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ORIGINAL PAPER

YIELD AND QUALITY OF WINTER WHEAT (*TRITICUM AESTIVUM* L.) DEPENDING ON MULTI-COMPONENT FOLIAR FERTILIZATION*

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Abstract

A field experiment on winter wheat was carried out in the 2017/2018 - 2019/2020 seasons. The research was carried out at the Podkarpackie Agricultural Advisory Center in Boguchwał, Poland. The experiment was performed in a random block design with four replications. The RGT Kilimanjaro (RAGT Semences) variety was selected for the research. 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. The combinations of foliar fertilizers used contain quickly digestible micro- (Mn, Zn, Cu) and macronutrients (N, P, K, Mg, S). The best results were achieved by applying foliar fertilization three times (variant H). The increase in grain yield obtained in relation to control (A) amounted to 0.62 t ha^{-1}. Compared to the control, the content of protein and microelements in the grain increased and the fibers decreased. Plant field measurements showed that the SPAD (Soil Plant Analysis Development) and LAI (Leaf Area Index) readings increased after foliar fertilization, but the index MTA (Mean Tip Angle) decreased compared to the control. Regarding the stomata conductivity of leaves (Gs), it was proved that the applied fertilization in variant H resulted in a reduction of this parameter in relation to the control.

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

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INTRODUCTION

Winter wheat fields cover a large area of farmland and yield high grain yields compared to other cereals. Černý et al. (2010) and Potarzycki et al. (2015) emphasize the high demand of this species for both macronutrients and micronutrients. They proved that mineral fertilization significantly increased the wheat yield, especially in soils with lower nutrient abundance. Podolska and Wyzińska (2011) and Niu et al. (2021) reported that use of large amounts of chemical fertilizers promotes high-yield agriculture, but is also associated with several problems, such as low fertilizer utilization rates, soil acidification, and soil salinization. Sztuder (2007) and Fageria et al. (2009) conclude that essential nutrients for crops are applied to soil to be taken up by the root system. However, it is also possible to use macronutrients and microelements in the form of foliar fertilizers. This solution is associated with important economic and environmental aspects (Ruszkowska, Wojcieska--Wyskupajtys 1996). In agricultural practice, foliar spraying is often preceded by an assessment of the nutritional status of plants (Zagórda, Walczyk 2007, Wach 2015, Smytkiewicz, Podleśny 2020) and the architecture of the field. Various methods, both destructive and nondestructive, serve this purpose (Rachoń et al. 2018). Jankowski et al. (2016) emphasize that foliar fertilizers allow increasing the yield of wheat without damaging the natural environment. Dick et al. (2016) showed that the use of nitrogen in the later development stages increases the protein content of wheat grains. The result was dependent on the location of the experiment and years of research. Sobolewska et al. (2020) confirmed that foliar fertilization had a positive effect on the volume and quality of winter wheat yield. However, it depended on the dose and application date of the fertilizers. Additionally, the effectiveness of foliar fertilizers relies on other factors, such as the weather or preceding crop. Tsvey et al. (2021) believe that spring fertilization is 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. (2020) achieved a marginal increase in yield and wheat grain quality after the foliar application of phosphorus. Fageria et al. (2009) showed that if foliar fertilization was applied with postemergence herbicides, insecticides, or fungicides, the yield increase could be higher and the cost of agrochemical application might be reduced. Thus, the issues in this area of interest are multifaceted and important.

The aim of the experiment was to evaluate the effect of eight variants of foliar fertilization on the yield and quality of winter wheat grains. The research hypothesis was that the applied fertilizer combinations would modify the tested parameters.

MATERIALS AND METHODS

A field experiment was carried out at the Podkarpackie Agricultural Advisory Center in Boguchwała (21°57′E, 49°59′N), Poland. The trials were performed in the 2017/2018 - 2019/2020 seasons. The investigated factor 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) variety was selected for the study. It is one of the most fertile varieties of winter wheat with good grain quality. Since 2017, it has been recommended for cultivation in the Podkarpackie Province.

Table 1

Winter wheat fertilization variants (L ha^{-1})

Variant of foliar fertilization	Development phase (skale 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 in the whole experiment: YaraMila 14-14-21 Viking (300 kg ha^{-1}) before the onset of vegetative growth in the spring, Yara Bela 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 (g L^{-1}): 64 N, 250 Mg, 50 Cu, 150 Mn, 80 Zn;

– YaraVita Kombiphos contains (g L^{-1}): 440 P, 75 K, 67 Mg, 10 Mn, 5 Zn;

– YaraVita Thiotrac contains (g L^{-1}): 200 N, 750 S.

The experiment was established on medium soil, very good wheat complex, valuation class II. It was a sandy loam soil, Haplic Luvisol (IUSS 2015), proper brown soil, slightly acidic (6.1-6.4 pH in KCl), and with the medium humus content (1.6-1.8%). The content 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) was high, magnesium was average (6.3-7.2 mg 100 g^{-1} of soil), and sulfur was low (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 analyses of soil samples were performed at the Regional Chemical and Agricultural Station in Rzeszów, according to Polish standards (Fotyma et al. 2015). Data on the weather conditions are given according to the measurements taken at the weather station of the Podkarpackie Agricultural Advisory Center in Boguchwała.

The area of a single plot was 15.0 m^2 and the separation strips were 1 m wide. Wheat seeds were sown to a depth of 3-4 cm and the width of the inter-rows was 12.5 cm. The preceding crop was winter oilseed rape. The seeds were treated with Gizmo 060 FS. Sowing was performed on 29.09.2017, 28.09.2018, and 01.10.2019. The sowing density was 350 seeds m^{-2}. Chemical plant protection was carried out during the growing season. Pesticides were used according to the manufacturer's recommendations. Chemical treatments were performed with a tractor sprayer and foliar fertilization was carried out 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, USA). Leaf greenness index (SPAD) was measured with a SPAD 502P chlorophyll meter (Konica Minolta, Japan). A LAI-2000 apparatus (LI-COR, USA) was used to determine the leaf area (LAI) and leaf angle (MTA). The Gs, SPAD, and LAI measurements were taken at the BBCH 75 phase. The ear counts were reported from an area of 1 m^2. The mean number of grains per ear and thousand kernel weight (TKW) were counted on 20 random plants. Harvesting was carried out on: 3.08. 2018, 30.07. 2019, and 11.08.2020. 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, Germany). 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, Denmark). The content of K, Mg, Zn, Mn, and Cu in the samples was determined by atomic absorption spectroscopy (FAAS) using a Hitachi Z-2000 apparatus (Tokyo, Japan). A Shimadzu UV-VIS spectrophotometer (Kyoto, Japan) and the vanadium-molybdenum method were used to determine phosphorus.

RESULTS AND DISCUSSION

The 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. The rainfall in May 2020, was high, while

July and August were dry. The temperatures in the analyzed period were generally above the long-term average. Only March in 2018 and May in 2020 were colder (Figure 1). Ceglar and Toreti (2021) report that good weather forecasting is important in the cultivation of plants. This allows you to minimize environmental stress and make rational agrotechnical decisions. Jarecki (2021) showed that variable weather conditions in the years of the research significantly modified the winter wheat yield.

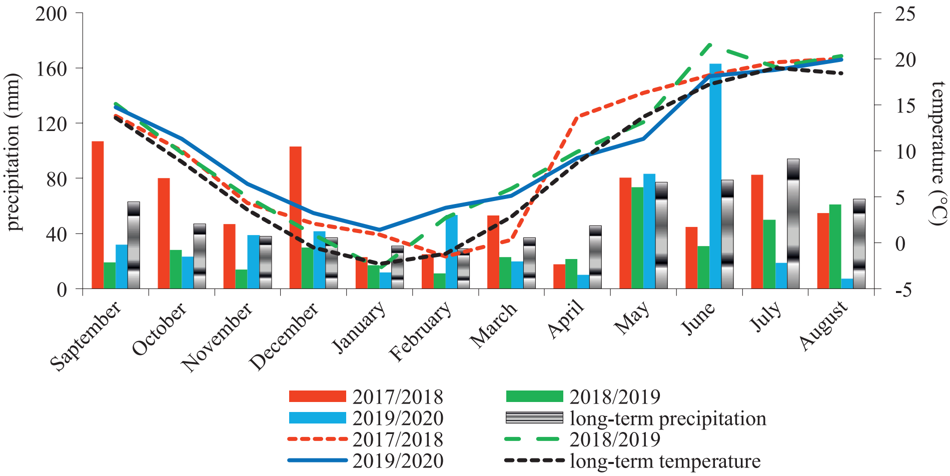

Fig. 1. Weather conditions

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 TKW in comparison to the control (A). As a result, wheat yield increased after foliar fertilization, except for spraying with YaraVita Gramitrel (B). The grain yield difference relative to the control after applying variants G and H was 0.58 t ha^{-1} and 0.62 t ha^{-1}, respectively. 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 TKW index decreased after foliar fertilization. Measurements of the stomatal conductivity of leaves (Gs) showed that variant H fertilization resulted this parameter being lower relative to the control (Table 2). Hlisnikovský et al. (2016) report that the yield of winter wheat grain ranged from 7.01 t ha^{-1} to 8.88 t ha^{-1}, depending on years of research, wheat variety or applied fertilization. Ferrari et al. (2021) showed that foliar nitrogen fertilization and soil fertilization had a similar effect on the volume and quality of winter wheat yield. However, foliar fertilization allowed a reduction of the amount of nitrogen by 25-40%. Turebayeva et al. (2022) report that direct sowing of winter wheat requires proper fertilization. They showed that the grain yield increased significantly after both soil and foliar fertilization compared to the control. Stankowski et al. (2021)

Table 2

Characteristics and parameters of winter wheat (means from 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}

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

proved that foliar fertilization increased the LAI and SPAD measurements compared to the control. The grain yield was the highest when three sprayings were applied during the plant growing period. Jarecki (2021) showed that fourfold foliar fertilization significantly increased the thousand kernel weight as well as SPAD and LAI indices compared to the control. As regards the stomatal conductivity of leaves (Gs), foliar fertilization can lower this parameter with respect to control. Lv et al. (2021) report that the effectiveness of foliar fertilization depends on many factors, e.g. dose, date of application or form of fertilizer. They believe that research in this field is important due to climate change.

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 grain content of microelements was noted (Table 3). The concentration of macronutrients was stable. Makarewicz et al. (2012) obtained the highest protein content in grain after foliar fertilization with urea. Jaskulska (2010) and Chwil et al. (2014) reported that foliar fertilizer had a greater impact on yield and gluten content than on the mineral composition of winter wheat grain and straw. Kocoń (2009) and Stankowski et al. (2021) proved that foliar fertilization had a positive effect on the quality of grain and flour of winter wheat. However, they achieved this effect after spraying the wheat three times. Tsvey et al. (2021) showed that nitrogen fertilizers had a stronger impact on the yield of winter wheat in years with optimal rainfall compared to a year with its deficiency. An increase in the protein content in wheat grain was obtained after urea spraying. Kantek and Korzeniowska (2013) showed that wheat had a high demand for manganese and copper. Blandino and Reyneri (2009) report that the use of fungicide and foliar fertilization had the most beneficial effect on the quality

Table 3

The chemical composition of the grain (means from year)

Parameter	Variant of foliar fertilization*							
	A	B	C	D	E	F	G	H
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, $p<0.05$.

of winter wheat grain. Therefore, they recommend a combined application of both sprays. However, Olesen et al. (2003) showed that an increase in the nitrogen content in leaves may induce disease development. This affects the quality of the obtained winter wheat grain.

CONCLUSIONS

1. The composition of fertilizers, their dose and the time of application modified the volume and quality of winter wheat grain yield.

2. The experiment showed that the best results were obtained when three fertilizers were combined and applied in the autumn and spring.

3. Smaller effects were obtained after the combined application of two fertilizers, while the weakest impact was produced by the application of a single fertilizer.

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