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Effect of Foliar Fertilization on the Physiological Parameters, Yield and Quality Indices of the Winter Wheat

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Abstract: The main purpose of the paper is to highlight the impact of foliar fertilization during the various growth stages of winter wheat and its role in achieving high-quality and superior production. Foliar fertilizers play a crucial role in calibrating and forming active growth intervals correlated with productivity factors. The research was conducted over a two-year period using the Andrada winter wheat variety. It involved the application of four different foliar fertilizers: basic mineral fertilization, FoliMAX Orange (two treatments and three treatments), FoliMAX CerealsMIX (two treatments and three treatments), and Microfert U (three treatments). Depending on the treatment, two or three applications of foliar with foliar fertilizers were carried out at various stages of winter wheat development, including pre-flowering and grain formation. The research method used to record physiological parameters was non-destructive (the leaves were not detached from the plant) and was based on the use of the CIRAS-3 foliar gas analyzer, which simultaneously determines several physiological and environmental indicators. As an indicator read by the device, photosynthesis was chosen for leaf temperature and leaf transpiration, correlated with production and quality indices. By applying the foliar fertilizer treatments to the wheat culture, we managed to increase production and improve the quality. After using different foliar fertilizers, the assimilation and physiological parameters had higher values of over 30 μmolm$^{-2}\cdot$s^{-1}. Foliar fertilization applied to the winter wheat variety resulted in an average production increase between 450 and 765 kg$\cdot$ha^{-1} and quality indices with a protein percentage between 11.5 and 12.6%, gluten content between 21.5 to 24.0% and the Zeleny index between 29.0 and 39.0%, and the mass of one thousand grains was between 48.0 and 50.5 g.

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

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1. Introduction

Wheat (*Triticum aestivum* L.) is one of the most adaptable crops under different environmental conditions, with very wide ecological plasticity to pedo-climatic conditions, occupying the largest agricultural acreages [1,2] and benefits from mechanisms of biological performance in adaptation to soil conditions [3].

Under severe drought conditions, photosynthetic function significantly diminishes to a great extent due to the deterioration of the photosynthetic apparatus [4], but when the drought does not persist for a long period of time, there are even reduced water reserves in the soil, applying foliar fertilization allow mechanisms to adapt and avoid tissue dehydration [5].

Current wheat breeding programs align with the rate of yield growth required to achieve the goal of doubling agricultural production [6,7]. Agricultural research and related sciences aim to minimize or eliminate other stress factors, such as extreme temperature fluctuations during critical growth stages (such as anthesis and grain filling phases), which cause significant yield losses in most wheat-growing areas [8], thus limiting production potential [9]. The fight against these stress factors is complex, however, due to the way plants react to various elements and the diversity of response pathways. It also triggers their genetic determination [10–12].

The choice of varieties depends on the area; both macro- and micronutrients applied to soil and foliar contribute to the proper nutrition of plants [13–16]. The pedoclimatic conditions associated with applied technology are decisive factors in the success of the wheat culture, both in terms of productivity and quantity [17,18]. Plant photosynthesis is one of the main links in the carbon circuit through which plant-bound CO_2 from the atmosphere [19]. At maturity, wheat performs mostly photosynthesis on the standard leaf and stem, this being the main source of assimilation of cereals during grain filling [20,21].

Foliar fertilization in the case of wheat crops is important for providing nutrients directly to the plants through the leaves, providing a quick and effective solution to correct nutritional deficiencies and stimulate plant growth, especially at critical moments of the development cycle [22–24].

Also, the applicability of foliar mulches is very wide, from the moment when the plants cover the ground until they are close to physiological maturity. In optimizing fertilization strategies, foliar application with different types of micro and macro elements has a positive effect on plant physiological parameters and growth yield of cereal crops and reduces soil pollution [25–27]. Grain filling in cereals is an important measure dependent on photosynthesis and environmental conditions after flowering, while storage capacity is established in the pre-flowering period, and this can be the deciding factor for yield [28].

Flag leaf physiological, morphological, and biochemical traits play a crucial role in determining grain yield and crop biomass [29]. Foliar fertilization in wheat crops is an important strategy for the direct supply of plant nutrients through foliar application at different vegetative stages. It serves as a quick and effective solution to correct nutrient deficiencies [30,31] and to stimulate plant growth; applying fertilizer [32] in the later stages of growth of wheat is an effective mitigation of drought stress [33], improving grain filling [34].

As found in one study, in cereals under conditions of severe drought or heat [35], photosynthesis is reduced in intensity depending on the species and the genotype, and the filling of the grains depends a lot on the remobilization of reserves from the stem to the grains. Through various studies, [36] found that as the grains fill the ear, the weight of the stalks decreases. High production capacity is often associated with a lower grain protein content [37]. The protein is the main component that determines the baking quality of wheat [38].

From the analysis of the average values obtained, it results that the additional fertilization ensures an increase in production as well as an increase in the average values of the other components of the yield or of the qualitative indices, also conferring a smaller variation of the values of these characters [39,40]. Furthermore, the correct management of fertilization is essential to guarantee the correct milling of wheat kernels [41–43], optimal flour quality [44–46], improved dough rheology, and best bread and bakery product characteristics [47,48].

Applying foliar fertilizer treatments to wheat culture is essential for increasing assimilation, plant growth, plant mass, quality, and yield. The main purpose of the paper is to identify the important physiological segments in the yield and quality of the winter wheat variety Andrada. Foliar fertilizers have the role of calibrating and forming the active growth intervals correlated with the productivity elements. Promoting and identifying the physiological mechanisms is useful in appreciating the biological development of winter wheat.

2. Materials and Methods

2.1. Biological Materials

The studies were conducted during the periods 2015–2016 and 2016–2017 using the Andrada winter wheat variety. This variety originates from two local genotypes, Dropia and Line T 57–90. It features an awned red spike measuring 9–11 cm, with large oval red grains.

The plant height ranges from 80 to 95 cm, with a thousand grain weight (TGW) ranging from 46 to 50 g. The variety exhibits reduced tillering capacity, between 1.5 and 2.5 tillers plant^{-1}, good winter resistance, excellent lodging resistance, and a very favorable vegetation period lasting between 265 and 270 days. The baking quality characteristics of the Andrada winter wheat variety notably reflect a protein content of 12 to 13%, exceptional gluten quality indicated by the gluten index value determined by the Perten method (76–100%), and bread volume with an average value of 520 cm^3 [49].

2.2. Research Methods

The experiments were conducted at the Agricultural Research and Development Station Turda (ARDS Turda), Romania, located at approximately 46°35′ latitude and 23°47′ longitude, in the physical-geographical unit of the Transylvanian Plain. The field experiment was organized on a Phaeozem soil type [50], with neutral pH (between 6.8–7.2; using potentiometric method in distilled water), clay soil (clay between 51.8–55.5%), with a humus content between 2.20–3.12% (using the Walkley–Black method), total nitrogen between 0.162–0.124% (using the Kjeldhal method), phosphorus between 0.9–5 ppm and well supplied with potassium between 126–140 ppm (using the Egner–Riehm–Domingo extraction method). A characteristic of this type of soil is rapid settlement upon repeated passage of heavy aggregates or if agricultural work is carried out in conditions of high humidity. The soil samples for chemical analysis were collected at a depth of 0–20 cm.

The precursor plant is soybean. The experiment was based on a bifactorial type $A \times B - R$: $6 \times 2 - 3$, according to the method of subdivided plots, the size of the experimental plots being 48 m^2 (4 m wide $\times$ 12 m long) $\times$ 6 plots per variant $\times$ 3 repetitions, and the total experimental area of 1288 m^2.

Stages of application of foliar fertilizers are the following:

1. Elongation of the straw, 3–4 internodes (BBCH 37–39; Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie);
2. The appearance of the bellows—the beginning of the spanking (BBCH 51–53);
3. Growing and filling grains (BBCH 71–73).

The experiments were carried out for two years with six variants:

V_1—Basic Mineral Fertilization (control-cv) (BMF);
V_2—BMF + 2 treatments (1 + 2) with Folimax Orange (FO);
V_3—BMF + 3 treatments (1 + 2 + 3) with Folimax Orange (FO);
V_4—BMF + 2 treatments (1 + 2) with Folimax CerealsMIX (FCM);
V_5—BMF + 3 treatments (1 + 2 + 3) with Folimax CerealsMIX (FCM);
V_6—BMF + 3 treatments (1 + 2 + 3) with Microfert U (MU).

Foliar fertilization (extra-radicular) with macro and microelements complements root nutrition, being an additional way of winter wheat nutrition that stimulates the elements of productivity and improves the quality of the harvest.

These fertilizers are applied foliarly (on the leaves and stems of the plants), and this is where the differentiation occurs: although the amount of nutrients absorbed is not very high, the degree of absorption is very high (it can even reach 100%), especially compared to fertilizers traditional, administered at ground level.

The latter are generally solid and need water (rain or irrigation) to penetrate the soil and be absorbed by plants through the root system. The applicability of foliar fertilizers is very wide, especially in recent years, with large areas of wheat being treated in this way in Romania.

The number of treatments and application phenophases were different, thus resulting in five gradations and a control variant in which there was only mineral fertilization. It should also be noted that all foliar fertilizations were carried out on the same mineral fertilization soil as in the control variant (Table 1).

Table 1. Foliar fertilizers used on winter wheat crop.

No	Trade Name, Content	Dose kg, L ha^{-1} per 250 L of Water
1	Folimax Orange (FO)—NPK 15-45-10 + micro	2.0 and 5.0 kg·ha^{-1} With phytosanitary treatment
2	Folimax CerealsMIX (FC)—8% N + 2% MgO + 3% B + 3% Cu + 4% Mn + 3% Zn + 46% SO_3 + micro	1.0 and 2.0 kg·ha^{-1} With phytosanitary treatment
3	MICROFERT U (MU)—NPK—90:30:30 g·L^{-1} + Mg + S, B, Co, Cu, Fe, Mn, Mo, Zn	3.0 and 5.0 L·ha^{-1} With phytosanitary treatment

2.3. Technology Used in the Experimental Site

Basic fertilization over the two years was carried out with an ensured foundation of 40 kg·ha^{-1} of nitrogen and phosphorus, simultaneously with sowing ($N_{20}P_{20}K_0$—200 kg·ha^{-1}), and ammonium nitrate providing an additional 60 kg·ha^{-1} of nitrogen was applied in spring, at the onset of vegetation, in the first week of March.

The experimental plots were established at the optimal sowing date for winter wheat (the second half of October) at a seeding density of 550 seeds m^{-2}. Basic fertilization was applied before plant sowing at a rate of $N_{50}P_{50}K_0$ kg ha^{-1}. A single crop protection treatment (herbicide + insecticide + fungicide) was applied to combat weeds, diseases, and pests during the stem elongation stage.

Over the two years, plowing was performed at a depth of 30 cm using the reversible Khun plow and the Gaspardo rotary harrow, achieving thorough soil processing. Sowing was done simultaneously with autumn fertilization, under optimal conditions for winter wheat sowing using the Directa 400 seeding machine, reducing soil compaction by minimizing passes over the surface. The seed incorporation depth was 3–5 cm, with row spacing of 18 cm, ensuring a density of 550 plants m^{-2}, and the seed quantity was 280 kg ha^{-1}. Harvesting took place in the first week of July using the Wintersteiger experimental plot combined.

In the conditions of the Transylvanian Plain, cereal crops are often attacked by diseases and pests, and enhanced attention is given from germination to emergence, providing preventive phytosanitary protection. Treatments were carried out considering meteorological conditions: air temperature and humidity, soil moisture, and precipitation. Herbicide application and treatments against pathogens and pests were done at the end of tillering (BBCH 28–30) when the infestation level and weed spectrum were high, following a complex scheme using chemicals with minimal environmental impact. Herbicide treatments were applied postemergence in the late tillering stage at the appearance of the first internode, targeting a broad spectrum of dicotyledonous weeds in the rosette stage with 2–4 leaves or more advanced. Weed infestation at the time of treatment averaged around 15–20%, with predominant weed species in the untreated control being *Amaranthus retroflexus*, *Chenopodium album*, *Convolvulus arvensis*, *Veronica heteriofolia*, *Setaria glauca*, *Delphnium consolida*, *Polygonum convolvulus*, *Polygonum aviculare*, *Veronica heteriofolia*, *Anagallis arvensis*. Disease (*Erysiphe graminis*, *Fusarium* spp., *Puccinia* spp., *Septoria tritici*) and pest (*Eurygaster integriceps*, *Lema melanopa*) control was ensured preventively by adhering to integrated control measures (crop rotation, seed treatment with fungicides before sowing) and curatively by conducting treatments in two vegetation stages—at the end of tillering and the booting phase (Table 2).

Table 2. Treatments used in the two years of winter wheat cultivation.

Application Phase	Destination	Product Name	Dose, L ha^{-1}	Active Substance
Treatment 1: Late Tilling phase (BBCH 28–30)	Herbicide	Sekator Progres OD	0.15	amidosulfuron 100 g L^{-1} + iodosulfuron-metil-Na 25 g L^{-1} + mefenpyr dietil 250 g L^{-1}
		Dicopur	1.0	600 g L^{-1} acid 2.4 D from dimethylamine salt
	Fungicides	Falcon 460 EC	0.6	tebuconazol 167 g L^{-1} + triadimenol 43 g L^{-1} + spiroxamina 250 g L^{-1}
	Isecticide	Biscaya 240 OD	0.2	240 g L^{-1} tiacloprid
	Growth Regulator	Stabilan 750 SL	1.4	clormequat chloride 750 g L^{-1}
	Adjuvant	Trend	0.25	Isodecyl ethoxylate alcohol: 90%
Treatment 2: Late Tilling phase (BBCH 51–53)	Isecticide	Calypso 480 SC	0.1	480 g L^{-1} tiacloprid
	Fungicides	Nativo 300 SC	1.0	clormequat chloride 750 g L^{-1}

2.4. Methods of Analysis and Processing of Experimental Data

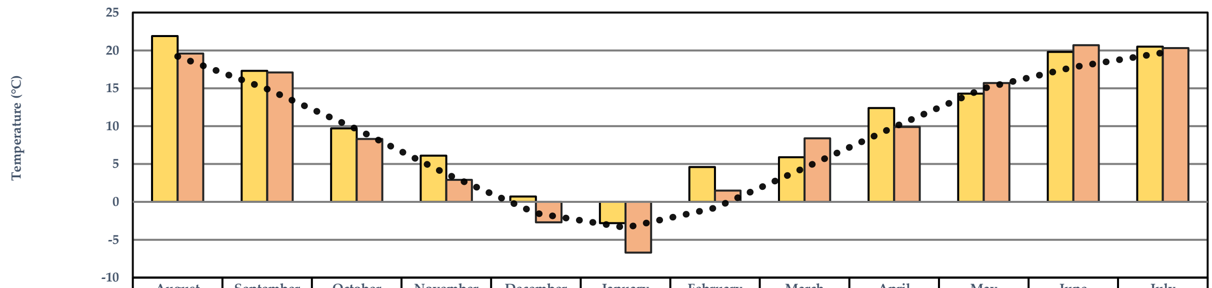
Physiological parameters were measured on the standard leaf after the last treatment with foliar fertilizers in June, and assimilation (A—µmol CO_2 m^{-2}·s^{-1}) transpiration rate (T—µmolm^{-2}·s^{-1}), leaf temperature (Tleaf) related to production and quality indices. The duration of the measurement was based on the duration of adaptation of the tissues in the assimilation chamber. The research method used was non-destructive (the leaves were not detached from the plant) and was based on the use of the CIRAS-3 foliar gas analyzer, which simultaneously determines several physiological and environmental. The determinations were carried out under semi-controlled conditions for normal CO_2 (390 µmolm^{-2}·s^{-1}) and of constant average ambient temperature at 27 °C. The measurements of the physiological parameters were carried out on the standard leaf after 20 days from the last treatment with foliar fertilizers in June, taking 25 readings per plant, for which the average was calculated, taking 9 winter wheat plants on each variant, at all 3 repetitions [51].

The study employed the ANOVA (analysis of variance) [52], for analysis, allowing for the execution of Least Significant Difference (LSD) tests at significance levels of 5%, 1%, and 0.1%. This approach facilitated the examination of relationships between experimental parameters and observations, as well as the execution of multiple comparisons using Fisher's LSD test, ultimately assessing the influence of fertilization on the biological growth of plants. Additionally, quality indices were determined using the Inframatic 8800 NIR grain analyzer.

3. Results

3.1. Climatic Conditions and Impact on Winter Wheat Cultivation Technology

Regarding the thermal regime (Figure 1), the average annual temperatures in the study period had values higher than the multiannual average, a fact that underlines the irreversible trend of global warming. This phenomenon is much more obvious if we notice that the average temperatures in the first year of the study are around 10.86 °C, and in the second, 9.58 °C, being higher than the average of 60 years ago when it was only 9.1 °C with a deviation of +1.7 °C from the multiannual average; 2016 is characterized as a warm year. The year 2017 started with a January colder than the multiannual average (deviation—3.3 °C), followed by two warm months (February and March). The months of April, May, and July were characterized as normal from a thermal point of view, followed by a summer with warm June, from a thermal point of view [53].



	August	September	October	November	December	January	February	March	April	May	June	July
2015–2016	21.9	17.3	9.7	6.1	0.7	-2.8	4.6	5.9	12.4	14.3	19.8	20.5
2016–2017	19.6	17.1	8.3	2.9	-2.7	-6.7	1.5	8.4	9.9	15.7	20.7	20.3
average 60 years	19.2	14.9	9.6	3.7	-1.5	-3.4	-0.8	4.5	9.9	15	17.8	19.7

Figure 1. The monthly temperatures recorded at ARDS Turda.

Regarding the rainfall regime, during the study period much larger oscillations of precipitation were observed, from excessively rainy to normal and excessively dry to normal. The amounts of precipitation that fell in the two years were much higher, exceeding by more than 200 mm the multiannual average of the last 60 years, which is 510.1 mm. Even if these years were excessively rainy, they compensated for this with the temperatures and ensured sufficient water in the soil, with the plant going through some of the most important phenophases (the appearance of the spike primordia—which coincides with the formation of the second internode, the bladder phase, anthesis, the formation and filling of the grains), determining a good development of the culture in the growth phases, development, and accumulation in the grain (Figure 2). Regarding the precipitation recorded in 2017, January was excessively dry, followed by a normal February. The spring months, March and April, were above the multiannual average, being rainy months; May, with little precipitation, was characterized as normal from a pluviometric point of view. The summer month, June, was deficient in terms of precipitation, but the month of July exceeded the multi-year average, being characterized as very rainy. Under these conditions, the rain occurred normally. In the process of straw elongation, normal internodes were formed, which was reflected in the normal tall height of the plants, and when the grain was collected in June, the lack of precipitation in 2017 caused lower biomass accumulation and higher production in 2016. The characterization of the thermal and pluviometric regime for the winter wheat crop in both years was based on the primary data recorded by the Turda Meteorological Station [54].

3.2. Interaction Results between Fertilization, Physiological Parameters, Yield and Quality Indices in Winter Wheat

Data processing indicates that foliar fertilization had a significant positive impact on yield and physiological parameters. The results obtained after the analysis of variance show a significant interaction at the level of assimilation, with an F value of 3.33 and $p < 0.05$. In addition, leaf temperature was also significantly affected by foliar fertilization, with an F value of 4.18 and $p < 0.05$. Production was significantly influenced by foliar fertilization, with an F value of 5.97 and $p < 0.001$. For evapotranspiration, no significant interaction was observed, with an F value of 1.34 and $p > 0.05$. Quality indicators did not show significant interactions or showed weak interactions (Table 3). Comparing the production values of the Andrada winter wheat variety over the two years of experiments, treated with various foliar fertilizers (FO, FC, and MU) in all variants, the foliar fertilizers exceeded the control (basic fertilization), being statistically confirmed as positive significant.

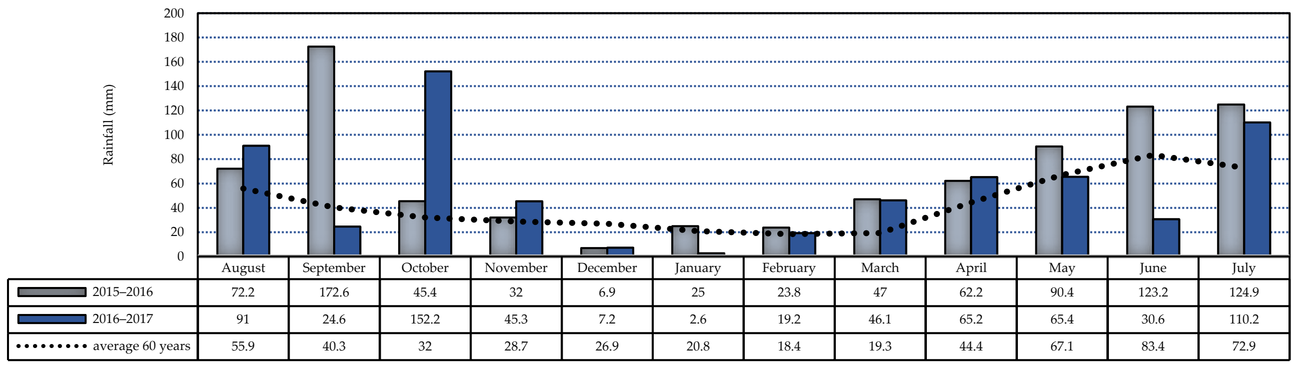


Figure 2. The monthly rainfall recorded at ARDS Turda.

Table 3. Statistical evaluation of the Physiological Indicators, Quality, and Yield by ANOVA.

Indicators	F	*p*
Assimilation (μmolm^{-2}·s^{-1})	3.33	0.007
Temperature of the leaf	4.18	0.002
Evapotranspiration (μmolm^{-2}·s^{-1})	1.34	0.264
Production (kg·ha^{-1})	5.97	$p < 0.001$
Thousand grain weight (TGW, g)	0.67	0.756
Protein (%)	1.32	0.275
Gluten (%)	1.41	0.231
Zeleny Indices (mL)	1.56	0.175
Marked effects are significant at $p < 0.05$		

From the processing of the results, it can be observed that production, assimilation, and leaf temperature were the only parameters that interacted significantly with the application of foliar fertilizers, as indicated by variance analysis. On the other hand, the quality índices and evapotranspiration did not show significant interactions or exhibited weak to very weak interactions (Table 3).

3.3. Results of the Interaction between Fertilization and Yield in Winter Wheat

The highest yields exceeding 7350 kg·ha^{-1} were achieved in the first year in the variants V_3, V_5, and V_6, which were treated with the foliar fertilizers FO, FC, and MU with three treatments with foliar fertilizer were applied, being statistically ensured as being very significantly positive compared to the witness.

In the variants V_2 and V_4, where two foliar treatments with FO and FC were applied, the productions obtained were over 7150 kg·ha^{-1}, being statistically assured as significantly positive.

In the second year, even if the productions obtained were lower compared to the first year, in the variants where three treatments with foliar fertilizer were applied, the production increases were over 400 kg·ha^{-1} for FO and 700 kg·ha^{-1} for FC variants where two treatments were applied (Table 4).

In the two years of a control experiment where only basic fertilization was applied in the first year, the production was higher by almost 300 kg·ha^{-1}; this difference is due to the much more favorable climatic conditions compared to the second year.

In the winter wheat variety in the two experimental years, the application of foliar fertilizers in the different phenophases of crop development was well capitalized; there is a positive correlation, a fact indicated by the *p* values [54–56].

Table 4. Correlation between yield and foliar fertilizers in winter wheat.

Year			**V$_1$**	**V$_2$**	**V$_3$**	**V$_4$**	**V$_5$**	**V$_6$**
Year I	Variant	Yield, kg·ha^{-1}	6770	7150	7380	7170	7495	7370
	V$_1$-control variant (cv)	6770		0.044	$p < 0.001$	0.012	$p < 0.001$	$p < 0.001$
	V$_2$-BMF + 2 trat. with FO	7150			0.147	0.553	0.010	0.043
	V$_3$-BMF + 3 trat with FO	7380				0.378	0.206	0.530
	V$_4$-BMF + 2 trat. with FCM	7170					0.038	0.138
	V$_5$-BMF + 3 trat. with FCM	7495						0.515
	V$_6$-BMF + 3 trat. with MU	7370						
Year II	Variant	Yield, kg ha^{-1}	6550	6975	7250	7010	7265	7180
	V$_1$-control variant (cv)	6550		0.011	$p < 0.001$	0.006	$p < 0.001$	$p < 0.001$
	V$_2$-BMF + 2 trat. with FO	6975			0.016	0.824	0.083	0.156
	V$_3$-BMF + 3 trat with FO	7250				0.026	0.437	0.268
	V$_4$-BMF + 2 trat. with FCM	7010					0.127	0.227
	V$_5$-BMF + 3 trat. with FCM	7265						0.735
	V$_6$-BMF + 3 trat. with MU	7180						
Years I + II	Variant	Yield, kg ha^{-1}	6770	7150	7380	7170	7495	7370
	V$_1$-control variant (cv)	6550	0.198	0.159	$p < 0.001$	0.107	0.003	0.008
	V$_2$-BMF + 2 trat. with FO	6975	0.002	0.507	0.066	0.658	0.268	0.437
	V$_3$-BMF + 3 trat with FO	7250	$p < 0.001$	0.040	0.675	0.063	0.718	0.485
	V$_4$-BMF + 2 trat. with FCM	7010	$p < 0.001$	0.214	0.198	0.304	0.600	0.852
	V$_5$-BMF + 3 trat. with FCM	7265	$p < 0.001$	0.002	0.391	0.003	0.109	0.056
	V$_6$-BMF + 3 trat. with MU	7180	$p < 0.001$	0.010	0.833	0.016	0.326	0.191

Notes: Values marked with red are significant.

3.4. Results of the Interaction between Fertilization and Assimilation in Winter Wheat

Between the untreated variant and the variants treated with the different foliar fertilizers, in the Andrada variety wheat crop, the assimilation had values between 27.7 and 32.8 µmol CO_2 m^{-2}·s^{-1} in the two years. In the first year, photosynthesis was more intense in variants V$_3$, V$_{5,}$ and V$_6$, where three treatments with foliar fertilizers were applied, recording values from 30.5 to 32.5 µmol CO_2 m^{-2}·s^{-1}. The highest value was recorded with the foliar fertilizer FC at the V$_5$ variant, where three foliar fertilizations were applied in addition to the basic fertilization, the average assimilation value exceeding 32.5 µmol CO_2 m^{-2}·s^{-1} (Table 5).

As for the second annual, photosynthesis increased by applying foliar fertilizer; the variants with the most intense assimilation were recorded in variants V$_5$ and V$_6$, achieving values of over 32.7 µmol CO_2 m^{-2}·s^{-1}, the highest value being at the foliar fertilizer Folimax Cereals mix and Microfert U.

The values obtained from the assimilation measurements in the two years showed that the highest values were obtained with the foliar fertilizer Folimax Cereals mix and Microfert U, the average of the assimilation values being between 31.8 and 32.8 µmol CO_2 m^{-2}·s^{-1}, with very significant positive differences compared to the control (Table 5). The application of foliar fertilizers was beneficial, the assimilation being more intense in the wheat crop with positive values statistically ensured.

The assimilation does not restrict the production potential of the plants, thanks to the nitrogen in the composition of the fertilizer and the microelements, stimulating the vigorous development of the plants, the production, and the quality of the crop, as also found [57,58].

Table 5. The correlation between leaf assimilation and foliar fertilizers in winter wheat.

Year			V_1	V_2	V_3	V_4	V_5	V_6
Year I	Variant	Assimilation, µmol CO_2 $m^{-2}\cdot s^{-1}$	25.9	27.7	30.8	28.0	32.5	31.8
	V_1-control variant (cv)	25.9		0.327	0.013	0.248	$p < 0.001$	0.004
	V_2-BMF + 2 trat. with FO	27.7			0.103	0.857	0.016	0.036
	V_3-BMF + 3 trat with FO	30.8				0.144	0.372	0.602
	V_4-BMF + 2 trat. with FCM	28.0					0.023	0.053
	V_5-BMF + 3 trat. with FCM	32.5						0.706
	V_6-BMF + 3 trat. with MU	31.8						
Year II	Variant	Assimilation,	27.1	29.6	30.2	28.5	32.8	32.7
	V_1-control variant (cv)	27.1		0.179	0.100	0.463	0.005	0.006
	V_2-BMF + 2 trat. with FO	29.6			0.746	0.530	0.097	0.111
	V_3-BMF + 3 trat with FO	30.2				0.344	0.174	0.196
	V_4-BMF + 2 trat. with FCM	28.5					0.026	0.031
	V_5-BMF + 3 trat. with FCM	32.8						0.943
	V_6-BMF + 3 trat. with MU	32.7						
Years I + II	Variant	Assimilation,	25.9	27.7	30.8	28.0	32.5	31.8
	V_1-control variant (cv)	27.1	0.507	0.051	0.025	0.169	$p < 0.001$	$p < 0.001$
	V_2-BMF + 2 trat. with FO	29.6	0.746	0.302	0.179	0.679	0.010	0.012
	V_3-BMF + 3 trat with FO	30.2	0.055	0.530	0.760	0.215	0.286	0.318
	V_4-BMF + 2 trat. with FCM	28.5	0.615	0.391	0.241	0.815	0.016	0.018
	V_5-BMF + 3 trat. with FCM	32.8	0.007	0.135	0.234	0.039	0.857	0.914
	V_6-BMF + 3 trat. with MU	32.7	0.018	0.255	0.411	0.084	0.578	0.628

Notes: Values marked with red are significant.

3.5. Results of the Interaction between Fertilization and Leaf Temperature in Winter Wheat

In winter wheat, the leaf temperature in both years of experience was influenced both by the environmental conditions and by the application of the foliar fertilizers FO, FC, and MU. In general, the leaf temperature had values close to the control, except for the V_2 variant that had 29.1 °C exceeding the control, being statistically assured as significantly positive. Between the untreated variant and variants treated with the various foliar fertilizers, for winter wheat, leaf temperature had values generally lower than the control. In the second year, the temperature of the leaves was higher than in the first, and variants V_2 and V_4 were higher than the control, the rest of the variants obtaining lower or equal values.

The wheat crop to which foliar fertilizers were applied obtained a higher assimilation, removing more carbon per unit time [59]. In the two years of experiment, this was influenced both by environmental conditions and by applying different foliar fertilizers, FO, FC, and MU, the highest temperature of the leaf, being on variants V_2 and V_4 where only two foliar fertilizations were applied (Table 6).

3.6. Interaction Res Ults between Fertilization Yield, Assimilation and Leaf Temperature in Winter Wheat

Data processing shows Gaussian dynamics, where the normal curve of the data shows an increase in production from 7200 to over 7400 kg ha^{-1}, with assimilation increasing from 30 and 32 µmol CO_2 $m^{-2}\cdot s^{-1}$ over a range of leaf temperature of 26–28 °C, after which when the temperature rises above 32 °C the leaves begin to reduce their activity by closing the stomata, assimilation decreases and with it the production also decreases (Figure 3). From the production graph, it can be seen that the Andrada wheat variety has a particular constancy when applying foliar fertilization; in addition to basic fertilization, there is a positive correlation between production, assimilation, and leaf temperature [60], as also found in [61].

Table 6. The correlation between leaf temperature and foliar fertilizers in winter wheat.

Year			V_1	V_2	V_3	V_4	V_5	V_6
Year I	Variant	T_{leaf}, °C	27.2	29.1	26.7	26.5	27.8	26.8
	V_1-control variant (cv)	27.2		0.016	0.546	0.380	0.432	0.546
	V_2-BMF + 2 trat. with FO	29.1			0.004	0.002	0.086	0.004
	V_3-BMF + 3 trat with FO	26.7				0.780	0.171	1.000
	V_4-BMF + 2 trat. with FCM	26.5					0.103	0.780
	V_5-BMF + 3 trat. with FCM	27.8						0.171
	V_6-BMF + 3 trat. with MU	26.8						
Year II	Variant	T_{leaf}, °C	26.1	26.7	24.9	26.5	25.9	26.1
	V_1-control variant (cv)	26.1		0.405	0.094	0.546	0.852	0.963
	V_2-BMF + 2 trat. with FO	26.7			0.016	0.816	0.311	0.380
	V_3-BMF + 3 trat with FO	24.9				0.027	0.134	0.103
	V_4-BMF + 2 trat. with FCM	26.5					0.432	0.516
	V_5-BMF + 3 trat. with FCM	25.9						0.889
	V_6-BMF + 3 trat. with MU	26.1						
Years I + II	Variant	T_{leaf}, °C	27.2	29.1	26.7	26.5	27.8	26.8
	V_1-control variant (cv)	26.1	0.507	0.051	0.025	0.169	$p < 0.001$	$p < 0.001$
	V_2-BMF + 2 trat. with FO	26.7	0.746	0.302	0.179	0.679	0.010	0.012
	V_3-BMF + 3 trat with FO	24.9	0.055	0.530	0.760	0.215	0.286	0.318
	V_4-BMF + 2 trat. with FCM	26.5	0.615	0.391	0.241	0.815	0.016	0.018
	V_5-BMF + 3 trat. with FCM	25.9	0.007	0.135	0.234	0.039	0.857	0.914
	V_6-BMF + 3 trat. with MU	26.1	0.018	0.255	0.411	0.084	0.578	0.628

Notes: Values marked with red are significant.

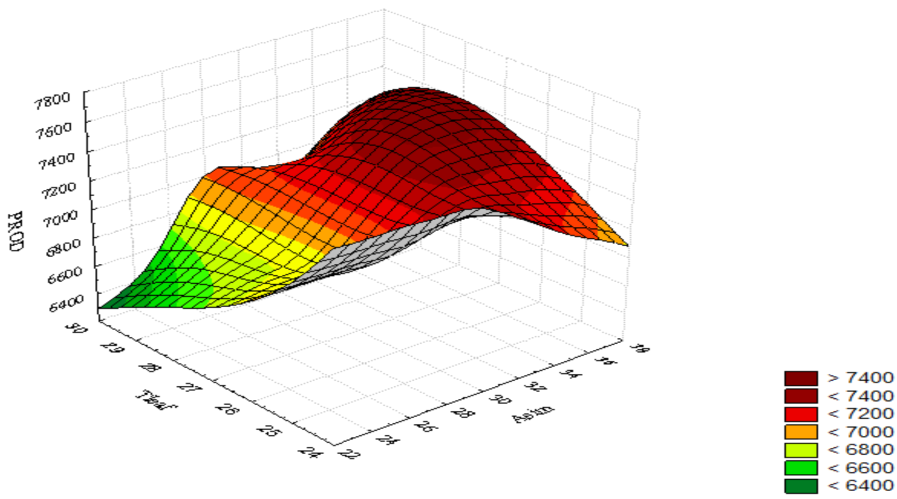


Figure 3. Multiple interactions between yield, assimilation, and leaf temperature.

3.7. Results of the Interaction between Foliar Fertilization and Quality Indices in Winter Wheat

The winter wheat variety Andrada maintains its pronounced stability, the mass of a thousand seeds of wheat, both in favorable and unfavorable environmental conditions [62], the values obtained being higher and balanced in all variants, not registering statistically assured differences compared to the control [63]. As for the quality of the grains of the Andrada winter wheat variety was influenced by the climatic conditions and foliar fertilization, the values obtained in both years of cultivation for the V_2, V_4 and V_5 variants were positive for the protein content with a concentration of over 12% in both years, where three foliar fertilizations were applied with FO and FC, and MU, in the phenophases of straw elongation (BBCH 37–39), bellows (BBCH 51–53) and grain filling (BBCH 69–71), registering statistically assured differences as distinct and very significantly positive compared to the mineral fertilized control variant. It is known that there is a negative correlation between high production capacity, which is often associated with a lower grain protein content as they obtained in their experiment, this being the main component that determines the baking quality of wheat [64,65].

Regarding the percentage of protein in the Andrada wheat variety, the values obtained in the two years of cultivation in the V_2, V_4, and V_5 variants were positive, where two or three foliar fertilizations with FO and FC were applied and MU.

In the variants V_3, V_5, and V_6, where three foliar fertilizations were applied in the phenophases of straw elongation, bellows, and grain filling, differences were recorded statistically assured as distinct and very significantly positive compared to the mineral fertilized control variant In the Andrada wheat variety, the percentage of gluten was higher on the variants where three foliar fertilizations V_3, V_5, and V_6 were applied with FO, FC, and MU (Table 7). For the Zeleny index, higher values were obtained in the second year, but there were no significant differences between the fertilized variants or the control.

Table 7. Quality indices for winter wheat in the two years.

Variant	**TGW, g**				**Difference±**		**Significance**	
Fertilizer/Variety	**Year I**	**Year II**	**Year I**	**Year II**	**Year I**	**Year II**	**Year I**	**Year II**
V_1-control variant (cv)	45.2	46.8	100.0	100.0	0.00	0.00	cv	cv
V_2-BMF + 2 trat. with FO	46.8	47.5	103.5	101.5	1.57	0.70	-	-
V_3-BMF + 3 trat with FO	45.0	45.9	99.5	98.2	−0.20	−0.83	-	-
V_4-BMF + 2 trat. with FCM	45.5	46.4	100.5	99.1	0.23	−0.40	-	-
V_5-BMF + 3 trat. with FCM	45.7	46.2	101.1	98.8	0.47	−0.55	-	-
V_6-BMF + 3 trat. with MU	46.1	46.9	101.9	100.4	0.83	0.17	-	-
LSD (*p* 5%) = 1.70 g; LSD (*p* 1%) = 2.3 g; LSD (*p* 0.1%) = 3.13 g								
Variant	**Protein, %**				**Difference±**		**Significance**	
Fertilizer/variety	**Year I**	**Year II**	**Year I**	**Year II**	**Year I**	**Year II**	**Year I**	**Year II**
V_1-control variant (cv)	11.2	11.8	100.0	100.0	0.00	0.00	cv	cv
V_2-BMF + 2 trat. with FO	11.9	12.2	106.9	104.0	0.70	0.43	**	-
V_3-BMF + 3 trat with FO	12.2	12.5	110.1	106.8	1.03	0.73	***	**
V_4-BMF + 2 trat. with FCM	11.7	12.0	105.2	102.5	0.53	0.27	*	-
V_5-BMF + 3 trat. with FCM	12.1	12.2	108.8	104.3	0.90	0.47	***	*
V_6-BMF + 3 trat. with MU	12.0	12.5	107.8	106.8	0.80	0.73	**	**
LSD (*p* 5%) = 0.46%; LSD (*p* 1%) = 0.62%; LSD (*p* 0.1%) = 0.84%								
Variant	**Gluten, %**				**Difference±**		**Significance**	
Fertilizer/variety	**Year I**	**Year II**	**Year I**	**Year II**	**Year I**	**Year II**	**Year I**	**Year II**
V_1-control variant (cv)	20.0	21.4	100.0	100.0	0.00	0.00	cv	cv
V_2-BMF + 2 trat. with FO	19.7	20.9	98.7	97.8	−0.27	−0.47	-	$_0$
V_3-BMF + 3 trat with FO	21.0	22.1	105.2	103.6	1.03	0.77	***	**
V_4-BMF + 2 trat. with FCM	19.7	21.1	98.5	98.8	−0.30	−0.27	-	-
V_5-BMF + 3 trat. with FCM	20.5	22.0	102.7	103.0	0.53	0.63	*	**
V_6-BMF + 3 trat. with MU	21.9	21.6	109.7	101.2	1.93	0.27	***	-
LSD (*p* 5%) = 0.46%; LSD (*p* 1%) = 0.63%; LSD (*p* 0.1%) = 0.85%								
Variant	**Zeleny index, mL**				**Difference±**		**Significance**	
Fertilizer/variety	**Year I**	**Year II**	**Year I**	**Year II**	**Year I**	**Year II**	**Year I**	**Year II**
V_1-control variant (cv)	44.5	47.8	100.0	100.0	0.00	0.00	cv	cv
V_2-BMF + 2 trat. with FO	39.9	45.9	82.3	94.7	−5.57	−1.80	$_{000}$	-
V_3-BMF + 3 trat with FO	44.4	49.4	96.7	104.9	−1.03	1.67	-	-
V_4-BMF + 2 trat. with FCM	40.0	46.6	82.6	96.3	−5.47	−1.23	$_{000}$	-
V_5-BMF + 3 trat. with FCM	40.6	48.2	84.6	101.4	−4.83	0.47	$_{000}$	-
V_6-BMF + 3 trat. with MU	45.6	46.5	100.3	96.2	0.10	−1.30	-	-
LSD (*p* 5%) = 1.99 mL; LSD (*p* 1%) = 2.71 mL; LSD (*p* 0.1%) = 3.67 mL								

Notes: cv—control variant;—insignificant; *—significant positive; **—significantly positive difference; ***—very significantly positive; $_0$—significant negative; $_{000}$—very significantly positive; LSD—Least Significant Difference.

The foliar fertilization applied to the Andrada wheat variety influenced both the yield and the quality indices, these falling into the good quality group as they also obtained

Moldovan in 2012 [49] and Racz in 2022 [63], obtaining a percentage of protein between 11.5 and 12.6 gluten 19.5 to 22.1 and the Zeleny index between 24.0 and 34.0 mL, and the TGW was between 45.0 and 47.5 g.

4. Discussion

The research over the two years has shown that the application of basic fertilization together with foliar fertilization has a positive effect, leading to a good development of the plants during the vegetation and finally to production of between 7200 and 7400 kg·ha^{-1}, to an intense assimilation of at 28 to over 32 µmol CO_2 m^{-2}·s^{-1} over a range of leaf temps, from 26 to 29 °C, after which when the temperature rises above 32 °C the leaves begin to reduce their activity by closing the stomata, the assimilation decreases and with this decrease the yield.

From the production graph, it can be seen that the Andrada wheat variety has a particular constancy when foliar fertilization is applied. In addition to basic fertilization, there is a positive correlation between production, assimilation, and leaf temperature [60], as was also found in [61].

Regarding the quality indices, protein, and gluten percentage la index of the Andrada wheat variety, the values obtained in the two years of cultivation by applying two or three treatments with foliar fertilizers that had in their composition in addition to N and P phosphorus and microelements had positive results, especially with FC and MU.

For the Andrada winter wheat variety, it could be stated that the three types of foliar fertilizers stimulate CO_2 absorption activity, and the other analyzed parameters show fluctuations from one fertilization variant to another, but in most cases, it is observed that foliar fertilization stimulates the physiological activity of the leaves [62–65].

The winter wheat variety Andrada maintains its pronounced stability, the mass of 1000 grains, both in favorable and unfavorable environmental conditions [49,66] through the application of foliar fertilizers, reacting positively to three variants out of six, and to FC and MU values were above the control treated with minerals only. Fertilization occurs, and even if the increases were not statistically ensured, the values obtained were between 45.5 and 48.5 g.

Regarding the percentage of protein in the Andrada wheat variety, the values obtained in the two years of cultivation in the V_2, $V_{4,}$ and V_5 variants were positive, where two or three foliar fertilizations with FO FC and MU. The foliar fertilization applied to the Andrada wheat variety influenced both the production and the quality indices, these falling into the good quality group [49,63] obtaining a percentage of protein between 11.5 and 12.6% gluten 19.5 to 22.1% and the Zeleny index between 24.0 and 34.0 mL.

5. Conclusions

The Andrada winter wheat variety is characterized by high photosynthetic activity in all variants where, in addition to the basic fertilizers, foliar fertilizations were applied in different phases of vegetation, obtaining productions of over 7350 kg·ha^{-1}, being analyzed through evapotranspiration which had close values regardless of the fact that the temperature was much higher, denoting a tolerance to drought, which hypothetically could be considered as an adaptation to the new climate changes.

On average, in the two experimental years with the Andrada winter wheat variety, it is observed that foliar fertilizers with micro and macro elements help had positive results on the physiological parameters and on the yield, obtaining increases of over 700 kg·ha^{-1} on the variants where or applied (basic fertilization + 3 treatments for all fertilizers used FO, FC, and MU).

Assimilation does not restrict the production potential of plants due to the nitrogen in the fertilizer composition and the microelements, promoting vigorous plant development, production, and crop quality.

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