on the interaction of fertilization with years of research. In 2020, the dose of 90 kg N ha^{-1}, including double foliar fertilization (variant F), exerted the most beneficial effect on this parameter. In 2021, the number of achenes in the head was similar after the application of fertilization variants D, E and F. However, it was significantly lower in the plot fertilized with the nitrogen dose of 60 kg ha^{-1} (Figure 3). Additionally, the applied foliar fertilization increased the number of achenes in the sunflower head, although the increment has been dependent on years.

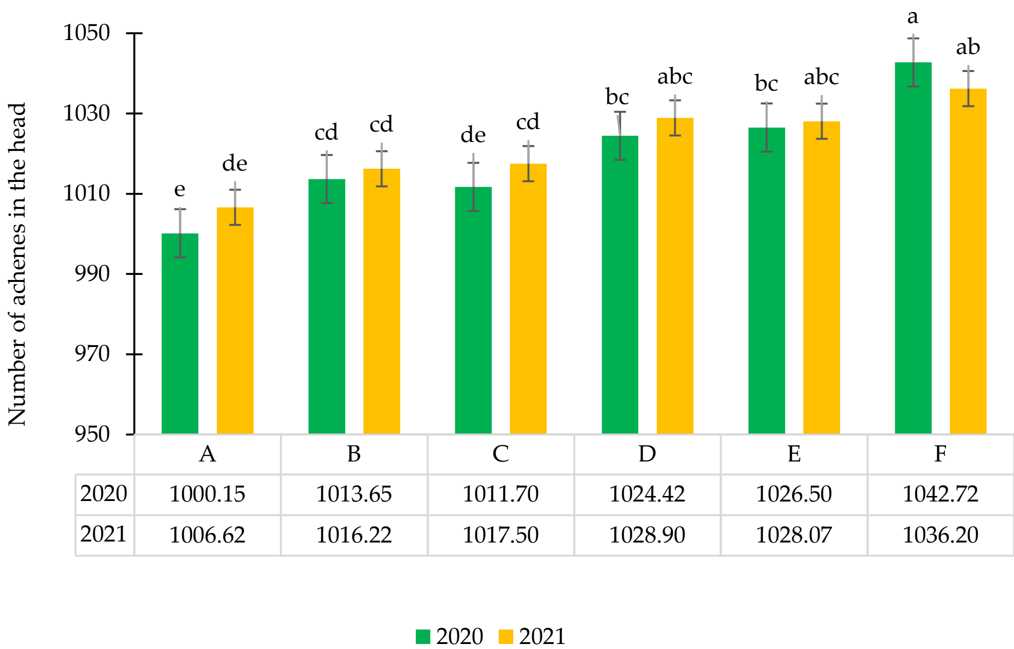


Figure 3. Number of achenes in the head. A–F—variants of fertilization. Different lowercase letters indicate significant differences ($p < 0.05$) according to the analysis of variance (ANOVA).

Thousand achene weight was slightly modified. It was shown that the dose of 90 kg N ha^{-1} in combination with double foliar fertilization (variant F) had a positive effect on the discussed parameter in 2021. The lowest TAW was obtained in 2020 after nitrogen application at a dose of 60 kg ha^{-1} (Figure 4). The small effect of foliar fertilization on the MTN can be explained by an increase in the number of achenes in the sunflower head.

Figure 4. Mass of a thousand achenes (g). A–F—variants of fertilization. Different lowercase letters indicate significant differences ($p < 0.05$) according to the analysis of variance (ANOVA).

In 2020, nitrogen fertilization together with double foliar fertilization reduced the hull weight compared to the dose of 60 kg N ha^{-1}. In 2021, only a higher dose of nitrogen along with two foliar sprayings (variant F) reduced the hull weight compared to the 60 kg N ha^{-1}

dose (Figure 5). These results are important for agricultural practice as they determine the quality of sunflower achenes.

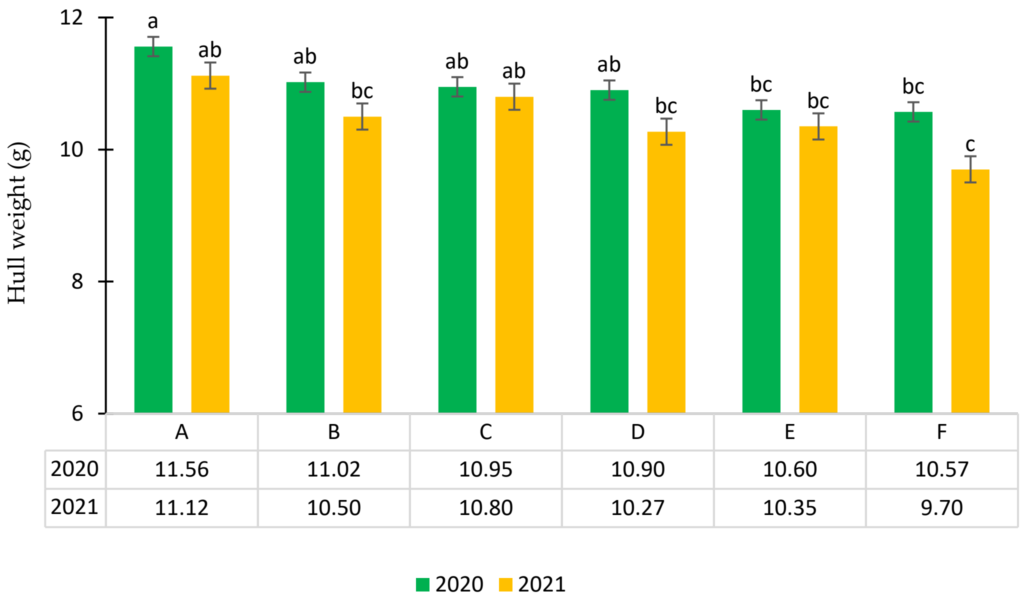


Figure 5. Hull weight (g). A–F—variants of fertilization. Different lowercase letters indicate significant differences ($p < 0.05$) according to the analysis of variance (ANOVA).

3.3. Yield of Achenes

The sunflower yield was dependent on the interaction of fertilization with the year of the study. In 2020, nitrogen fertilization (60 or 90 kg ha^{-1}) in combination with double foliar fertilization significantly increased the achene yield compared to the 60 kg N ha^{-1} dose. In 2021, no significant differences between the fertilization variants were detected. On average, in the experiment, the sunflower yield was higher in 2021 compared to 2020 (Figure 6).

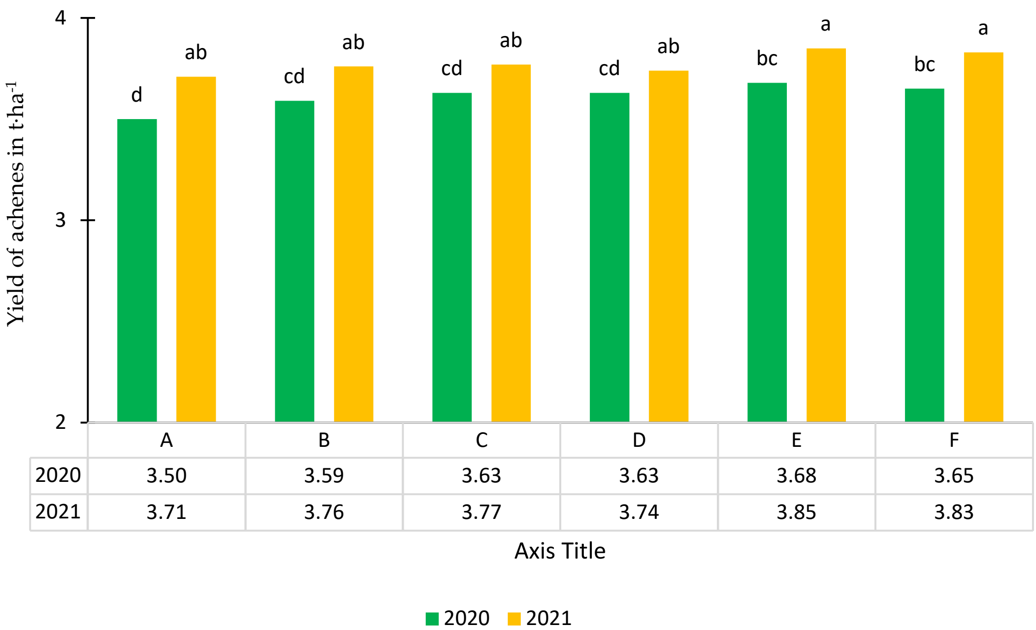


Figure 6. Yield of achenes in t·ha^{-1}. A–F—variants of fertilization. Different lowercase letters indicate significant differences ($p < 0.05$) according to the analysis of variance (ANOVA).

3.4. Chemical Composition

The fat content in achenes was higher in 2021 compared to 2020. The higher nitrogen dose increased the protein content in achenes compared to the lower dose. The protein content was also increased by double foliar fertilization. The ash content was not modified by the experimental factor. However, the fiber content was higher after fertilization with 60 kg N ha^{-1} (variant A) compared to variant F (Table 5).

Table 5. Chemical composition of achenes in % DM.

Factor	Fat	Protein	Ash	Fiber
		Fertilization		
A	46.61 ± 0.66	14.45 ± 0.56 ^{d}	4.20 ± 0.16	15.04 ^{a}
B	46.47 ± 0.81	15.02 ± 0.83 ^{b}	4.28 ± 0.19	14.71 ^{ab}
C	46.83 ± 1.03	14.70 ± 0.63 ^{cd}	4.32 ± 0.16	14.85 ^{ab}
D	46.72 ± 1.21	15.07 ± 0.81 ^{b}	4.34 ± 0.12	14.44 ^{ab}
E	46.43 ± 0.99	14.93 ± 0.66 ^{bc}	4.35 ± 0.13	14.62 ^{ab}
F	46.31 ± 1.32	15.40 ± 0.71 ^{a}	4.36 ± 0.11	14.24 ^{b}
		Years		
2020	46.06 ± 0.76 ^{b}	14.91 ± 0.66	4.29 ± 0.15	14.56 ± 0.35
2021	47.08 ± 0.94 ^{a}	14.86 ± 0.78	4.33 ± 0.14	14.74 ± 0.38

A–F—variants of fertilization. Results are expressed as mean value ± standard deviations. Different letters in the same column indicate significant differences (p < 0.05) according to the analysis of variance (ANOVA).

3.5. Fat and Protein Yield

In 2021, nitrogen fertilization with double foliar spraying significantly increased the fat yield compared to variants A and B. The use of nitrogen with a single foliar fertilization also increased the fat yield, but only compared to the 60 kg N ha^{-1} dose. In 2020, fat yield varied less between fertilization variants. It was only shown that nitrogen fertilization with a single micronutrient spraying had a more favorable effect on the fat yield in relation to the dose of 60 kg N ha^{-1} (Figure 7).

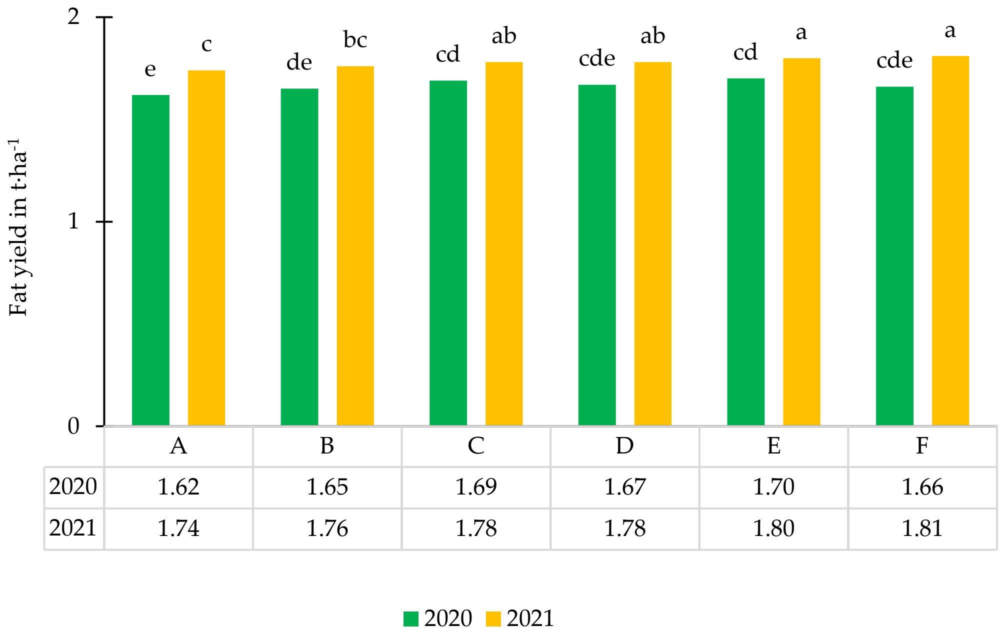
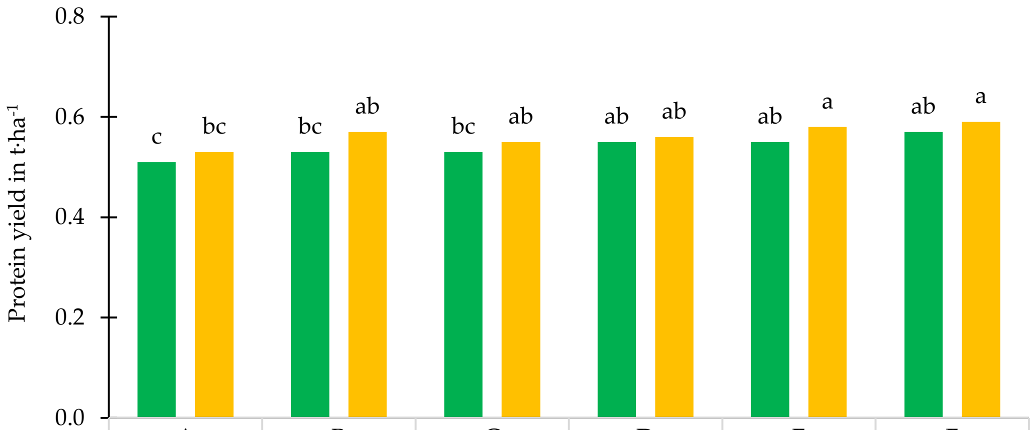


Figure 7. Fat yield in t·ha^{-1}. A–F—variants of fertilization. Different lowercase letters indicate significant differences (p < 0.05) according to the analysis of variance (ANOVA).

In 2021, nitrogen fertilization together with double foliar fertilization significantly increased the protein yield compared to variants A and B. In 2020, it was shown that more intensive fertilization (variants D, E and F) showed a better effect on the protein yield compared to the 60 kg N ha^{-1} dose (Figure 8). Therefore, it should be concluded that the effect of fertilization on sunflower yielding is modified by weather conditions. This, in turn, determines the profitability of the applied fertilization.



	A	B	C	D	E	F
2020	0.51	0.53	0.53	0.55	0.55	0.57
2021	0.53	0.57	0.55	0.56	0.58	0.59

2020 2021

Figure 8. Protein yield in t·ha^{-1}. A–F—variants of fertilization. Different lowercase letters indicate significant differences ($p < 0.05$) according to the analysis of variance (ANOVA).

3.6. Economic Results

The result of economic calculations showed that the best option was nitrogen fertilization at a dose of 60 kg ha^{-1} in combination with double foliar fertilization. Variants C and A also provided good results. The use of 90 kg N ha^{-1} was the least profitable, which was related to the obtained yield and the high price of nitrogen fertilizer (Table 6).

Table 6. Economic result of the applied fertilization per 1 ha.

Fertilization	Mean Yield (t·ha^{-1})	Mean Yield (EUR·ha^{-1})	Fertilization Cost (EUR·ha^{-1})	Economic Result (EUR·ha^{-1})
A	3.61	1976.01	133.80	1842.21
B	3.68	2014.32	200.70	1813.62
C	3.70	2025.27	151.63	1873.64
D	3.69	2019.80	218.53	1801.27
E	3.77	2063.58	169.46	1894.12
F	3.74	2047.16	236.36	1810.80

4. Discussion

Weather conditions varied in the years of the study, which modified the effectiveness of the applied fertilization (Figure 1). The mean difference in achene yields between 2020 and 2021 was 0.16 t ha^{-1}. Fatahi et al. [60] have stated that sunflower requires optimal precipitation and air temperature for proper growth and development. These factors modify both the size and quality of the achene yield. Černý et al. [61] showed that a moderate precipitation and higher temperature had the most beneficial effect on the sunflower yield. Hlisnikovský et al. [6] confirmed that achene and biomass yields were mainly influenced by weather conditions in each year. Ahmad et al. [62] demonstrated that sunflower is a drought-resistant plant, but a long-term lack of water always reduces the yield. Mahpara et al. [63] argued that drought tolerance of plants could be increased by soil or foliar nitrogen fertilization. In turn, Neves et al. [64] reported that fertilization with Si and B reduced the effect of water deficit in sunflower cultivation.

In the present study, the height of sunflower plants ranged from 158.75 to 172.22 cm. Fertilization in the dose of 90 kg N ha^{-1} increased plant height in relation to 60 kg N ha^{-1}. In the experiment of Sher et al. [7], the height of the sunflower plants ranged from 106 to 187 cm. It depended on the variety and was modified by variable irrigation. Lakshman et al. [65] reported that the average height of sunflower plants was 120.1 cm.

The applied fertilization variants significantly Increased head diameter, but no differences in this parameter were proven between the years. The number of achenes in the head was dependent on the interaction of fertilization with the years of the study. Sher et al. [7] showed that the head diameter ranged from 10.9 to 18.3 cm and significantly varied over the years. In a study of Ravikumar et al. [66], the diameter of the head and the number of achenes in the head were significantly increased by fertilization with sulfur, boron and zinc. Sher et al. [7] showed that the TAW of sunflower ranged from 46.4 g to 89.7 g, which resulted from both varietal differences and study years. Lakshman et al. [2] proved that yield, its individual components and oil content in achenes mainly depended on sunflower variety.

A higher dose of nitrogen had a positive effect on the growth and nutritional status of plants. This was confirmed by the measurements of the LAI and SPAD indices. When nitrogen fertilization was combined with double foliar fertilization, a further increase in the SPAD index was noted. The obtained SPAD results varied over the years, which confirmed that the effectiveness of foliar spraying depended on the weather. Dastorani et al. [67] and Takács et al. [68] have demonstrated that modern measurement techniques enrich the outcome of agricultural experiments compared to traditional methods. Sher et al. [7] obtained significantly lower SPAD measurements for sunflower and mostly non-significant differences between the variants tested. Li et al. [8] reported that irrigation and optimal fertilization of sunflower had a positive effect on the nutritional status of the plants. This was confirmed by physiological measurements, including the SPAD index. Ravikumar et al. [66] showed that the LAI index increased under the influence of soil fertilization with NPKS and foliar fertilization with B and Zn. Al-Amery et al. [39] and Andrade et al. [47] proved that the biometric traits evaluated, including leaf area, were significantly affected by boron fertilization. Hussein et al. [69] reported that sunflower responded favorably to fertilization with macro- and micronutrients. They confirmed the effects of fertilization with plant measurements, such as the LAI or SPAD indices. In turn, Joergensen et al. [70] reported that measuring the δ15N value in sunflower samples was a useful but not ideal tool for detecting fraudulent inorganic nitrogen fertilization on organic farms.

The yield of sunflower achenes ranged from 3.5 to 3.85 t ha^{-1}, which was a good result. In agricultural practice, sunflower yields range from 2.5 to 3 t ha^{-1}. In the first year of the research, nitrogen fertilization in combination with double foliar fertilization increased the achene yield compared to the 60 kg N ha^{-1} dose. This result was not statistically confirmed in the second year of the study. Sher et al. [7] obtained a lower sunflower yield from 1.6 to 2.7 t ha^{-1}. These authors also showed yield variation in one year, while in the following year, there were no significant differences. Dastorani et al. [67] reported that sunflower yielded high from 3.5 to 4.6 t ha^{-1}, depending on plantation irrigation. Ravikumar et al. [66] proved that NPKS fertilization together with foliar application of B and Zn significantly increased the yield of sunflower achenes and straw compared to NPK fertilization.

In the present experiment, variants with more intensive fertilization reduced the percentage of hull in sunflower achenes. The results, however, depended on the year of the study. Lindström et al. [71] reported that removal of the hull (pericarp) in sunflower (*Helianthus annuus* L.) reduced fiber and increased protein in seed meals. Thus, high hullability (H), the ease with which the pericarp is mechanically separated from the seed (kernel), is desirable.

The applied fertilization variants modified the protein and fiber content of sunflower achenes. It was shown that a higher dose of nitrogen increased the protein content of the seeds, but had no effect on fat content. Sher et al. [7] showed significant differences in fat content in sunflower achenes and protein content was more stable. Göçmen et al. [72] report that the fat content varies between 38.93% and 41.81%. Mehmood et al. [73] showed that nitrogen increased the protein content of sunflower achenes and lowered the fat content. They proved that fat content was positively affected by boron fertilization. Shehzad et al. [36] confirmed that nitrogen and boron fertilization resulted in a significant decrease in fat content and an increase in protein in sunflower achenes.

In the second year of the study, fat yield was most favorably affected by nitrogen fertilization combined with foliar fertilization, compared to fertilization only with nitrogen. As a result, each variant yielded about 1.8 t ha^{-1} of crude fat. In a study of Dastorani et al. [67], fat yields ranged from 1.44 to 1.77 t ha^{-1}. Carvalho et al. [74] showed that fat yield depended on the variety and years of study. On average, they obtained yields between 0.87 and 1.14 t ha^{-1} of fat, which mainly depended on plantation irrigation.

The calculations showed that the optimal option was to apply a dose of 60 kg N ha^{-1} together with double foliar fertilization. Fertilization with 60 kg N ha^{-1} with a single foliar application also gave satisfactory results. The use of 90 kg N ha^{-1} was the least cost-effective in each variant, based on the yield obtained and the cost of nitrogen fertilizer. Similar results were obtained by Hlisnikovský et al. [6], who showed that fertilization at a dose of 60 kg N ha^{-1} was sufficient for sunflower. In contrast, they considered fertilization with B, Zn and Mo unnecessary when the soil was rich in these micronutrients. Ribeiro and Raiher [75] reported that fertilizer costs and yield had a decisive impact on the economic outcome of sunflower cultivation. Souza et al. [25] showed that higher nitrogen doses (0, 30, 60, 90 and 120 kg ha^{-1}) were economically justified. They obtained a return of the costs incurred even at the dose of 120 kg ha^{-1}, but only for two sunflower varieties. Sheoran et al. [76] proved that fertilization with macro- and micronutrients (NPK, S, Zn, B) was economically justified in relation to NPK. This was confirmed by higher production efficiency (4.7–8.0%) and profitability (0.50–0.97 USD/ha/day). Mehmood et al. [73] showed that fertilization with nitrogen (150 kg ha^{-1}) and boron (2 kg ha^{-1}) resulted in maximum net income and the benefit/cost ratio. Shehzad and Maqsood [36] reported that nitrogen and boron fertilization resulted in varied economic effects. They depended mainly on the dose and proportion of the ingredients used.

5. Conclusions

Weather conditions varied during the study years, which modified the results of several studied parameters, including the yield of achenes, fat and protein. A higher dose of nitrogen had a positive effect on the growth and nutritional status of plants. This was confirmed by higher LAI, SPAD, yield components and protein content in achenes compared to the lower nitrogen dose. Foliar fertilization, especially double spraying, resulted in better plant nutrition (SPAD) and an increase in the head diameter, number of achenes in the head, TAW and protein content in achenes. The applied fertilization variants modified the yield of achenes only in 2020. At that time, it was shown that the yield was higher after application of nitrogen fertilization in combination with two foliar sprayings. Significantly lower yields were obtained after applying a dose of 60 kg N ha^{-1}. The fat content of achenes varied between the years, reaching 46.06% DM in 2020 and 47.08% DM in 2021. Economic calculations showed that the best option was nitrogen fertilization at a dose of 60 kg ha^{-1} in combination with double foliar fertilization. The application of the 90 kg N ha^{-1} dose in each variant was less profitable. Optimal doses of fertilizers improve the size and quality of the sunflower yield. In addition, they determine the profitability of cultivation. Therefore, research in this area should be continued.

Funding: This research received no external funding.

Data Availability Statement: The data presented in this study are available upon request from the author.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Ailwar, B.P.; Ghodke, M.K.; Tathe, R.G. Heterosis for yield and yield contributing traits in sunflower (*Helianthus annuus* L.). *Electron. J. Plant Breed.* **2020**, *11*, 950–953. [CrossRef]
2. Lakshman, S.S.; Chakrabarty, N.R.; Kole, P.C. Economic heterosis in sunflower (*Helianthus annuus* L.): Seed yield and yield attributing traits in newly developed hybrids. *Electron. J. Plant Breed.* **2020**, *11*, 461–468. [CrossRef]
3. Tangyu, M.; Fritz, M.; Ye, L.; Börner, R.A.; Morin-Rivron, D.; Campos-Giménez, E.; Bolten, C.J.; Bogicevi, B.; Wittmann, C. Co-cultures of *Propionibacterium freudenreichii* and *Bacillus amyloliquefaciens* cooperatively upgrade sunflower seed milk to high levels of vitamin B_{12} and multiple co-benefits. *Microb. Cell Fact.* **2022**, *21*, 48. [CrossRef] [PubMed]
4. Dilipkumar, P. Chapter 130-Sunflower (*Helianthus annuus* L.) seeds in health and nutrition. In *Patel, Nuts and Seeds in Health and Disease Prevention*; Victor, R., Preedy, R.R.W., Vinood, B., Eds.; Academic Press: Cambridge, MA, USA, 2011; pp. 1097–1105. [CrossRef]
5. Zeinalzadeh-Tabrizi, H.; Hosseinpour, A.; Ghaffari, M.; Haliloglu, K. Genetic structure and marker-trait associations in parental lines of sunflower (*Helianthus annuus* L.). *Iran. J. Plant Physiol.* **2022**, *12*, 3955–3971. [CrossRef]
6. Hlisnikovský, L.; Kunzová, E.; Hejcman, M.; Škarpa, P.; Menšík, L. Effect of nitrogen, boron, zinc and molybdenum application on yield of sunflower (*Helianthus annuus* L.) on greyic phaeozem in the Czech Republic. *Helia* **2016**, *39*, 91–111. [CrossRef]
7. Sher, A.; Suleman, M.; Sattar, A.; Qayyum, A.; Ijaz, M.; Sami-Ul Allah, A.-Y.R.; Al-Hashimi, A.; Elshikh, M.S. Achene yield and oil quality of diverse sunflower (*Helianthus annuus* L.) hybrids are affected by different irrigation sources. *J. King Saud Univ. Sci.* **2022**, *34*, 102016. [CrossRef]
8. Li, Z.; Fontanier, C.; Dunn, B.L. Physiological response of potted sunflower (*Helianthus annuus* L.) to precision irrigation and fertilizer. *Sci. Hortic.* **2020**, *270*, 109417. [CrossRef]
9. Watanabe, T.; Okada, R.; Urayama, M. Differences in ionomic responses to nutrient deficiencies among plant species under field conditions. *J. Plant Nutr.* **2022**, *45*, 1493–1503. [CrossRef]
10. Hammad, H.; Tahir, M.A.; Sabah, N.U.; Sarwar, G.; Aftab, M.; Manzoor, M.Z.; Riaz, A.; Niaz, A.; Arif, M. Phosphorus utilization efficiency by sunflower (*Helianthus annuus* L.) from sparingly soluble P source under P deficient environment. *Pak. J. Agric. Res.* **2021**, *34*, 294–299. [CrossRef]
11. Kováčik, P.; Kozánek, M.; Takáč, P.; Galliková, M.; Varga, L. The effect of pig manure fermented by larvae of house flies on the yield parameters of sunflowers (*Helianthus annus* L.). *Acta Univ. Agric. Silvic. Mendel. Brun.* **2010**, *58*, 147–154. [CrossRef]
12. Mokgolo, M.J.; Mzezewa, J.; Odhiambo, J.J.O. Poultry and cattle manure effects on sunflower performance, grain yield and selected soil properties in Limpopo Province, South Africa. *S. Afr. J. Sci.* **2019**, *115*, 6. [CrossRef]
13. Sharma, K.L.; Neelaveni, K.; Katyal, J.C.; Srinivasa Raju, A.; Srinivas, K.; Kusuma Grace, J. Effect of combined use of organic and inorganic sources of nutrients ons yield, soil fertility, and overall soil quality in rainfed alfisol. *Commun. Soil Sci. Plant Anal.* **2008**, *39*, 1791–1831. [CrossRef]
14. Soleymani, F.; Ahmadvand, G.; Safari Sanjani, A.A. The effect of chemical, biological and organic nutritional treatments on sunflowers yield and yield components under the influence of water deficit stress. *J. Agroecol.* **2016**, *8*, 107–119. [CrossRef]
15. Oshundiya, F.O.; Olowe, V.I.O.; Sowemimo, F.A.; Odedina, J.N. Seed yield and quality of sunflower (*Helianthus annuus* L.) as influenced by staggered sowing and organic fertilizer application in the humid tropics. *Helia* **2014**, *37*, 237–255. [CrossRef]
16. Sefaoglu, F.; Ozturk, H.; Ozturk, E.; Sezek, M.; Toktay, Z.; Polat, T. Effect of organic and inorganic fertilizers, or their combinations on yield and quality components of oil seed sunflower in a semi-arid environment. *Turk. J. Field Crops* **2021**, *26*, 88–95. [CrossRef]
17. Rocha, J.G.; Alves, L.S.; Tavares, O.C.H.; Stark, E.M.L.M.; Fernandes, M.S.; Castro, R.N.; Santos, A.M.; Souza, S.R. Metabolic characterization and oil profile of sunflower cultivars cultivated with increasing nitrogen doses. *Biosci. J.* **2020**, *36*, 266–279. [CrossRef]
18. Oyinlola, E.Y.; Ogunwole, J.O.; Amapu, I.Y. Response of sunflower (*Helianthus annuus* L.) to nitrogen application in a savanna alfisol. *Helia* **2010**, *33*, 115–126. [CrossRef]
19. Ahmad, M.I.; Ali, A.; He, L.; Latif, A.; Abbas, A.; Ahmad, J.; Ahmad, M.Z.; Asghar, W.; Bilal, M.; Mahmood, M.T. Nitrogen effects on sunflower growth: A review. *Int. J. Biosci.* **2018**, *12*, 91–101.
20. Sincik, M.; Goksoy, A.T.; Dogan, R. Responses of sunflower (*Helianthus annuus* L.) to irrigationand nitrogen fertilization rates. *Zemdirb.-Agric.* **2013**, *100*, 151–158. [CrossRef]
21. Kandil, A.A.; Sharief, A.E.; Odam, A.M.A. Response of some sunflower hybrids (*Helianthus annuus* L.) to different nitrogen fertilizer rates and plant densities. *Int. J. Environ. Agric. Biotechnol.* **2017**, *2*, 2978–2994. [CrossRef]
22. Zeng, W.Z.; Xu, C.; Wu, J.W.; Huang, J.S.; Zhao, Q.; Wu, M.S. Impacts of salinity and nitrogen on the photosynthetic rate and growth of sunflowers (*Helianthus annuus* L.). *Pedosphere* **2014**, *24*, 635–644. [CrossRef]
23. Zeng, W.; Xu, C.; Huang, J.; Wu, J.; Ma, T. Emergence rate, yield, and nitrogen-Use efficiency of sunflowers (*Helianthus annuus*) vary with soil salinity and amount of nitrogen applied. *Commun. Soil Sci. Plant Anal.* **2015**, *46*, 1006–1023. [CrossRef]
24. Ozturk, E.; Polat, T.; Sezek, M. The effect of sowing date and nitrogen fertilizer form on growth, yield and yield components in sunflower. *Turk. J. Field Crops* **2017**, *22*, 143–151. [CrossRef]
25. Souza, A.R.E.; Souza, Ê.G.F.; Tartaglia, F.L.; Santos, A.P.; Barros Júnior, A.P.; Silveira, L.M.; Bezerra Neto, F.; Santos, M.G. Economic indicators of nitrogen fertilization in sunflower cultivars. *Biosci. J.* **2020**, *36*, 1938–1950. [CrossRef]
26. Eltarabily, M.G.; Burke, J.M.; Bali, K.M. Effect of deficit irrigation on nitrogen uptake of sunflower in the low desert region of California. *Water* **2019**, *11*, 2340. [CrossRef]

27. Soleymani, A. Light response of sunflower and canola as affected by plant density, plant genotype and N fertilization. *J. Photochem. Photobiol. B Biol.* **2017**, *173*, 580–588. [CrossRef] [PubMed]
28. Qadeer, A.; Tahir, M.M.; Abbasi, M.K.; Ali, A.; Rasheed, A. Morphological and phenological responses of sunflower to nitrogen fertilization and plant growth promoting rhizobacteria under rainfed conditions in Pakistan: Morpho-phenological responses of sunflower to plant growth promoting rhizobacteria and nitrogen. *Proc. Pak. Acad. Sci. B Life Environ. Sci.* **2021**, *56*, 41–48. Available online: https://ppaspk.org/index.php/PPAS-B/article/view/184 (accessed on 28 July 2022).
29. Travlos, I.; Papastylianou, P.; Alexos, A.; Kanatas, P.; Bilalis, D.; Tsekoura, A.; Kakabouki, I.; Cheimona, N. Changes of weed flora due to nitrogen addition in sunflower. *Not. Bot. Horti Agrobot. Cluj-Napoca* **2019**, *47*, 1337–1339. [CrossRef]
30. Hajduk, E.; Gąsior, J.; Właśniewski, S.; Nazarkiewicz, M.; Kaniuczak, J. Influence of liming and mineral fertilization on the yield and boron content of potato tubers (*Solanum tuberosum* L.) and green mass of fodder sunflower (*Helianthus annuus* L.) cultivated in loess soil. *J. Elem.* **2017**, *22*, 411–426. [CrossRef]
31. Alves, L.S.; Stark, E.M.L.M.; Zonta, E.; Fernandes, M.S.; Santos, A.M.; Souza, S.R. Different nitrogen and boron levels influence the grain production and oil content of a sunflower cultivar. *Acta Sci. Agron.* **2017**, *39*, 59–66. [CrossRef]
32. Alipatra, A.; Banerjee, H.; Bhattacharyya, K.; Bandopadhyay, P.; Ray, K. Yield and quality of hybrid sunflower (*Helianthus annuus*) as affected by irrigation and fertilization. *Indian J. Agric. Sci.* **2019**, *89*, 1419–1424.
33. Gomes, K.R.; Viana, T.V.; Sousa, A.; Costa, G.G.; Azevedo, F.R.B. Irrigation and organic and mineral fertilization in sunflower crop. *Comun. Sci.* **2018**, *8*, 356–366. [CrossRef]
34. Milev, G. Effect of foliar fertilization on sunflower (*Helianhtus annuus* L.). *Agric. Sci. Technol.* **2015**, *7*, 324–327.
35. El-Din Mekki, B. Effect of boron foliar application on yield and quality of some sunflower (*Helianthus annuus* L.) cultivars. *J. Agric. Sci. Technol.* **2015**, *5*, 309–316. [CrossRef]
36. Shehzad, M.A.; Maqsood, M. Integrated nitrogen and boron fertilization improves the productivity and oil quality of sunflower grown in a calcareous soil. Turk. *J. Field Crops* **2015**, *20*, 213–222. [CrossRef]
37. Shehzad, M.A.; Maqsood, M.; Wajid, S.A.; Anwar-ul-Haq, M. Dry matter partitioning and mineral constitution response of sunflower (*Helianthus annuus*) to integrated nitrogen and boron nutrition in calcareous soils. *Int. J. Agric. Biol.* **2016**, *18*, 257–265. [CrossRef]
38. Bozca, F.D.; Leblebici, S. Interactive effect of boric acid and temperature stress on phenological characteristics and antioxidant system in *Helianthus annuus* L. *S. Afr. J. Bot.* **2022**, *147*, 391–399. [CrossRef]
39. Al-Amery, M.M.; Hamza, J.H.; Fuller, M.P. Effect of boron foliar application on reproductive growth of sunflower (*Helianthus annuus* L.). *Int. J. Agron.* **2011**, *230712*, 1–5. [CrossRef]
40. Khalid, D.; Saad, D.; Kacem, M.; Ezzahra, N.F.; Fouad, A.; Abdelhadi, A.H. Sunflower response to Boron supply when grown in a silty clay soil. *J. Saudi Soc. Agric. Sci.* **2020**, *19*, 81–86. [CrossRef]
41. Asad, A.; Blamey, F.P.C.; Edwards, D.G. Effects of boron foliar applications on vegetative and reproductive growth of sunflower. *Ann. Bot.* **2003**, *92*, 565–570. [CrossRef]
42. Ekmekçi, Y.; Erdal, Ş.Ç.; Nalçaiyi, A.S.B.; Çiçek, N. Acquisition of boron tolerance by salt pretreatment in two sunflower cultivars. *Turk. J. Bot.* **2020**, *44*, 4. [CrossRef]
43. Fernández, V.; Brown, P.H. From plant surface to plant metabolism: The uncertain fate of foliar-applied nutrients. *Front. Plant Sci.* **2013**, *4*, 289. [CrossRef] [PubMed]
44. Brown, P.H.; Shelp, B. Boron mobility in plants. *Plant Soil* **1997**, *193*, 85–101. [CrossRef]
45. Baraich, A.A.K.; Gandahi, A.W.; Tunio, S.; Chachar, Q. Influence of micronutrients and their method of application on yield and yield components of sunflower. *Pak. J. Bot.* **2016**, *48*, 1925–1932.
46. Bhattacharyya, K.; Mandal, J.; Banerjee, H.; Alipatra, A.; Ray, K.; Phonglosa, A. Boron fertilization in sunflower (*Helianthus annuus* L.) in an Inceptisol of West Bengal, India. *Commun. Soil Sci. Plant Anal.* **2015**, *46*, 528–544. [CrossRef]
47. Andrade, A.F.; Vicosi, K.A.; Bueno, A.M.; Flores, R.A.; Santos, C.L.R.; Santos, G.G.; Mesquita, M. Nutritional and biomass aspects of *Helianthus annuus* according to boron application in the soil. *Aust. J. Crop Sci.* **2021**, *15*, 899–908. [CrossRef]
48. Singh, D.B.; Sharma, P.K.; Sanjula, S. Oil yield and fatty acid profile of staggered sown spring sunflower (*Helianthus annuus* L.) in response to foliar application of boron and tiba. *Appl. Biol. Res.* **2017**, *19*, 156–163. [CrossRef]
49. Khan, I.; Ahmad Anjum, S.; Khan Qardri, R.W.; Ali, M.; Umer Chattha, M.; Asif, M. Boosting achene yield and yield related traits of sunflower hybrids through boron application strategies. *Am. J. Plant Sci.* **2015**, *6*, 1752–1759. [CrossRef]
50. Pattanayak, S.; Behera, A.K.; Das, P.; Nayak, M.R.; Jena, S.N.; Behera, S. Performance of summer sunflower (*Helianthus annuus* L.) hybrids under different nutrient management practices in coastal Odisha. *J. Appl. Nat. Sci.* **2017**, *9*, 435–440. [CrossRef]
51. Kumar, A.; Tripti, M.M.; Bruno, L.B.; Rajkumar, M. Synergistic effect of ACC deaminase producing *Pseudomonas* sp. TR15a and siderophore producing *Bacillus aerophilus* TR15c for enhanced growth and copper accumulation in *Helianthus annuus* L. *Chemosphere* **2021**, *276*, 130038. [CrossRef]
52. Hajduk, E.; Nazarkiewicz, M.; Gąsior, J.; Właśniewski, S.; Kaniuczak, J. Effect of fertilization on the Mo content in potato tubers (*Solanum tuberosum* L) and sunflower biomass (Helianthus annuus L.) cultivated on a Luvisol formed from loess. *J. Elem.* **2020**, *25*, 1115–1126. [CrossRef]
53. Steiner, F.; Zoz, T. Foliar application of molybdenum improves nitrogen uptake and yield of sunflower. *Afr. J. Agric. Res.* **2015**, *10*, 1923–1928. [CrossRef]

54. Škarpa, P.; Kunzová, E.; Zukalová, H. Foliar fertilization with molybdenum in sunflower (*Helianthus annuus* L.). *Plant Soil Environ.* **2013**, *59*, 156–161. [CrossRef]
55. Li, C.; Wang, L.; Wu, J.; Blamey, F.P.C.; Wang, N.; Chen, Y.; Ye, Y.; Wang, L.; Paterson, D.J.; Read, T.L.; et al. Translocation of foliar absorbed Zn in sunflower (*Helianthus annuus*) leaves. *Front. Plant Sci.* **2022**, *13*, 757048. [CrossRef] [PubMed]
56. Kandhro, M.N.; Abbasi, Z.A.; Soomro, A.A.; Leghari, N.; Keerio, M.I.; Shah, A.N.; Jamro, G.M.; Mangrio, N.; Tunio, S.P. Evaluation of irrigation frequencies and seed priming with plant nutrients on growth and yield of sunflower (*Helianthus annuus* L.) genotypes. *Pak. J. Agric. Res.* **2021**, *34*, 58–69. [CrossRef]
57. Li, C.; Wang, P.; Menzies, N.W.; Lombi, E.; Kopittke, P.M. Effects of changes in leaf properties mediated by methyl jasmonate (MeJA) on foliar absorption of Zn, Mn and Fe. *Ann. Bot.* **2017**, *120*, 405–415. [CrossRef]
58. Li, C.; Wang, P.; Lombi, E.; Wu, J.; Blamey, F.P.C.; Fernández, V.; Howard, D.L.; Menzies, N.W.; Kopittke, P.M. Absorption of foliar applied Zn is decreased in Zn deficient sunflower (*Helianthus annuus*) due to changes in leaf properties. *Plant Soil* **2018**, *433*, 309–322. [CrossRef]
59. IUSS Working Group WRB. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps. In *Word Reference Base for Soil Resources 2014, Update 2015*; Word Soil Resources Reports No. 106; FAO: Rome, Italy, 2015; p. 192.
60. Fatahi, A.; Safarian Zengir, V.; Sobhani, B.; Kianian, M.K.; Ghahremani, A. Assessment and zoning of suitable climate for economic development of cultivation of Sunflower (*Helianthus annuus*) garden crop (Ardabil Province, Iran). *Eur. J. Hortic. Sci.* **2022**, *87*, 1–12. [CrossRef]
61. Černý, I.; Veverková, A.; Kovár, M.; Mátyás, M. The variability of sunflower (*Helianthus annuus* L.) yield and quality influenced by the weather conditions. *Acta Univ. Agric. Silvic. Mendel. Brun.* **2013**, *61*, 595–600. [CrossRef]
62. Ahmad, H.M.; Wang, X.; Ur-Rahman, M.; Fiaz, S.; Azeem, F.; Shaheen, T. Morphological and physiological response of *Helianthus annuus* L. to drought stress and correlation of wax contents for drought tolerance traits. *Arab. J. Sci. Eng.* **2022**, *47*, 6747–6761. [CrossRef]
63. Mahpara, S.; Shahnawaz, M.; Rehman, K.; Qaisarani, T.B.; Ahmad, R.; Khan, F.U. Nitrogen fertilization induced drought tolerance in sunflower: A review. *Pure Appl. Biol.* **2019**, *8*, 1675–1683. [CrossRef]
64. Neves, J.M.G.; Aquino, L.A.; Berger, P.G.; Neves, J.C.L.; Rocha, G.C.; Barbosa, E.A. Silicon and boron mitigate the effects of water deficit on sunflower. *Rev. Bras. Eng. Agríc. Ambient.* **2019**, *23*, 175–182. [CrossRef]
65. Lakshman, J.S.S.; Ghotke, M.K.; Kar, J. Estimation of economic heterosis for seed and oil yield in sunflower (*Helianthus annuus* L.) hybrids for coastal saline belt. *Electron. J. Plant Breed.* **2021**, *12*, 335–341. [CrossRef]
66. Ravikumar, C.; Karthikeyan, A.; Senthilvalavan, P.; Manivannan, R. Effect of sulphur, zinc and boron on the growth and yield enhancement of sunflower (*Helianthus annuus* L.). *J. Appl. Nat. Sci.* **2021**, *13*, 295–300. [CrossRef]
67. Dastorani, M.; Albaji, M.; Nasab, S.B. Crop response and water productivity of sunflower (*Helianthus annuus* L.) drip-irrigated with magnetically treated and non-magnetically treated water with variable salinity. *Water SA* **2022**, *48*, 90–96. [CrossRef]
68. Takács, P.; Kovács, Z.; Száz, D.; Egri, Á.; Bernáth, B.; Slíz-Balogh, J.; Nagy-Czirok, M.; Lengyel, Z.; Horváth, G. Mature sunflower inflorescences face geographical east to maximize absorbed light energy: Orientation of *Helianthus annuus* heads studied by drone photography. *Front. Plant Sci.* **2022**, *13*, 842560. [CrossRef]
69. Al Myali, A.A.H.; Alnuaimi, J.J.J.; Hussain, M.H. Effect of bio-fertilizer, organic manure, nano zinc oxid and interaction on the growth parameters for sunflower plant *Helianthus annuus* L. *J. Kerbala Agric. Sci.* **2020**, *7*, 1–19.
70. Joergensen, R.G.; Toncea, I.; Boner, M.; Heß, J. Evaluation of organic sunflower fertilization using δ^{15}N values. *Org. Agric.* **2019**, *9*, 365–372. [CrossRef]
71. Lindström, L.I.; Franchini, M.C.; Nolasco, S.M. Sunflower fruit hullability and structure as affected by genotype, environment and canopy shading. *Ann. Appl. Biol.* **2022**, *180*, 338–347. [CrossRef]
72. Göçmen, E.; Salbaş, B.; Erdem, T. Effects of different irrigation regimes on seed yield, oil content and fatty acid quality of the sunflower in Thrace region. *Turkey. J. Elem.* **2022**, *27*, 597–609. [CrossRef]
73. Mehmood, A.; Saleem, M.F.; Tahir, M.; Sarwar, M.A.; Abbas, T.; Zohaib, A.; Abbas, H.T. Sunflower (*Helianthus annuus* L.) growth, yield and oil quality response to combined application of nitrogen and boron. *Pak. J. Agric. Res.* **2018**, *31*, 86–97. [CrossRef]
74. Carvalho, L.M.; Carvalho, H.W.L.; Carvalho, C.G.P. Yield and photosynthetic attributes of sunflower cultivars grown under supplemental irrigation in the semiarid region of the Brazilian Northeast. *Pesqui. Agropecu. Bras.* **2020**, *55*, e01715. [CrossRef]
75. Ribeiro, M.F.S.; Raiher, A.P. Economic performance of sunflower in family farming systems of southeastern Paraná, southern Brazil. *Ciênc. Rural* **2013**, *43*, 786–791. [CrossRef]
76. Sheoran, P.; Sardana, V.; Chander, S.; Kumar, A.; Meena, M.D.; Bali, A.; Sharma, P. Sulphur, boron and zinc nutrition to improve productivity, profitability and oil quality in sunflower (*Helianthus annuus*). *Indian J. Agric. Sci.* **2018**, *88*, 1746–1754.