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Reaction of Winter Wheat (*Triticum aestivum* L.) Depending on the Multi-Component Foliar Fertilization †

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Abstract: Winter wheat is a popular cultivated grain, and to produce high and good-quality yields, it requires proper fertilization. In a field experiment, the reactions of winter wheat, cv. RGT Kilimanjaro with multicomponent foliar fertilization were assessed. The tested factor were foliar fertilizers used in various combinations: (A)—Control, (B)—YaraVita Gramitrel, (C)—YaraVita Kombiphos, (D)—YaraVita Thiotrac, (E)—YaraVita Gramitrel + YaraVita Kombiphos, (F)—YaraVita Gramitrel + YaraVita Thiotrac, (G)—YaraVita Kombiphos + YaraVita Thiotrac, (H)—YaraVita Gramitrel + YaraVita Kombiphos + YaraVita Thiotrac. It was shown that the variable weather conditions over years of research had a modifying effect on the yields. The best results were achieved by applying three times foliar fertilization (variant H). The obtained increase in grain yield in relation to the control (A) amounted to 0.62 t·ha^{-1}. The innovation of the experiment is its possibility to limit the dose of soil fertilizers in the cultivation of winter wheat without reducing the size and quality of the grain yield. This has an important ecological and economic aspect. The combinations of used foliar fertilizers contain rapidly digestible micro- (Mn, Zn, Cu) and macronutrients (N, P, K, Mg, S). Compared to the control, the content of protein and microelements in the grain increased and the fibers decreased. Plant field measurements showed that index SPAD (Soil Plant Analysis Development) and LAI (Leaf Area Index) readings increased after foliar fertilization, but the index MTA (Mean Tip Angle) was decreased compared to the control. In the case of the stomata conductivity of leaves (Gs), it was proven that the applied fertilization in variant H resulted in a reduction in measurements compared to the control.

Keywords: common wheat; foliar fertilization; macronutrients; micronutrients; yield components; yield; chemical composition

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1. Introduction

Winter wheat covers a large sown area and produces high grain yields compared to other cereals. Černý et al. [1] emphasized the great need of this species for both macronutrients and micronutrients. They proved that mineral fertilization significantly increased wheat yield, especially in soils with lower nutrient abundance. Fageria et al. [2] concluded that essential nutrients for crops are applied to the soil to be taken up by the root system. It is also possible to use macronutrients and microelements in the form of foliar fertilizers, which has an important economic and environmental impact. In agricultural practice, foliar spraying is often preceded by an assessment of the nutritional status of plants and the architecture of the field. Various methods, both destructive and nondestructive, serve this purpose [3]. Jankowski et al. [4] emphasized that foliar fertilizers allow the yield of wheat to be increased without damaging the natural environment. Dick et al. [5] showed that the use of nitrogen in the later development stages increases the protein content of wheat grains, dependent on the location of its use and years of research. Sobolewska et al. [6] confirmed that foliar fertilization has a positive effect on the size and quality of winter wheat yield; however, this is determined by the dose and date of the applied fertilizers. Additionally, the effectiveness of foliar fertilizers depends on other factors, such as weather or forecrop. Tsvey et al. [7] found that spring fertilization was the most important for winter wheat. The highest grain yield (6.90 t·ha^{-1}) was obtained after the combined use of solid and foliar fertilizers. In turn, Froese et al. [8], after foliar application of phosphorus, achieved a marginal increase in yield and wheat grain quality. Fageria et al. [2] showed that if foliar fertilization is applied with postemergence herbicides, insecticides, or fungicides, the yield can be increased, and the cost of agrochemical application is reduced. Therefore, the issues in the studied area are multifaceted and topical.

2. Materials and Methods

A field experiment was carried out at the Podkarpackie Agricultural Advisory Center in Boguchwała (21°57′ E, 49°59′ N). The tests were performed in the 2017/2018–2019/2020 seasons. The investigated factors were various variants of winter wheat fertilization, as presented in Table 1. The experiment was performed in a randomized block design with four replications. The RGT Kilimanjaro (RAGT Semences Poland, Ltd. Toruń, Poland) variety was selected for the study. It is one of the most fertile varieties of winter wheat with a good grain quality. Since 2017, it has been recommended for cultivation in the Podkarpackie Province.

Table 1. Scheme of diversified fertilization of winter wheat (L·ha^{-1}).

Variant of Foliar Fertilization	Development Phase (Scale BBCH)			
	BBCH 14	BBCH 28	BBCH 49	BBCH 73
(A)—Control	-	-	-	-
(B)—YaraVita Gramitrel	1	1	1	
(C)—YaraVita Kombiphos	-	4	3	-
(D)—YaraVita Thiotrac	-	-	-	5
(E)—YaraVita Gramitrel+YaraVita Kombiphos	1 + 0	0.5 + 2	0.5 + 2	-
(F)—YaraVita Gramitrel + YaraVita Thiotrac	1	1	1	5
(G)—YaraVita Kombiphos + YaraVita Thiotrac	-	4	3	5
(H)—YaraVita Gramitrel + YaraVita Kombiphos + YaraVita Thiotrac	1 + 0	0.5 + 2	0.5 + 2	5

Solid fertilizers were used for the whole experiment: YaraMila 14–14–21 Viking (300 kg·ha^{-1}) before the start of vegetation in the spring, YaraBela EXTRAN (200 kg·ha^{-1}) in the stem shooting phase, and YaraBela Sulfan (200 kg·ha^{-1}) at the beginning of the heading stage. In autumn, solid fertilizers were not applied. The following were selected for foliar fertilization:

- YaraVita Gramitrel (contains per g·L^{-1}: 64 nitrogen, 250 magnesium, 50 copper, 150 manganese, 80 zinc);
- YaraVita Kombiphos (contains per g·L^{-1}: 440 phosphorus, 75 potassium, 67 magnesium, 10 manganese, 5 zinc);
- YaraVita Thiotrac (contains in g·L^{-1}: 200 nitrogen, 750 sulfur).

The experiment was established on a medium soil, very good wheat complex, valuation class II. It was proper brown soil, slightly acidic (6.1–6.4 pH in KCl), and had a medium humus content (1.6–1.8%). The contents of assimilable phosphorus (17.6–19.3 mg·100 g^{-1} of soil) and potassium (21.9–22.6 mg·100 g^{-1} of soil) were high, magnesium was average (6.3–7.2 mg·100 g^{-1} of soil), and low sulfur (64.3–71.6 mg·100 g^{-1} of soil). The content of micronutrients was average except for low boron (0.9–1.2 mg·1000 g^{-1} of soil). The analysis of soil samples was performed at the Regional Chemical and Agricultural Station in Rzeszów, according to Polish standards. The weather conditions were given according to the quotations of the weather station of the Podkarpackie Agricultural Advisory Center in Boguchwała.

The area of a single plot was 15.0 m^2 and the insulation strips were 1 m. The seeds were sown to a depth of 3–4 cm, and the width of the inter rows was 12.5 cm. The forecrop was winter oilseed rape. The seed was treated with Gizmo 060 FS (50 $mL \cdot 100\ kg^{-1}$ of grain). Sowing was carried out on 29 September 2017, 28 September 2018, and 1 October 2019. The sowing rate was 350 $seeds \cdot m^{-2}$. Chemical plant protection was carried out during the growing season. Pesticides were used according to the manufacturer's labels. Chemical treatments were performed with a tractor sprayer and foliar fertilization with a knapsack sprayer. The development phases are given according to the BBCH scale (Bundesanstalt, Bundessortenamt und CHemische Industrie). Measurement of the stomatal conductivity of the leaves (Gs) was performed with a Porometer SC-1 apparatus (Meter, NE Hopkins Ct, Pullman, WA, USA). Leaf greenness index (SPAD) was measured with a SPAD 502P chlorophyllometer (Konica Minolta, Tokyo, Japan). A LAI-2000 apparatus (LI-COR, Lincoln, USA) was used to determine the leaf area (LAI) and leaf angle (MTA). The Gs, SPAD, and LAI measurements were measured in the BBCH 75 phase. Ear counts were reported from an area of 1 m^2. The mean number of grains per ear and MTZ was counted on 20 random plants. Harvesting was carried out on: 3 August 2018, 30 July 2019, and 11 August 2020. The yield obtained was converted into 1 ha at 14% grain moisture. The chemical composition of the grain was determined by the near-infrared method with a FT-LSD MPA spectrometer (Bruker Company, Billerica, MA, USA). To determine the individual elements, the grain samples were mineralized in HNO_3: $HClO_4$: $HS2O_4$ in the ratio 20:5:1 in an open system in a Tecator heating block (FOSS, Hillerød, Denmark). The content of K, Mg, Zn, Mn, and Cu in the obtained samples was determined by atomic absorption spectroscopy (FAAS) using the Hitachi Z-2000 apparatus (Tokyo, Japan). The Shimadzu UV-VIS spectrophotometer (Kyoto, Japan), vanadium–molybdenum method, was used to determine phosphorus.

3. Results and Discussion

Weather conditions were variable in the years of the study, which influenced the effectiveness of foliar feeding. Rainfall below the long-term average was recorded in April. In May 2020, rainfall was intense, while July and August were dry. The temperatures in the analyzed period were generally above the long-term average. Only March 2018 and May 2020 were colder (Figure 1). Ceglar and Toreti [9] reported that weather forecasting is important for the cultivation of plants, minimizing environmental stress and allowing for rational agrotechnical decisions to be made.

Foliar fertilization had no significant effect on the spike density per m^2 and the number of grains per spike. It was shown that the applied variants of fertilization (C, D, E, F, G, H) significantly increased the MTZ in comparison to the control (A). As a result, wheat yield increased after foliar fertilization, except when sprayed with YaraVita Gramitrel (B). The obtained grain yield difference after applying variants G and H was 0.58 $t \cdot ha^{-1}$ and 0.62 $t \cdot ha^{-1}$, respectively, compared to the control. Foliar fertilizers had a positive effect on the nutritional status of plants (SPAD index) and on the LAI index compared to the control. In turn, the MTA index decreased after foliar fertilization. Measurement of the stomatal conductivity of the leaves (Gs) showed that variant H fertilization resulted in a reduction in readings relative to the control. After foliar fertilization, the protein content of the grain increased, and the fibers decreased. Under the influence of foliar fertilization, except for variant D, an increase in the content of microelements in the grain was noted (Table 2). The concentration of macronutrients was stable. Chwil et al. [10] reported that foliar fertilizer had a greater impact on yield and gluten content than on the mineral composition of winter wheat grain and straw.

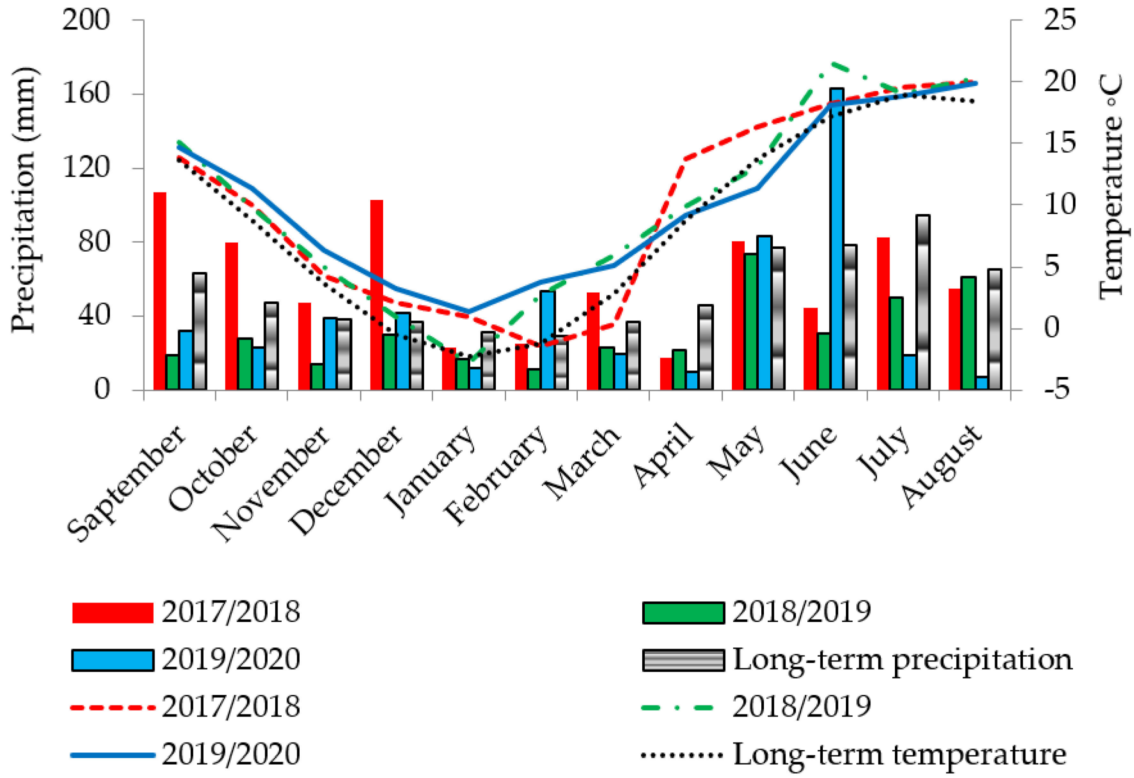

Figure 1. Weather conditions.

Table 2. Features and parameters of winter wheat (mean for year).

Parameter	Variant of Foliar Fertilization *							
	A	B	C	D	E	F	G	H
Number of ears (pcs·m^2)	586	588	587	586	590	589	588	589
Number of grains per spike	31.2	31.4	31.5	31.7	32.0	32.2	32.3	32.4
1000 grain weight (g)	41.3 ^{c}	41.6 ^{bc}	41.8 ^{b}	42.3 ^{ab}	42.0 ^{b}	42.5 ^{a}	42.8 ^{a}	42.8 ^{a}
Yield (t·ha^{-1})	7.55 ^{c}	7.68 ^{bc}	7.73 ^{b}	7.82 ^{ab}	7.97 ^{ab}	8.06 ^{ab}	8.13 ^{a}	8.17 ^{a}
SPAD	50.3 ^{c}	51.2 ^{b}	51.0 ^{b}	53.8 ^{a}	51.4 ^{b}	54.2 ^{a}	54.0 ^{a}	54.4 ^{a}
LAI	3.95 ^{c}	4.09 ^{a}	4.12 ^{a}	3.98 ^{b}	4.13 ^{a}	4.09 ^{a}	4.12 ^{a}	4.15 ^{a}
MTA	57.3 ^{a}	55.2 ^{b}	55.0 ^{b}	53.5 ^{c}	55.0 ^{b}	53.4 ^{c}	53.3 ^{c}	53.2 ^{c}
Gs	692.2 ^{a}	690.2 ^{ab}	688.4 ^{ab}	675.2 ^{ab}	687.2 ^{ab}	678.6 ^{ab}	372.2 ^{ab}	371.3 ^{b}
Protein (% DM)	13.8 ^{c}	14.2 ^{b}	14.2 ^{b}	14.6 ^{a}	14.2 ^{b}	14.7 ^{a}	14.7 ^{a}	14.8 ^{a}
Starch (% DM)	62.4	62.3	62.1	62.3	62.5	61.9	61.5	61.3
Ash (% DM)	1.46	1.48	1.48	1.46	1.49	14.48	1.51	1.50
Fiber (% DM)	2.88 ^{a}	2.82 ^{b}	2.81 ^{b}	2.77^c	2.80 ^{b}	2.76 ^{c}	2.76 ^{c}	2.75 ^{c}
P (g·kg^{-1})	3.31	3.28	3.35	3.25	3.36	3.23	3.36	3.34
K (g·kg^{-1})	3.83	3.80	3.86	3.79	3.85	3.78	3.87	3.86
Mg (g·kg^{-1})	1.21	1.28	1.23	1.19	1.32	1.27	1.22	1.30
Cu (mg·kg^{-1})	2.24 ^{b}	2.29 ^{a}	2.22 ^{a}	2.18 ^{b}	2.34 ^{a}	2.33 ^{a}	2.18 ^{a}	2.26 ^{a}
Mn (mg·kg^{-1})	25.3 ^{b}	25.6 ^{a}	25.3 ^{a}	24.9 ^{b}	25.8 ^{a}	25.7 ^{a}	25.4 ^{a}	26.1 ^{a}
Zn (mg·kg^{-1})	37.2 ^{b}	37.8 ^{a}	37.4 ^{a}	36.4 ^{b}	37.8 ^{a}	37.6 ^{a}	37.2 ^{a}	37.9 ^{a}

*—see Table 1. Mean values with different letters in columns are statistically different, $p < 0.05$.

4. Conclusions

Foliar fertilization is a commonly used procedure in plant cultivation. As a result of the experiment, it was shown that both the composition of the fertilizer, the dose and the time of application modified the size and quality of winter wheat grain yield. Therefore, it is important to determine the best variant of foliar fertilization for agricultural practice. The experiment showed that the best results were obtained when combined with three fertilizers in the fall and spring. Smaller effects were obtained after the combined application of two fertilizers and the lowest effect after the application of a single fertilizer.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/IOCAG2022-12292/s1.

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