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The Impact of Foliar Fertilization on the Physiological Parameters, Yield, and Quality Indices of the Soybean Crop

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Abstract: Presented research was carried out in 2021 and 2022 on the Felix soybean variety at the Agricultural Research and Development Station Turda, located in the Transylvanian Plain, Romania. In this experiment, complex fertilizer NPK 20:20:0 was applied as a basic fertilizer in a dose of 200 kg ha^{-1} at the sowing stage, to which foliar fertilizer Agro Argentum Forte treatment was added in different doses and at different application stages. The main purpose of the study was to identify the suitable stages of foliar application in soybean cultivation for effective vegetative development, yield, and quality purposes. The impacts of the fertilization system and the climatic conditions on the physiological parameters, assimilation, yield, and quality were evaluated. Technology showed that the physiological parameters were positively influenced, following the foliar fertilization with Agro Argentum Forte, with average assimilation values recorded above 23.0 µmol CO_2 m^{-2}s^{-1} in the year 2021 and 22.4 µmol CO_2 m^{-2}s^{-1} in the year 2022. Soybean crop was influenced by climatic conditions and the application of foliar fertilizers in different phases of growth and development, obtaining higher yields, as well as higher protein and oil content. The soybean yield and quality indices (protein, oil, and mass of a thousand seeds) were higher in 2021 than in 2022 for the variants treated with foliar fertilizers compared to the control, resulting in an improvement in seed quality in 2021 with a yield of 3560 kg ha^{-1}, while 2022 saw a lower yield of 1805 kg ha^{-1}. The application of basic mineral fertilizers in combination with foliar fertilization had a significantly positive impact on the quality indicators of soybean seeds. The highest yields were achieved when the foliar treatment was applied in the early pod formation stage.

Keywords: soybean; foliar fertilizer; assimilation; yield; quality indices

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1. Introduction

Soybean (*Glycine max* (L.) Merrill) is one of the oldest cultivated plants since Ancient times [1,2], i.e., over 7000 years ago [3], with a very rich nutritional value, and was cultivated in America and Europe from 1739 to 1740 [4–6]. It later appeared in Romania, and then appeared in Transylvania in 1876, expanding widely after 1930 [7].

The Felix soybean variety was created from the early Maple Presto x Merit varieties that originated in North America [8]; it has very good characteristics, is productive, is resistant to falling and shattering, and has a short vegetation period (making it possible to be harvested in mid-September) [7,8], thus making it a very good precursor for other crops [9,10]. An increase in interest in soybean crop is expected in the coming years [11,12], making it the main source of protein and oil worldwide [13–15].

Soybean is considered the "golden plant" of mankind, the "miracle plant", or the "plant of the future" [16], making it one of the most important sources of vegetable proteins [17–19], and it has great agronomical importance given its ability to fix atmospheric nitrogen, following symbiosis with bacteria of the genus Rhizobium [16,20].

The determination of plant physiological processes and assimilation parameters in soybean culture treated with foliar fertilizers is essential for its growth and development, as well as the plant's mass [21], quality, and yield [22]. The maximum intensity of the photosynthesis process in soybean is achieved when the leaves reach their full maturity and maximum size [23], and the stem and pods have a lower respiratory intensity [24].

Foliar fertilization is advantageous in the sense that nutrients are absorbed through the aerial parts of plants, in controlled quantities and at certain stages, as well as from leaves into seeds [25], thus representing an ecological method that can be used to reduce negative impacts on the soil and correct nutritional deficiencies [26]. It can increase soybean yield by obtaining high-quality seeds, thus representing an alternative method of plant nutrition supply [27]. Macro- and micronutrients are important for the growth and development stages of soybean; most of the assimilated nutrients are exported to the seeds [21]. Nitrogen is a macronutrient that is required in large quantities and is supplemented by foliar fertilizers [28], as well as by symbiotic processes. It is considered that nitrogen has a significant impact on the growth and development stages, and is also part of the protein structure [29]. Applying small doses of foliar fertilization is considered a useful strategy to provide additional nitrogen and therefore increase crop yield [16]. Potassium is the most common element in plant tissue; it plays a key role in regulating cellular osmotic potential and activates over 60 enzymes mainly involved in the synthesis of sugars, starches, and proteins [15,29]. However, many authors have reported that high yields with superior quality indices are given both by genetic development and sustainable management practices [8,24,29].

The research hypothesis from which our research states that silver in the composition of Agro Argentum Forte strengthens the immune system and, in combination with nitrogen and potassium, helps optimize and stimulate photosynthesis, aiding plant development and crop yield.

The main purpose of the study was to identify the suitable stages for foliar application in soybean cultivation for the successful vegetative development of crop yield and quality. The impacts of the fertilization system and climatic conditions on physiological parameters, assimilation, yield, and quality were evaluated.

2. Materials and Methods

The studies were carried out over two years, in the period 2021–2022, using the early Felix soybean variety as a biological material, created at Agricultural Research and Development Station Turda, located in the Transylvanian Plain, Romania. Felix soybean variety is a very productive, with high-quality indices, which proved to be quite resistant to drought and high temperatures [7,16]. Experiments were carried out on Faeoziom-type soil [30], with a neutral pH, humus content at a depth of 0–30 cm between 2.14 and 3.12% and clay between 51.8 and 55.5%, and preceding crop was maize.

Fertilization was carried out on a deposit provided with 40 kg ha^{-1} of nitrogen and active phosphorus substance, and sowing (N20:P20:K0-200 kg ha^{-1}) was simultaneously carried out as a basic fertilization, to which foliar fertilizer Agro Argentum Forte treatment was added in different doses and at different application stages. The composition of Agro Argentum Forte foliar fertilizer is as follows: total nitrogen N = 9%, potassium K = 6%, nano-elemental silver Ag = 1%, tri-distilled (vitalized) water H_2O, and a pH value density of 7. The treatment was applied in two different vegetation phases, at the beginning of the pod formation and at the beginning of the seed formation.

The experimental factors are described below.

Factor A—The fertilization system:

a1—basic mineral fertilization NPK (20:20:0);

a2—basic mineral fertilization + foliar fertilization (100 mL ha^{-1} in 500 L of water), in the initial stage of pod formation (50 days after emergence);

a3—basic mineral fertilization + foliar fertilization (100 mL ha^{-1} in 500 L of water), in the initial stage of seed formation (70 days after emergence).

Factor B—The climatic conditions of the two experimental years:

b1—2021;

b2—2022.

The stages for foliar fertilization were established in accordance with the scoring scale used by Fehr and Caviness (1977) [31]. The research methods used were non-destructive (the leaves were not detached from the plant) and were based on the use of the CIRAS-3 foliar gas analyzer, which simultaneously determines several physiological and environmental indicators (PP System, Amesbury, MA, USA) [32].

The measurements of the physiological parameters were carried out under semi-controlled conditions for normal CO_2 r (390 µmol mol^{-1}) and variable PAR (0 to 2000 µmol $m^{-2}s^{-1}$) when the plants entered the final stage of grain formation in the pods (90 days from emergence) with 15 plant $readings^{-1}$ of 5 soybean plants in 3 repetitions in August during the two experimental years. Measurement duration was based on the adaptation time of the tissues in the test chamber and for the analysis of the assimilation (A = µmol CO_2 $m^{-2}s^{-1}$), sub-stomatal CO_2 concentration (Ci = µmol mol^{-1}), stomatal conductance (SC = mmol H_2O $m^{-2}s^{-1}$), transpiration (T = mmol H_2O $m^{-2}s^{-1}$), photosynthetically active internal radiation (PARi = µmol $m^{-2}s^{-1}$), CO_2 reference (CO_2 r = 390 µmol mol^{-1}), leaf-to-air vapor pressure deficit (VPD = kPa), photosynthetic water use efficiency (WUE = mmol CO_2 mol^{-1} H_2O), and leaf temperature (T leaf = °C).

The soybean harvest was separately carried out with the Wintersteiger combined with each repetition in the variant. The soybean yield (seeds) obtained on each experimental lot was weighed and converted to the standard soybean moisture (13%). The quality indices were obtained using the Inframatic 9500 NIR seed analyzer.

The data analysis system was ANOVA—Polyfact soft, version 4 (analysis of variance), with LSD values of 5%, 1%, and 0.1% [33], and the correlations between experimental parameters and observations showed multiple comparisons (Fisher's LSD); thus, the effect of fertilization on the biological development of plants was evaluated.

3. Results

3.1. Climatic Conditions and Impact on Soybean Crop Development

The weather conditions of the two experimental years (2021 and 2022) (Figure 1; Turda Meteorological Station, longitude: 23°47′, latitude: 46°35′) were different, with average monthly temperatures being much higher during the growing season than the multiannual averages taken over the last 65 years, except for 2021, when the average monthly temperature was lower in April and May, with deviations of −2.2 °C and −0.9 °C from the multiannual average, respectively. In the three summer months, higher temperatures were recorded, the warmest being the month of July, with a positive deviation of 2.9 °C, and the month of September had a normal temperature, close to the values specific to the period. The average monthly temperatures during the vegetation period in 2022 varied, with the months of June, July, and August (characterized as warm months) showing values that were higher than the average, with deviations of 2.5–3.5 °C.

From a pluviometric point of view (Figure 2), precipitation during the vegetation period fluctuated in 2021; the lowest amount in June was compared to the average (with a deviation of −39.6 mm), and the highest amount of precipitation was found in July (with a deviation of +45.1 mm).

The soybean crop in the 2021 agricultural year emerged and developed during the vegetation phases; even if the plants suffered due to the drought in June, foliar fertilization had a beneficial effect, and the rainfall in July ensured sufficient water in the soil, determining the progression of the crop in the growth, development, and seed accumulation phases.

Otherwise, the months of August, September, and October were slightly dry, leading to a timely harvest of the crop.

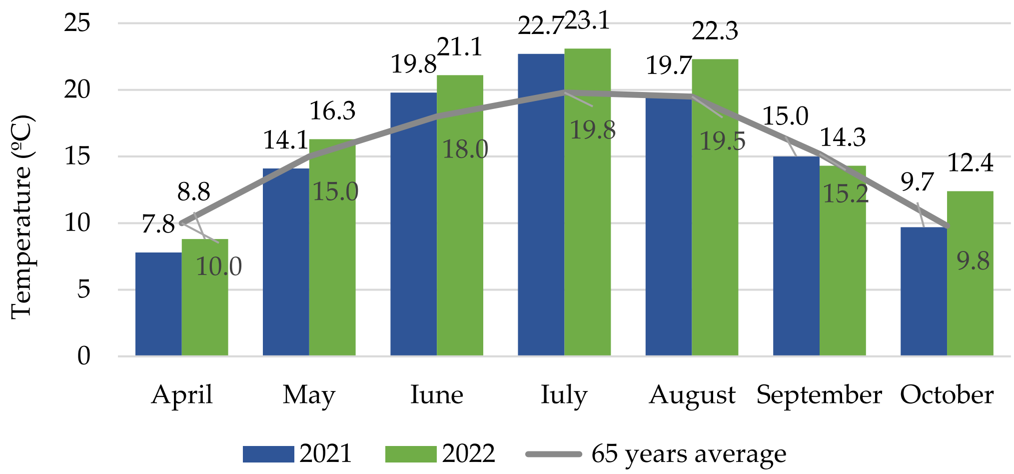

Figure 1. Monthly temperatures (°C) recorded at the Agricultural Research and Development Station Turda during 2021–2022.

The year 2022 was characterized as dry during the vegetation period, and the months of June and July were dry, influencing the flowering process and the beginning of pod formation, respectively, and the months of August and September were excessively rainy, causing difficulties and delaying the harvest period.

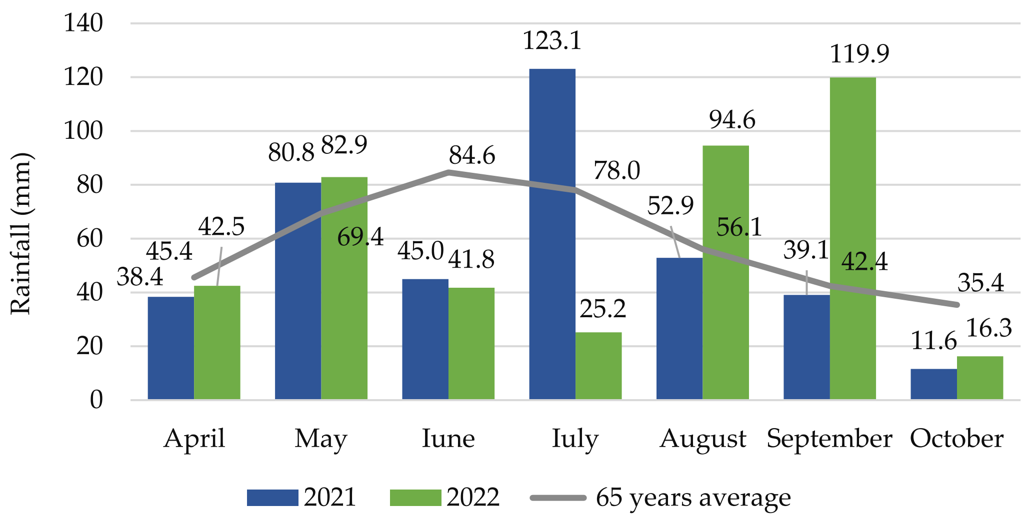

Figure 2. Monthly rainfall (mm) recorded at the Agricultural Research and Development Station Turda during 2021–2022.

3.2. Effect of the Fertilization System and Climatic Conditions on the Physiological Parameters

Foliar fertilization applied to the soybean crop led to a significant increase in the substomatal CO_2 concentration, demonstrating more efficiency in the highest photosynthesis values observed in variants a2 and a3 in the year 2021, and values above 260 µmol mol^{-1} were obtained, as shown in Table 1.

The total stomatal conductance during the transfer (mmol H_2O m^{-2}s^{-1}) from the leaf to the atmosphere was higher in 2021, with values ranging from 455 to 500 mmol H_2O m^{-2}s^{-1}, than in the year 2022, which saw lower values ranging from 191 to 217.5 mmol H_2O m^{-2}s^{-1}.

Transpiration was more intense following the use of variants treated with foliar fertilizer; the year 2021 saw higher values (over 5.7 mmol H_2O m^{-2}s^{-1}) compared to the year 2022. An increase in the photosynthetic water use efficiency (WUE) in soybeans benefited the foliar fertilized variants in both years; in 2021, the values for variants a2 and a3 ranged from 2.77 to 2.93 mmol CO_2 mol^{-1} H_2O, whereas high temperatures and little precipitation were recorded in 2022, with values for variants a2 and a3 ranging from 4.97 to 5.30 mmol CO_2 mol^{-1} H_2O.

The leaf-to-air vapor pressure deficit (VPD) in the soybean crop was lower in the foliar fertilized variants of 2021; the opening of the stomata helped to increase the CO_2 absorption, ranging from 1.23 kPa in the a2 variant to 1.07 kPa in the a3 variant. In the year 2022, i.e., a less favorable year, the VPD was higher than 1.90 kPa in variant a2 and 1.77 kPa in variant a3.

In the year 2021, the plants that received foliar fertilization had a lower vapor pressure deficit in the leaves, which allowed for the increased absorption of CO_2, whereas the year 2022 was less favorable for plant growth and development; due to these unfavorable conditions, the leaf-to-air VPD could not demonstrate the foliar fertilized variants.

Photosynthetically active internal leaf radiation (PARi) was more intense in 2021, with average values ranging between 1350 and 1500 µmol m^{-2}s^{-1}, as compared to 2022 when photosynthetically active internal leaf radiation had lower average values between 1122 and 1377 µmol m^{-2}s^{-1}. The average leaf temperature (Tleaf) values were more constant in 2021, ranging from 26.4 to 26.6 °C; they oscillated more in 2022, ranging from 25.9 to 26.9 °C. An analysis of the physiological parameters of the Felix variety showed that they were higher in 2021 than in 2022, with the exception of the photosynthetic WUE and that of VPD.

Table 1. Physiological parameters on the soybean variety Felix treated with foliar fertilizer.

Photosynthesis Parameters	Year	Fertilization System		
		a_1	a_2	a_3
Reference CO_2 (CO_2 r), µmol mol^{-1}		390	390	390
Sub-stomatal CO_2 concentration (Ci), µmol mol^{-1}	2021 2022	257.0 178.0	260.0 197.0	265.5 204.0
Stomatal conductance (SC), mmol H_2O m^{-2}s^{-1}	2021 2022	500 217.7	478.5 195.0	455.0 191.0
Transpiration (T), mmol H_2O m^{-2}s^{-1}	2021 2022	4.00 3.50	5.70 4.30	5.60 3.70
Photosynthetic water use effciency (WUE), mmol CO_2 mol^{-1} H_2O	2021 2022	2.00 4.83	2.77 4.97	2.93 5.30
Leaf-to-air vapor pressure deficit (VPD), kPa	2021 2022	1.30 2.00	1.23 1.90	1.07 1.77
Photosynthetically active radiation internal (PARi), µmol m^{-2}s^{-1}	2021 2022	1350 1122	1500 1157	1466 1377
Leaf temperature (T_{Leaf}), °C	2021 2022	26.4 25.9	26.5 26.9	26.6 26.1

Notes: a_1—basic mineral fertilization (BMF); a_2—BMF + foliar fertilization − pod formation; a_3—BMF + foliar fertilization − grain formation.

3.3. Effect of the Fertilization System and the Climatic Conditions on Assimilation and Yield

In soybean culture, assimilation in the years 2021 and 2022 (Table 2) was lower in the variant where only mineral fertilization was applied compared to the variants where supplement was applied with foliar fertilizer, and the values oscillated between 21.4 and 23.0 µmol CO_2 m^{-2}s^{-1}.

In 2021, the foliar fertilization variant a2 phase of the beginning of pod formation and the a3 phase of the beginning of the formation and filling of grains had average assimilation values of 23.0 µmol CO_2 m^{-2}s^{-1} and 22.5 µmol CO_2 m^{-2}s^{-1}, respectively, and the values were found to be distinctly significant. In 2022, the assimilation was slightly lower; there were no differences between the fertilized variants, and statistical differences were only significant compared to the control.

A reduction in production values from 3495 kg ha^{-1} in 2021 to 1745 kg ha^{-1} in 2022 was mainly due to climatic conditions, which fail to highlight the effect of fertilizers applied during different growth stages.

Table 2. The effect of the fertilization system on the assimilation and yield of soybean.

Fertilization System	Assimilation (μmol CO_2 m^{-2}s^{-1})		Difference (±)		Significance	
	2021	2022	2021	2022	2021	2022
a_1—basic mineral fertilization (BMF)	21.7	21.4	cv	cv	cv	cv
a_2—BMF + foliar fertilization − pod formation	23.0	22.4	1.30	1.00	**	*
a_3—BMF + foliar fertilization − seeds formation	22.5	22.2	0.80	0.80	*	*
LSD p 5% = 0.71 μmol CO_2 m^{-2}s^{-1}; LSD p 1% = 1.14 μmol CO_2 m^{-2}s^{-1}; LSD p 0.1 % = 2.03 μmol CO_2 m^{-2}s^{-1}						
Fertilization System	**Yield (kg ha^{-1})**		**Difference**		**Significance**	
	2021	**2022**	**2021**	**2022**	**2021**	**2022**
a_1—basic mineral fertilization (BMF)	3328	1444	cv	cv	cv	cv
a_2—BMF + foliar fertilization − pod formation	3562	1828	233.3	384.3	**	***
a_3—BMF + foliar fertilization − seeds formation	3495	1745	166.7	301.3	*	**
LSD p 5% = 122.7 kg ha^{-1}; LSD p 1% = 190.6 kg ha^{-1}; LSD p 0.1% = 321.3 kg ha^{-1}						

Notes: cv—control variant; *—significant positive; **—significantly positive difference; ***—very significantly positive; LSD—least significant difference.

3.4. Interaction between Yield, Assimilation, and Physiological Parameters

For the year 2022, the regression band is more restrictive at assimilation values above 21.4–22.4 μmol CO_2 m^{-2}s^{-1}; under these conditions, the potential yield was 1444–1828 kg ha^{-1}, while in the year 2021, the assimilation restriction was around 21.7–23.0 μmol CO_2 m^{-2}s^{-1}, with a yield of 3328–3562 kg ha^{-1}. In general, the regression bands indicate the differences between the two years and establish a narrow range of variation in assimilation. The phenomenon is based on the existence of physiological stress in 2022, as well as the lack of water during the period of flowering and pod formation, which leads to a yield decrease in 2022.

In the optimal conditions of 2021, assimilation does not restrict the yield potential of plants, thanks to nano-silver (Ag), nitrogen (N), and potassium (K) in the composition of the fertilizer, stimulating vigorous plant development, as well as the yield and quality of the culture (Figure 3).

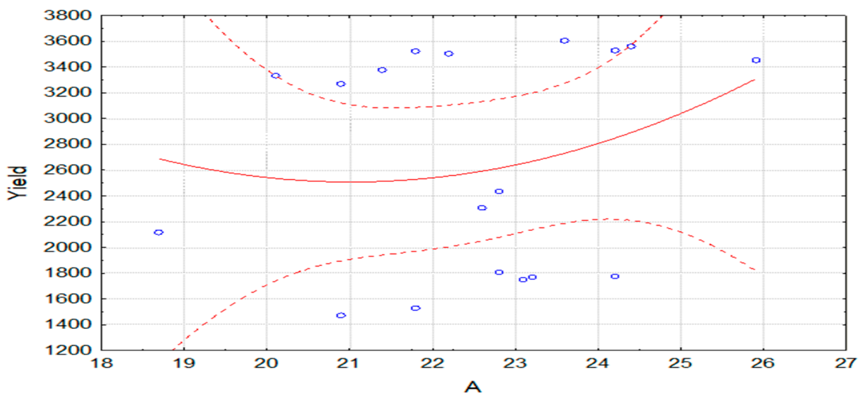

Figure 3. Interaction between yield (kg ha^{-1}) and assimilation (A, μmol CO_2 m^{-2}s^{-1}); ◦: interaction of the analyzed parameters; ¨: confidence interval; ¯: polynomial regression curve.

Sub-stomatal CO_2 concentration is a parameter with an arched polynomial regression curve, with the yield increasing above 220 µmol mol^{-1} in typical years (2021). In the years characterized by water stress (2022), the maximum potential yield was 2600 kg ha^{-1} at a sub-stomatal CO_2 concentration of 260–280 µmol mol^{-1}. Regression bands indicate realistic yield forecast potential at sub-stomatal CO_2 concentration values of 240–270 µmol mol^{-1} (Figure 4).

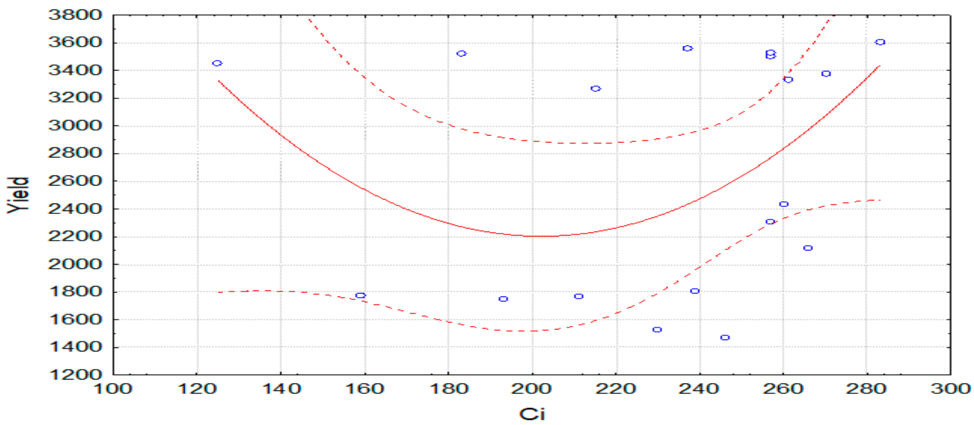

Figure 4. Interaction between the yield (kg ha^{-1}) and sub-stomatal CO_2 concentration of the sub-stomatal cavity (Ci, µmol mol^{-1}); °: interaction of the analyzed parameters; ¨: confidence interval; ¯: polynomial regression curve.

The total stomatal conductance is a parameter with a strong ability to predict potential yields in soybean. In the climatic deficit year of 2022, at low conductance values (below 400 mmol H_2O m^{-2}s^{-1}), constant yields of 1600–2000 kg ha^{-1} can be obtained. Under these conditions, the maximum yield potential was 2400 kg ha^{-1}; however, to reach this level, a theoretical conductance of 500–600 mmol H_2O m^{-2}s^{-1} was needed. In an optimal year for the soybean crop, the potential yield increase was more than 3600 kg ha^{-1} in proportion to the increase in conductance, reaching a maximum of 400 mmol H_2O m^{-2}s^{-1} (Figure 5).

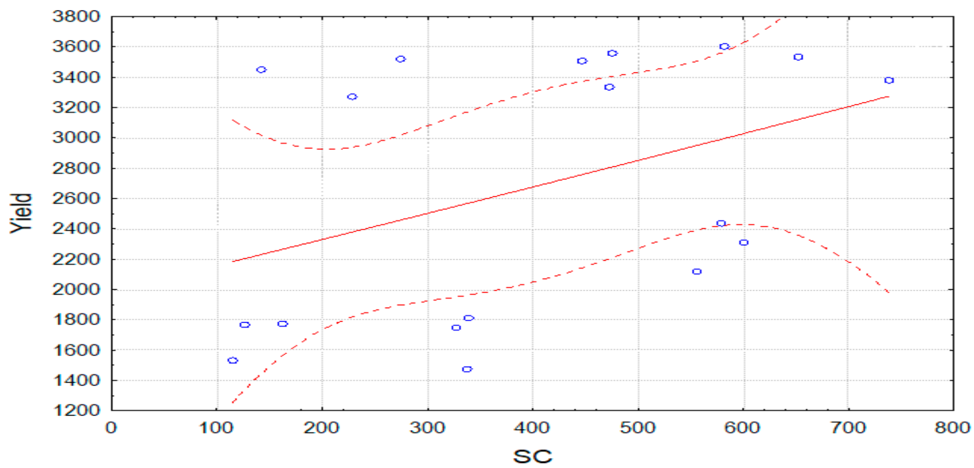

Figure 5. Interaction between yield (kg ha^{-1}) and stomatal conductance (SC, mmol H_2O m^{-2}s^{-1}); °: interaction of the analyzed parameters; ¨: confidence interval; ¯: polynomial regression curve.

Photosynthetically, active internal radiation (PARi, µmol m^{-2}s^{-1}) is the only parameter whose increase is directly proportional to the potential yield (Figure 6). The regression curve establishes a potential increase in the yield from 1800 kg ha^{-1} at a PARi of more than 800 µmolm^{-2}s^{-1} and to more than 3000 kg ha^{-1} at a radiation rate of more than

1300 μmolm^{-2}s^{-1}. In an optimal year (2021), PARi had values above 1400 μmol m^{-2}s^{-1}, while in poor climatic conditions (2022), the maximum yield could be reached at a radiation value of 1500 μmolm^{-2}s^{-1}.

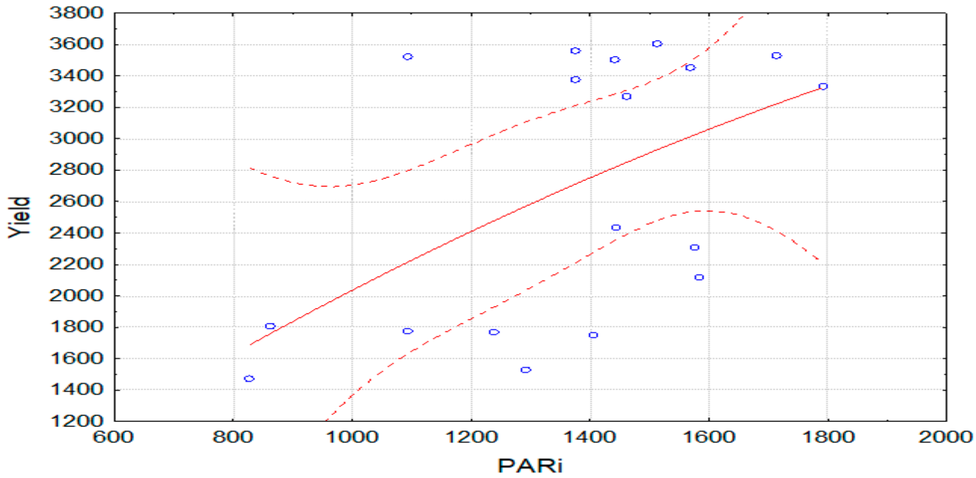

Figure 6. Interaction between yield (kg ha^{-1}) and photosynthetically active radiation internal (PARi, μmol m^{-2}s^{-1}); °: interaction of the analyzed parameters; ¨: confidence interval; ¯: polynomial regression curve.

Transpiration at the leaf level (T, mmol H_2O m^{-2}s^{-1}) had homogeneously distributed values in 2021 and grouped values in 2022. The regression curve obtained indicates an increase in the potential yield from a value of 1800 kg ha^{-1} at a transpiration level of 3 mmol H_2O m^{-2}s^{-1} up to a value of 3400 kg ha^{-1} in transpiration conditions above 6 mmol H_2O m^{-2}s^{-1}. Higher yields over 3400 kg ha^{-1} were obtained in the range of 4 and 6 mmol H_2O m^{-2}s^{-1} of transpiration (Figure 7).

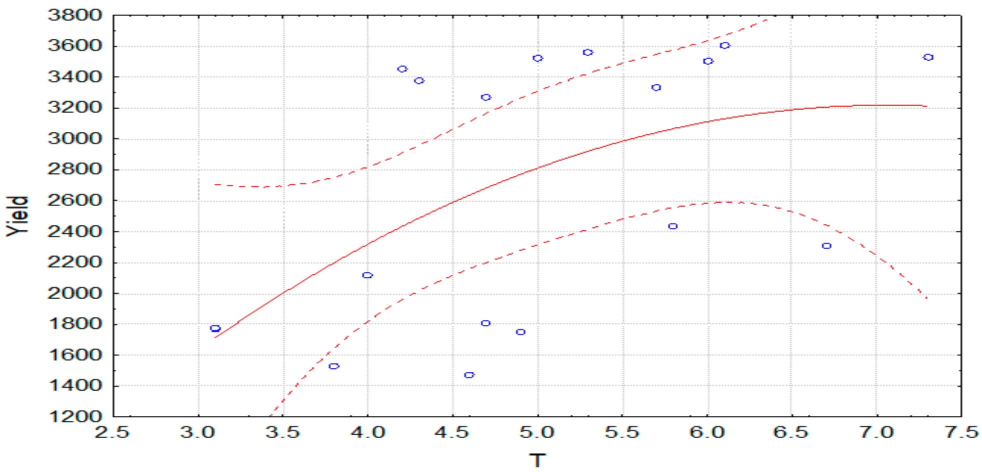

Figure 7. Interaction between yield (kg ha^{-1}) and transpiration at leaf level (T, mmol H_2O m^{-2}s^{-1}); °: interaction of the analyzed parameters; ¨: confidence interval; ¯: polynomial regression curve.

The photosynthetic water use efficiency (WUE, mmol CO_2 mol^{-1} H_2O), associated with the potential yield, is directly influenced by climate, as noted by James Bunce in 2016 [34]. Generally, at an efficiency value of 1.0 mmol CO_2 mol^{-1}, the potential H_2O yield was 2200 kg ha^{-1} and increased to 3200 kg ha^{-1} at an efficiency value of 2.7 mmol CO_2 mol^{-1} H_2O (Figure 8).

In the year 2021, the climatic conditions stimulated a higher leaf-to-air vapor pressure deficit (VPD), while in the water stress conditions of 2022, the values were higher. The leaf-to-air vapor pressure deficit is closely connected to the climate of each experimental year. The potential yields were located from 3200 to 3500 kg ha^{-1}, with VPD values as low as 0.6 and 1.2 kPa (optimal climatic year), and reached up to 3400 kg ha^{-1} when the leaf VPD ranged from 1.6 to 2.6 kPa (climatic stress) (Figure 9).

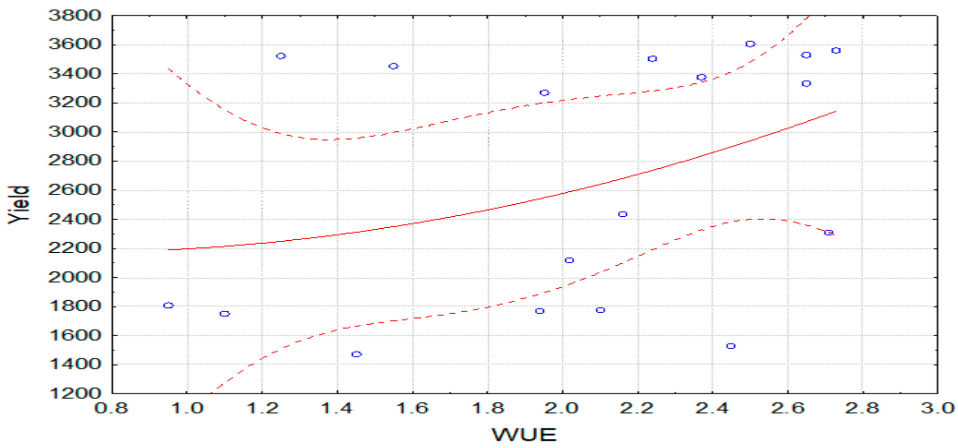

Figure 8. Interaction between yield (kg ha^{-1}) and the photosynthetic water use efficiency (WUE, mmol CO_2 mol^{-1} H_2O); °: interaction of the analyzed parameters; ¨: confidence interval; ¯: polynomial regression curve.

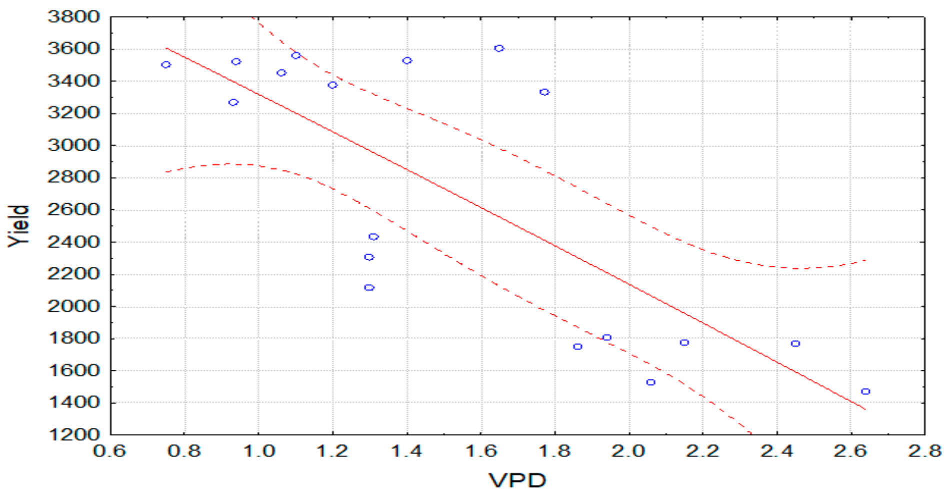

Figure 9. Interaction between the yield (kg ha^{-1}) and the leaf-to-air vapor pressure deficit (VPD, kPa); °: interaction of the analyzed parameters; ¨: confidence interval; ¯: polynomial regression curve.

3.5. Effect of the Fertilization System and Climatic Conditions on Soybean Quality Indices

In both years, distinctly significant differences in the percentages of proteins between the variants treated with foliar fertilizer and the control were achieved in the a3 variant, with average values exceeding 41% in 2021 and 36.4% in 2022 (Table 3).

The highest percentage of oil was achieved in both variants to which the foliar fertilizer was applied, but the highest percentage of oil over 19.53% was obtained in the a3 variant during the pod formation phase, and the differences were very significantly positive to the control variant.

In the case of the mass of a thousand seeds (MTS) of soybean, for the Felix variety, the difference between the control and both variants to which the foliar fertilizer was applied exceeded 192.0 g in 2021. For both a2 and a3 variants, the differences were significantly positive compared to the control variant; however, in 2022, there were no differences between the foliar fertilizer and the control variant.

Table 3. Soybean quality indices depending on the fertilization system.

Fertilization System	Protein (%)		Protein (%)		Difference (±)		Significance	
	2021	2022	2021	2022	2021	2022	2021	2022
a_1—basic mineral fertilization (BMF)	40.00	35.50	100.0	100.0	cv	cv	cv	cv
a_2—BMF + foliar fertilization − pod formation	40.73	36.20	101.9	102.0	0.73	0.70	*	*
a_3—BMF + foliar fertilization − seeds formation	41.00	36.40	102.6	102.6	1.00	0.90	**	**
LSD p 5% = 0.53%; LSD p 1% = 0.85%; LSD p 0.1% = 1.52%								
Fertilization System	**Oil (%)**		**Oil (%)**		**Difference (±)**		**Significance**	
	2021	**2022**	**2021**	**2022**	**2021**	**2022**	**2021**	**2022**
a_1—basic mineral fertilization (BMF)	18.60	16.57	100.0	100.0	cv	cv	cv	cv
a_2—BMF + foliar fertilization − pod formation	19.17	17.13	103.4	103.9	0.57	0.57	**	**
a_3—BMF + foliar fertilization − seeds formation	19.53	17.27	105.6	104.8	0.93	0.70	***	***
LSD p 5% = 0.24%; LSD p 1% = 0.38%; LSD p 0.1% = 0.69%								
Fertilization System	**MTS (g)**		**MTS (%)**		**Difference (±)**		**Significance**	
	2021	**2022**	**2021**	**2022**	**2021**	**2022**	**2021**	**2022**
a_1—basic mineral fertilization (BMF)	181.90	150.93	100.0	100.0	cv	cv	cv	cv
a_2—BMF + foliar fertilization − pod formation	192.27	155.77	105.7	103.2	10.37	4.83	*	-
a_3—BMF + foliar fertilization − seeds formation	193.73	156.00	106.5	103.4	11.83	5.07	*	-
LSD p 5% = 10.33 g; LSD p 1% = 16.39 g; LSD p 0.1% = 28.66 g								

Notes: cv—control variant;-: insignificant; *—significant positive; **—significantly positive difference; ***—very significantly positive; LSD—least significant difference.

4. Discussion

High temperatures used during the experiment period had a negative effect on the development of the soybean plants [7,30,35], which caused a decrease of more than 40–60% in the yield. The high temperatures during the day (35 °C) throughout the flowering phase determined the decrease in the yield, as also observed by Gibson and Mullen in 1996 [36], who carried out various experiments.

Soybean culture is sensitive to water deficit, especially during the period of vegetative growth and development [37–39]; thus, it is possible to have a significant reduction in the leaf surface and even the abortion of flowers [40–42], a lower assimilation of nutrients [43], a smaller number of pods [7,40], as well as a 14–32% reduction in grain size (as observed by Souza et al. in 1997) [44], all of which led to a decrease in yield, as also revealed by the data obtained by Van Heerden and Krüger in 2002 [45]. Excess soil water is equally harmful, limiting the yield potential, as observed by Santos and Carlesso in 1998 [46] and Lobato et al. in 2008 [47], who carried out various experiments.

In 2021, the radiation of the active photosynthetically active radiation internal (PARi) throughout the vegetation period (April–September) was observed to be higher, which led to an increase in assimilation, and the leaf temperature was more constant, which allowed the soybean crop to maintain a good rate of growth and development compared to in 2022 when the PARi was lower and the leaf temperature fluctuated more, which led to a decrease in assimilation and affected plant development.

The physiological parameter values were higher in the soybean crop in 2021 in the variants where foliar fertilizer was applied in the different vegetation phenophases. Fertilizer had a greater effect on the plants in 2021 compared to in 2022, in which only the photosynthetic water use efficiency and leaf-to-air vapor pressure deficit were higher in less favorable years, with greater assimilation in temperature oscillations.

During the growing season, assimilation is characterized by three maxima, corresponding to the phenophases of leaf formation and development, flowering, and the accumulation and storage of reserve substances in seeds [48]. Between the variants on which Agro Argentum Forte was applied, significant positive differences were found in both analyzed years, and a higher yield was obtained when fertilization was applied in the initial phase of the pod formation, especially in years that were more favorable to the crop. This aspect indicates the potential of maintaining the plants at a high level of physiological functioning thanks to nano-elements silver (Ag), total nitrogen (N), and potassium (K) under favorable climatic conditions [49,50].

In soybeans, the quality indices of the Felix variety were very different in the years 2021 and 2022 due to large fluctuations in temperature and precipitation from one month to another and from one year to another, consequently influencing the quality of the harvest [51,52]. In the two years of cultivation, following the application of foliar fertilization in the different vegetation phases, there were differences in quality indices both in protein and oil production compared to the control where foliar fertilization was not applied.

The application of basic mineral fertilizers in combination with foliar fertilization had a significantly positive impact on the quality indicators of soybean seeds in both the 2021 and 2022 cultivation years. The highest yields were achieved when the foliar treatment was applied in the early pod formation stage.

5. Conclusions

In the soybean culture, with regards to the assimilation of the Felix variety in the variants where treatments with foliar fertilizers were applied in both years, the reaction of plants was positive and statistically assured compared to the control.

By applying the foliar fertilizer Agro Argentum Forte to the soybean crop, in the two years, the composition of the foliar fertilizers (nano-silver (Ag), nitrogen (N), and potassium (K)) was found to interact with the chloroplasts, and the effect of photosynthesis increased, meaning that the plants were more vigorous in treated variants, increasing the efficiency of crop productivity.

In soybean, differences in the yield and quality indices between the two years (protein, oil, and MTG) in the variants treated with the foliar fertilizer were much higher compared to those of the control variant, causing an increase in the seed quality and yield (over 3495–3562 kg ha^{-1} in 2021 and over 1745–1828 kg ha^{-1} in 2022).

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