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THE INFLUENCE OF FOLIAR FERTILIZER APPLICATION ON THE MACRO AND MICRO NUTRIENT CONTENT AND YIELD OF WHEAT PLANTS (*TRITICUM AESTIVUM*)

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Abstract

In 2022, on the chernozem from Caracal, in the wheat soils sown on 1,100 ha in the production farms of SCDA Caracal, the non-didactic department of the University of Craiova, in two locations: Caracal and Stoenești, FOLIQ 36 Nitrogen was administered to 7 wheat varieties: Glosa, Otilia, Izvor, Avenue, Gabrio, Euclide and Caro line. Leaf samples were taken from 13 physical blocks (one not treated with foliar fertilizer and 12 fertilized with foliar in two doses) in accordance with the leaf sampling instructions approved by the Analitycal Services Laboratory of Yara UK Limited-Packlington. Macro- and micro-nutrients were determined by laboratory analysis in England as follows: nitrogen (%), phosphorus (%), potassium (%), calcium (%), magnesium (%), sulphur (%), iron (ppm), zinc (ppm), manganese (ppm), boron (ppm), copper (ppm), molybdenum (ppm). Interpretation of the results showed that a dose of 1 l/ha significantly increased the zinc content, iron content and nitrogen content of the plant; significantly distinctive also the copper and sulphur content of the plant was increased; very significantly increased were the boron content and phosphorus content of the plant. The same dose also influenced yield very significantly. In general, Gabrio, Avenue and Euclide varieties showed high yields but also high nitrogen, boron, copper, calcium and phosphorus contents.

Key words: *foliar fertilizers, increase, macroelements, microelements, wheat, yield*

INTRODUCTION

Among cereals, common wheat (*Triticum aestivum ssp. vulgare*) is the most important crop, constituting the basis of human nutrition. The large share of the world's wheat-growing area also highlights the economic importance of this particular crop compared to other cereals. About 60% of wheat production is used for food and the concentration of macro- and microelements found in grains is, therefore, of great importance. In developing countries, it contributes to the edible dry matter and daily net intake of calorie consumption by 28% and 60%, respectively [27].

To increase crop yields, an important role is played by mineral fertilization (especially nitrogen and phosphorus), which is also the most expensive input in crop management, given the exaggerated increase in their prices over recent years. Fageria et al. [7] concluded that essential crop nutrients are applied to the soil to be taken up by the root system. It is also possible to use macro- and micronutrients as foliar fertilizers, which has an important economic and environmental impact [23].

Foliar fertilization is a procedure frequently and increasingly used recently for plant cultivation technologies. In agricultural practice, foliar spraying is often preceded by an assessment of the plant's nutritional status and field architecture. Various methods, both destructive and non-destructive, serve this purpose [23]. Jankowski et al. [10] pointed out that foliar fertilizers allow increasing wheat yield without damaging the natural environment.

The effectiveness of foliar fertilizers depends on several factors such as: soil nutrient reserve, previous crop type, applied dose, date of fertilization, weather conditions at the time of fertilization [11]. Tsvey et al. [29] found that spring fertilization has the most importance for winter wheat.

Foliar application of nutrients is an important crop management strategy to maximise crop yield and increase nutrient concentration for the edible parts of plants. The production of cereals with sufficiently high concentrations of mineral nutrients is of great importance for human and animal nutrition.

Foliar fertilizers are increasingly used in agricultural practice to maximize yield potential for *Triticum aestivum* L. Foliar fertilization can effectively reverse nutrient (macronutrient) deficiencies, and can be used as the main method of supplying the micronutrients needed by plants [10, 17, 18].

Nutrient content is an important quality characteristic of edible and fodder cereals [23], so that the production of healthy cereals is a high priority in maintaining human and animal health.

Many of the nutrient accumulation studies regarding wheat and other cereal crops have typically investigated only macronutrients. Investigations in this regard, including micronutrient accumulation for cereals date back more than 20 years and have involved older varieties that may differ considerably from modern varieties in terms of nutrient metabolism.

Updated knowledge on the accumulation of macro- and micronutrients for wheat during growth, especially under N fertilization conditions, is important and may have implications for crop nutrient management [9].

The economic value of wheat varieties is determined by yield size and its quality.

In this context, the objective of this study was to determine the effect of foliar fertilizer use on the yield and macro- and micronutrient content of wheat plants grown on a chernozem soil at SCDA Caracal - Romania.

MATERIALS AND METHODS

Characteristics of the experimental site and climatic trend

The experiments were set up in 2022, on a chernozem soil in the production farms of SCDA Caracal, the non-didactic department of the University of Craiova (Romania), in two locations: Caracal and Stoenești.

Caracal region is located in the South of the country (Coordinates: 44°06′45″N 24°20′50″E), on the plains between the lower parts of the Jiu and Olt rivers. The region's plains are well known for their agricultural specialty in cultivating grains.

Stoenești is a commune in the Olt county, Romania, being located in the South of the country (Coordinates: 44°05′54″N 24°29′02″E).

The climatic characteristics of the studied regions are presented in Table 1.

During the months in autumn and winter, temperatures were much higher than the multiannual average. In spring, monthly average temperatures deviated from the multiannual average, with negative deviations in March and April. Since May, temperatures have been above normal, combined with a lack of precipitation just during the grain filling period.

The number of days with temperatures $\geq 30^0$C was extremely high: 9 days in May and 26 days in June in Caracal, an absolute record in the last 5 years. In terms of rainfall, 364 mm were recorded in Caracal between October 1, 2021 and June 30, 2022, by only 25.5 mm less than the multiannual average, but with uneven distribution. In Stoenești, the difference was far greater, over 70 mm for the entire growing season.

Rainfall in October (101.4 mm and 92.0 mm respectively) contributed to a good seedbed preparation and uniform plant emergence. Heavy rainfall, above normal, was recorded only in December and April. The climatic conditions did not ensure favourable development of the wheat crop, with yields being quite low for the area's soil potential.

Table 1. The climatic characteristics of the studied regions*

	Specification	X	XI	XII	I	II	III	IV	V	VI	TAY	AAY
CARACAL												
T °C	Monthly average	10.2	7.4	2.6	2.0	4.2	4.3	11.1	18.1	23.0		9.2
	The absolute minimum	-0.6	-2.3	-8.6	-9.2	**-9.8**	-8.5	-3.5	3.5	12.2		
	The absolute maximum	23.9	23.1	14.3	15.5	17.4	22.5	26.0	32.4	**38.6**		
	No of days with $T^0 \geq 30^0C$	-	-	-	-	-	-	-	9	26	35	
	No of days with $T^0 \leq -10^0C$	-	-	-	-	-	-	-	-	-		
	Normal	11.7	5.1	0.3	-1.3	0.8	6.0	12.0	17.7	21.6		8.2
	Difference ± Normal	-1.5	+2.3	+2.3	+3.3	+3.4	-1.7	-0.9	+0.4	+1.4		+1.0
Pp (mm)	Monthly total	101.4	28.0	60.8	19.2	4.8	13.2	77.8	44.6	14.2	364.0	
	Multiannual average	46.0	37.0	39.1	30.8	26.3	34.2	47.8	58.6	69.7	389.5	
	Difference ± Normal	+55.4	-9.0	+21.7	-11.6	-21.5	-21.0	+30.0	-14.0	-55.5	-25.5	
STOENEȘTI												
T °C	Monthly average	10.3	7.9	2.9	2.3	4.8	5.0	11.3	17.5	21.6		9.0
	The absolute minimum	-0.1	-1.2	-7.8	**-10.8**	-7.6	-8.6	-1.3	5.0	11.6		
	The absolute maximum	22.8	23.7	15.2	16.2	16.6	23.2	24.3	31.2	**35.3**		
	No of days with $T^0 \geq 30^0C$	-	-	-	-	-	-	-	3	14	17	
	No of days with $T^0 \leq -10^0C$	-	-	-	-	-	-	-	-	1	1	
	Normal	11.7	5.1	0.3	-1.3	0.8	6.0	12.0	17.7	21.6		8.2
	Difference ± Normal	-1.4	+2.8	+2.6	+3.6	+4.0	-1.0	-0.7	-0.2	0.0		+0.8
Pp (mm)	Monthly total	92.0	18.0	62.4	10.3	2.0	5.6	50.4	45.0	26.5	312.2	
	Multiannual average	46.0	37.0	39.1	30.8	26.3	34.2	47.8	58.6	69.7	389.5	
	Difference ± Normal	+46.0	-19.0	+23.3	-20.5	-24.3	-28.6	+2.6	-13.6	-43.2	-77.3	

*T^0 = Temperature; Pp = Precipitations; TAY = Total agricultural year; AAY = Average of the agricultural year.
Source: Own calculation.

Treatments, Experimental Design, and Crop Management

The FOLIQ 36 Nitrogen foliar fertilizer containing 36% N + 4% MgO + microelements (boron, copper, iron, manganese, molybdenum and zinc) - producer and distributor Agrii Romania - was applied to 7 wheat cultivars: Glosa, Otilia, Izvor, Avenue, Gabrio, Euclide and Caro line in wheat soils sown on 1,100 ha in production farms at the two locations.

Three leaf samples were taken from 13 physical blocks (one not treated with foliar fertilizer and 12 foliar-fertilised at 0.5 l/ha and 1 l/ha) in accordance with the sampling instructions approved by the Analitycal Services Laboratory of Yara UK Limited-Packlington (York, YO42 1DN).

Three hundred grams of clean, pathogen-free flag leaves were randomly sampled, stored in ziblock bags and labeled with field data: sample reference, location, physical block, sample number, culture, date received.

Half of the samples were taken from physical blocks fertilised with 0.5 l/ha at various fertilisation rates (Glosa BF 301, Glosa BF 27, Glosa Stoe BF 304, Izvor Stoe BF 292, Izvor + Otilia BF 291, Otilia BF 515) and the other 6 from physical blocks with the second treatment (total dose of 1 l/ha) (Caro 1, Caro 2, Caro 4, Avenue, Gabrio, Euclide).

The macro- and micro-nutrient content of the plants was determined by laboratory analysis in England as follows: nitrogen (%), phosphorus (%), po-tassium (%), calcium (%), magnesium (%), sulphur (%), iron (ppm), zinc (ppm), manganese (ppm), boron (ppm), copper (ppm), molybdenum (ppm).

Starting from the implications of macro- and microelements on the development of the wheat plant, their values were analysed in relation to the reference value, the correlations between yield and each element, as well as the influence of treatment on yield according to the application rate of foliar fertilizer.

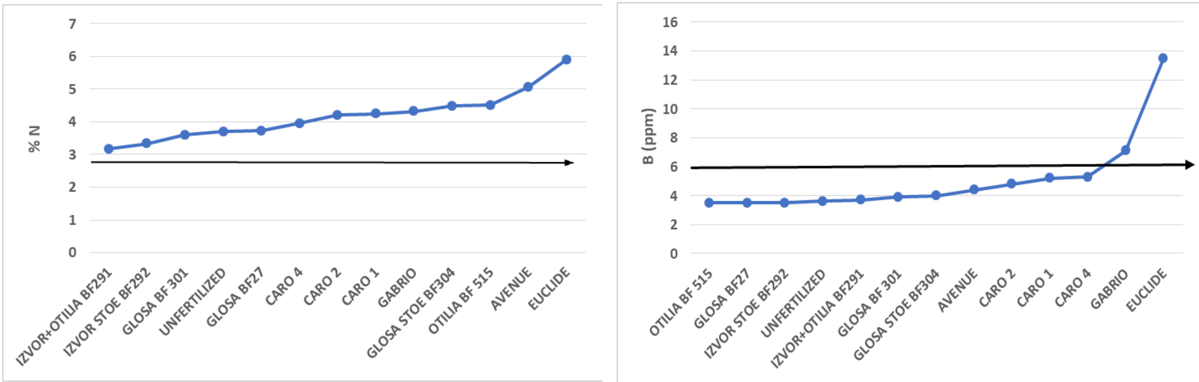
Statistical Analysis

To process the data, the limiting differences (LD) were calculated through the analysis of variance for three variants: unfertilized, one treatment with Folique 36 Nitrogen and 2 treatments with Folique 36 Nitrogen in 6 repetitions; to determine a linear relationship between two variables, Pearson's test was used to indicate the direction and strength of the relationship through correlation coefficients; the amplitude of the macro and microelement content was graphically displayed and correlated with the reference value.

RESULTS AND DISCUSSIONS

Macro and microelement content of wheat plants

The *nitrogen* content ranged from 3.17% to 5.9%, with a reference value limit of 3 (Figure 1a). All variants analysed had values above this limit. Thus the formation of chlorophyll, essential for photosynthesis, took place, resulting in greener, well-developed crops in all variants but especially for Avenue and Euclid. The boron content ranged from 3.5% to 13.5%, with a limit of 6 (Figure 1b). Of the variants analysed, only Gabrio and Euclide were well above the reference value, indicating that the two had a higher capacity for grain formation, boron being important for pollen germination and pollination.



(a) **(b)**

Fig. 1. Nitrogen content (%) (a) and boron content (%) (b) for the wheat plants analysed
Source: Own calculation.

In terms of *calcium* concentration, whose reference value is 0.4%, the variants analysed ranged from 0.28 to 0.57 (Figure 2a). Half of the variants were above the reference value, the highest values being recorded by Otilia BF515, Avenue and Euclid. Calcium in higher concentration helped the development of roots and aboveground parts.

Copper, another extremely important macro-element in plant development, including disease resistance, recorded values between 5.6-12.1%, the reference value being 7% (Figure 2b). Half of the values obtained were above this limit but Otilia, Avenue, Gabrio and Euclid stood out clearly. These were also the most productive, with copper playing an important role in grain development and its number.

The *iron* content ranged from 89 ppm to 194 ppm, with the reference value limit being 50 ppm (Figure 3a). All variants analysed had values above this limit. Plants in all variants showed healthy vegetative growth, especially Caro and Avenue.

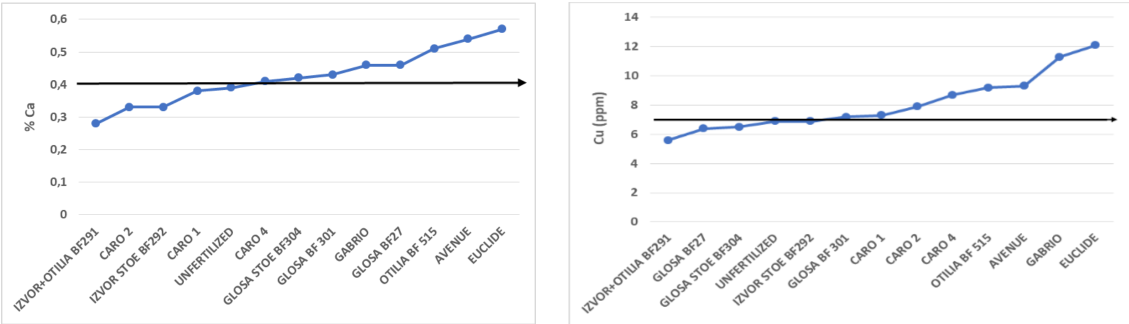
Phosphorus content, also extremely important, had values between 0.25 and 0.47 ppm, the reference value being 0.3 ppm (Figure 3b). Most of the variants were above this limit. The highest values were recorded by Gabrio and Euclid which explains the high active uptake of other elements in these varieties, with them having in most cases high values of macro and mi-croelements.

Magnesium recorded values of 0.08-0.21 ppm, the reference value being 0.12 ppm. With the exception of two, both belonging to the Izvor variety, all others were above the reference value (Figure 4a).

Manganese, which is important for root and aboveground growth, recorded values between 34.1-129 ppm. With one exception (Izvor + Glosa mixture), all values were above the reference value - 35 ppm (Figure 4b).

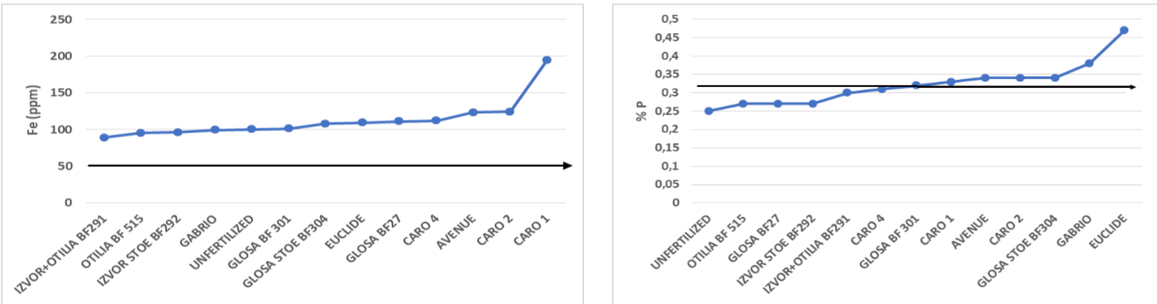
Molybdenum values ranged from 0.08-0.56 ppm, compared to a reference value of 0.1 ppm. As for manganese, with one exception (Glosa variety), all molybdenum values are above the reference value (Figure 5a).

Potassium, an extremely important macroelement in the development of disease resistance, was quite low for wheat plants (2.48-4.6%). Only the variety Euclid recorded values above the reference limit - 3.6% (Figure 5b).



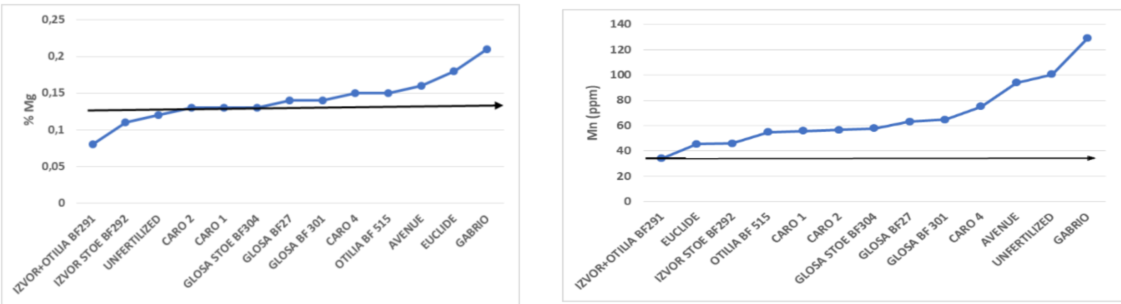
(a) **(b)**

Fig. 2. Calcium (%) (a) and copper (%) (b) content for the wheat plants analysed.
Source: Own calculation.



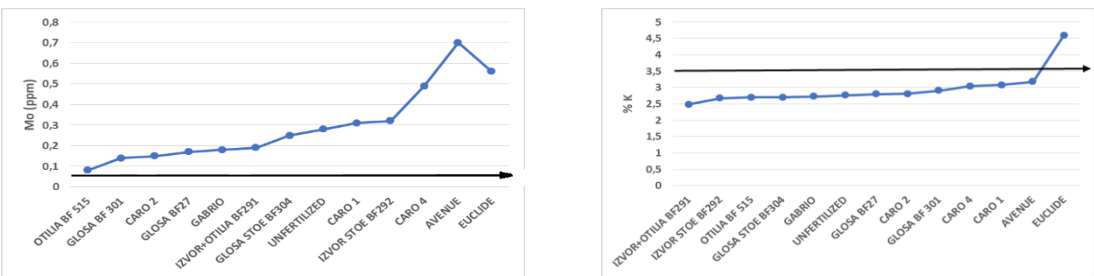
(a) **(b)**

Fig. 3. Iron (ppm) (a) and phosphorus (ppm) (b) content for the wheat plants analysed.
Source: Own calculation.



(a) **(b)**

Fig. 4. Magnesium (ppm) (a) and manganese (ppm) (b) content for the wheat plants analysed.
Source: Own calculation.



(a) **(b)**

Fig. 5. Molybdenum content (ppm) (a) and potassium content (%) (b) for the wheat plants analysed.
Source: Own calculation.

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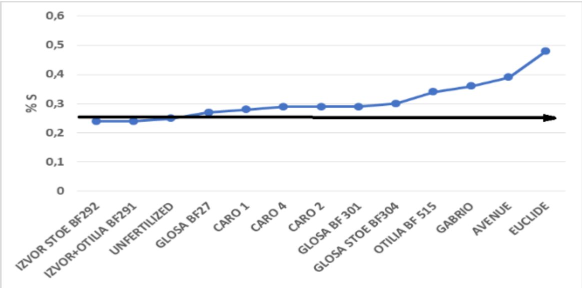
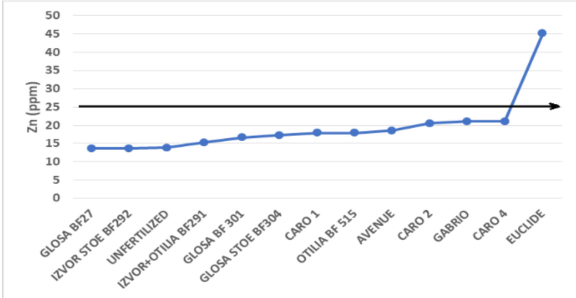
Sulphur is much more present in plants, with values ranging from 0.24 to 0.48 ppm. Besides two exceptions, both related to the Izvor variety, all the others recorded values above the reference limit - 0.25 ppm (Figure 6a). As in the case of potassium, *zinc* is found in lower concentration at wheat plants (13.7-45.2 ppm). Above the refer-ence value of 25 ppm, only Euclid is found (Figure 6b).



(a)



(b)

Fig. 6. Sulphur (ppm) (a) and zinc (pm) (b) content for the wheat plants analysed.
Source: Own calculation.

Regarding the influence of foliar fertilizer treatment on wheat on the content of macro and microelements, it was observed that a single treatment with a dose of 0.5 l/ha is not sufficient to improve their content. Moreover, it leads to a distinctly significant decrease in manganese content, thus seriously damaging the chlorophyll forming process.

Treatment with 1 l/ha foliar fertilizer significantly improves nitrogen content, zinc content, iron content; distinctly significantly improves copper content, sulphur content, very significantly improves boron content. Thus, the treatment has a major influence on healthy vegetative growth, grain and yield formation and on raising the level of disease tolerance (Figure 7).

Influence of foliar fertilizer treatment on wheat yield

In terms of yield, it ranged from 3,500 kg/ha for the variant not treated with foliar fertilizer, to 5,897 kg/ha for the variant treated with 1 l/ha, the increase being very significant (Figure 8). This increase in yield was recorded when each of the physical blocks analysed had a base fertilisation provided by solid chemical fertilisers, as shown in Table 2.

The two aspects highlighted below show that Avenue, Euclide and Gabrio varieties benefited from a much higher nitrogen input, resulting in significantly higher yields. In conclusion, the analysis of the yield obtained is based on its variability according to the nitrogen supply, which is also variable. The correlation coefficient (r = 0.723) shows that the two elements are highly positively correlated. An increase in the nitrogen supply also brought with it an increase in production. Figure 9 shows the amount of wheat yielded at an input of 1 kg nitrogen active substance (a.s.)/ha, differentiated from 31.8 kg to 58.5 kg. Although with a lower yield, the Izvor variety made better use of each kg of nitrogen a.s./ha on the Caracal chernozem (58.5 kg wheat/1 kg nitrogen a.s.). Hypothetically, equalizing the amount of nitrogen applied by solid chemical fertilizers, the results suggest that the variability of yield is given by the foliar fertilizer input. In practice, the genetic contribution of the variety in terms of production capacity, its capacity to valorise nitrogen and the climatic conditions that have been differentiated from one location to another must be taken into account.

The N nutritional status of wheat is affected not only by the amount of N accumulated in the plant, but also by other nutrients that are responsible for its uptake and subsequent transformation in plant [1]. This applies to nutrients such as Ca, P, K, Mg, S and micronutrients. The availability of these nutrients depends on the pH of the soil, which also affects the architecture of the root system [14].

Fig. 7. Influence of foliar fertilizer treatment on the content of macro- and microelements for wheat plants grown at Caracal.
Source: Own calculation.

Following foliar fertilization with FOLIQ 36 Nitrogen, from our experience, all the variants tested recorded plant nitrogen content values above the reference limit, with two of the varieties standing out as greener and better developed crops. As other studies have suggested, intensive wheat fertilization with N is a common strategy to achieve high yield and high N content in the grain [21]. The wheat management strategy requires an indepth assessment of the effectiveness of the applied rates of N fertilizers, as other authors have also noted [28].

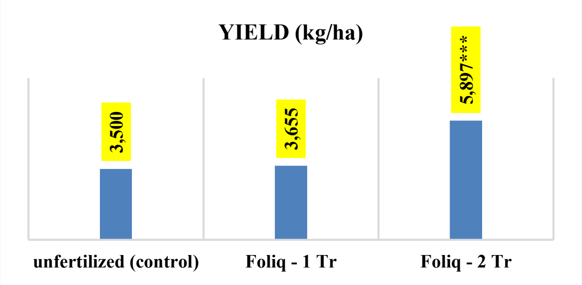


Fig. 8. Influence of foliar fertilizer treatment on wheat yield (Kg/ha)
Source: Own calculation.

Table 2. Fertilisation level of the variants analysed

Variant	Foliar fertilizer dose (l/ha)	Intake N	Intake P
Unfertilized (Control)	0	99	34
GLOSA BF301	0.5	65	0
GLOSA BF27	0.5	65	0
GLOSA STOE BF304	0.5	65	0
IZVOR STOE BF292	0.5	65	0
IZVOR+OTILIA BF291	0.5	65	0
OTILIA BF515	0.5	99	34
CARO 1	1	140.00	50
CARO 2	1	140.00	50
CARO 4	1	140.00	50
AVENUE	1	130.00	40
EUCLIDE	1	130.00	40
GABRIO	1	130.00	40

Source: Own calculation.

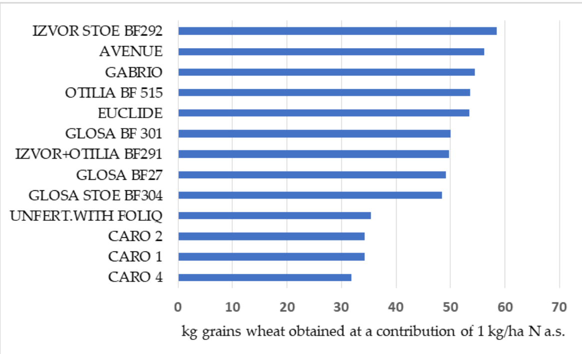


Fig. 9. Nitrogen valorisation in terms of the quantity of wheat obtained per 1 kg nitrogen a.s. administered/ha
Source: Own calculation.

Boron is an important element for pollen germination and pollination [20]. Our results showed that only two variants passed well above the reference value, indicating that they had a higher grain forming capacity. However, as some studies show, the boron applied to the soil was more effective than boron foliar applications [25]. On the other hand, the application of calcium in higher concentrations helped the development of roots and aboveground parts of the wheat variants tested. This is also consistent with other results obtained both for wheat [16] and other plants [30].

In the case of copper, half of the values obtained were above the reference limit, but four variants stood out in terms of productivity. This confirms the importance of copper in grain development and its numbers.

Iron content was above the reference value, with direct implications for vegetative growth in all wheat variants analysed. This is also supported by other authors, as iron is essential for the formation and function of chlorophyll and, therefore, for healthy vegetative growth [5, 15].

From experience, it has been found that a single treatment with 0.5 l/ha FOLIQ 36 Nitrogen is not sufficient to improve the macro and micro nutrient content of wheat plants. On the contrary, it leads to a distinctly significant decrease in the manganese content, thus causing serious damage to the chlorophyll forming process, as has been reported by other authors [32].

Potassium, an extremely important macro-element for the absorption and redistribution of water and nutrients of plants, was rather low for the wheat plants tested, with only one variety showing a value above the reference limit. Treatment with 1 l/ha foliar fertilizer improved the macro and microelement content of wheat plants suggesting major influence on healthy vegetative growth, grain and yield development and increased disease tolerance levels, in line with other results from the field [3, 4, 14].

The proper management of nutrients is necessary for a successful wheat crop production. Generally, the cautious nutrient supply at the right time, right rate and right place has a tremendous effect on wheat yield and ensures the health and consistency of soils and the environment [19, 22].

Wheat grain yields show a linear, and at the same time, a strong depend-ence on grain density, especially for modern wheat varieties

[24]. The size of wheat grain yields depends on the nitrogen supply to plants over a period of time from stem elongation to heading [8, 31]. The results of our study showed that an increase in the nitrogen supply also resulted in an increase in yield, with the results suggesting that the variability in yield is due to foliar fertilizer supply, as noted by other authors [2, 28]. In practice, however, the genetic contribution of the variety in terms of its production capacity, its ability to utilize nitrogen, and the climatic conditions that differed from one location to another must be taken into account. This hypothesis is also supported by other authors [11, 29].

The economic value of wheat varieties is determined by the size of production and its quality. In this sense, in order to assess the extent to which the content of macro- and microelements of the plant influences wheat yield, the correlations between them were analysed, highlighting the varieties that responded best to the fertilizer input through the content analysed.

It should be noted that the correlation between iron content and yield was not revealed, the coefficient of determination and the correlation coefficient being practically insignificant. The results suggest that high iron content for the plant does not necessarily ensure a high yield, as iron is only essential for healthy vegetative growth. However, similar to other essential plant nutrients, iron plays multiple roles within a plant [6, 12, 13, 26]. Following the results presented and by analysing them, some clear recommendations for improving the content of macro and microelements in the plant in the sense of balance were outlined for each wheat variety tested. This could be particularly essential for increasing wheat yield, especially on low to medium fertility soils. In this context, we plan to further research this topic in the future, at other locations and on other soil types.

CONCLUSIONS

The results showed that a dose of 1 l/ha foliar fertilizer significantly improved the zinc content, iron content and nitrogen content of the wheat plant; distinctly significantly improved the copper content and sulphur content of the plant; very significantly improved the boron content and phosphorus content of the plant. These results suggest that the treatment has a major influence on healthy vegetative growth, grain formation and yield, and increased disease tolerance levels.

High coefficients of determination showed relationships between yield on the one hand and copper and sulphur content on the other hand. In general, Gabrio, Avenue and Euclide varieties showed high yields but also high nitrogen, boron, copper, calcium and phosphorus contents.

A single treatment with 0.5 l/ha foliar fertiliser is not sufficient to improve the plant's macro and micronutrient content. On the contrary, it leads to a distinctly significant decrease in the manganese content, thus seriously damaging the chlorophyll forming process.

Hypothetically, equating the amount of nitrogen applied by solid chemi-cal fertilizers, the results suggest that yield variability is driven by foliar fertilizer input. In practice, however, the genetic contribution of the variety in terms of its production capacity, its nitrogen utilisation capacity and climatic conditions must be taken into account.

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