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EFFECTS OF DIFFERENT FERTILIZER TREATMENTS ON GRAIN YIELD AND YIELD COMPONENTS OF SPRING WHEAT

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Abstract
The present research was carried out to investigate the effects of different fertilizer treatments on grain yield and yield components of spring wheat (*Triticum aestivum* L.) 'Harenda' cultivar. The five treatments were as follows: control (standard NPK fertilization), standard NPK fertilization plus liquid NPK (10-11-11) fertilizer, standard NPK fertilization plus liquid NPK (10-11-11) fertilizer with microelements, standard NPK fertilization plus calcium micronized suspension fertilizer, and standard NPK fertilization plus Cu, Mn, Zn, Ca micronized suspension fertilizers. The field trials were conducted in 2017 at the Experimental Site of Institute of Soil Science and Plant Cultivation – State Research Institute in Puławy, Poland. Applications of calcium micronized suspension foliar fertilizer and a mixture of Cu, Mn, Zn, Ca micronized suspension fertilizers significantly increased grain yield of spring wheat, respectively by 44.5% and 38.6% in comparison with control (standard NPK fertilization). These fertilizer treatments also enhanced yield components of spring wheat. Moreover, micronized suspension fertilizers (Ca and the mixture of Cu, Mn, Zn, Ca) had a significant effect on ear number and thousand grain weight of spring wheat compared to control and NPK fertilizers. Liquid NPK and micronutrient-enriched NPK fertilizers had a significant effect on thousand grain weight compared to control.
Key words: liquid fertilizer, micronized suspension, microelement, fertilization.

Introduction

Spring wheat (*Triticum aestivum* L.) is an important grain crop in Poland and in the world. Because of the increase in the rate of population growth and the decrease of areas of arable land, improving the grain yield is the way to meet food demand. Grain yield of cereals is the product of the following components: the number of spikes per unit area, the number of kernels per spike and thousand kernel weight (Bulman & Hunt, 1988). It can be increased due to the use of improved cultivars and nutrient management. Optimal fertilizer management is necessary to maintain sustainable yields, improve nutrient use efficiency of fertilizers, and save fertilizer resources (Chuan *et al.*, 2016). The macro- and micronutrients play an important role in the crop nutrition and thus they are important for achieving higher yields, better growth and development of plants (Imran & Gurmani, 2011). Nitrogen (N), phosphorus (P), and potassium (K) are primary nutrients in crop nutrition. N is a primary constituent of proteins, enzymes, chlorophyll, and metabolic processes involved in the synthesis and transfer of energy (Raun & Johnson, 1999). P is a component of energy compounds (e.g., ATP and ADP) and thus it is involved in biochemical pathways. Orthophosphates play a role in plant metabolic processes such as photosynthesis and respiration (Plaxon & Tran, 2011). Potassium is vital for growth as an enzyme activator that promotes metabolism. K provides abiotic stress tolerance (e.g. under drought stress), regulate stomatal opening and helps plants adapt to water deficit (Hasanuzzaman *et al.,* 2018). Calcium (Ca) is a regulator of physiological and biochemical processes in plants, especially in response to abiotic stresses (Bowler & Fluhr, 2000). This element is known as a second messenger and can delay or promote leaf senescence (Bowler & Chua, 1994), which is a terminal stage of leaf development (Thakur, Sharma, & Kishore, 2016). Ca is also believed to have an influence on the development of heat shock proteins that help the plant tolerate the stress of prolonged heat (Goswami *et al.*, 2014). Foliar calcium applications enhanced wheat yield and its components, increased transpiration rates, photosynthesis rate, stomatal conductance and chlorophyll content in spring wheat (Dolatabadian *et al.*, 2013). Micronutrients (i.e., Fe, Cu, Zn, B, Mn, and Mo) are required for growth of plants (Welch *et al.*, 1991). According to Stępień & Wojtkowiak (2016), micronutrients such as Cu, Mn, and Zn are mostly needed by plants. Many studies have showed that small quantities of foliar-applied micronutrients (solitary or in association with others) significantly increase yield, its components and enhance growth and quality of wheat grain (Ziaeian & Malakouti, 2001; Asad & Rafique, 2002; Ali *et al.*, 2009; Ali, 2012; Raza *et al.*, 2014; Gomaa *et al.*, 2015; Rawashdeh & Sala, 2015). Zinc (Zn) is responsible for the formation of growth hormones (auxin), seed and grain formation, plant height, protein syntheses, transformation and consumption of carbohydrates. Zn is known to have an important role as metal component of enzymes or as a functional, structural or regulatory cofactor of a wide number of enzymes (Hotz & Braun, 2004; Esfandiari *et al.*, 2016). Copper (Cu) is an enzyme activator, plays an important role in the metabolism of N compounds and indirect role in chlorophyll production, and increases sugar contents. Micronutrients such as Mn and Zn have an effect on protein biosynthesis by adjusting the activity of peptidases and controlling protein metabolism (Ronen, 2007; Hänsch & Mendel, 2009). Iron (Fe) promotes formation of chlorophyll as well as enzyme mechanism which operates the respiratory systems of cells and is involved in reactions of cell division and growth (Ronen, 2007).

There are known several types of fertilizer applications. One of the methods is broadcasting of fertilizers over the soil surface (Finck, 1982). Another method is a foliar fertilization, also known as foliar feeding. It is a technique of feeding plants by applying liquid fertilizers directly on the leaves or the stem (Nasiri *et al*., 2010). Fertilizers used for foliar applications are in solution or suspension. Because of the fast absorption of nutrients through the leaf cuticle or stomata, the deficiencies of macro- and microelements can be quickly corrected after being diagnosed by observation or foliar analysis. Low application rates and uniform distribution of nutrients are the main advantages of this type of application (Finck, 1982). Despite the fact that foliar fertilization is supplementary and cannot replace the basal fertilization, it is very effective. Foliar feeding should be done during periods of low temperature and relatively high humidity. The best results of feeding can be obtained during cloudy weather, in the early morning or in the evening. The application of foliar liquid fertilizers in concentrations above the recommended doses can cause leaf burning and necrosis.

The major types of fluid fertilizers are clear liquids and suspension fertilizers. Clear liquids are completely water-soluble while suspensions are partially dissolved in water, and the nutrients are suspended in the saturated solution. Suspension fertilizers are characterized by higher concentrations of nutrients than solutions of liquid clear fertilizers. Materials of low solubility are used for production of suspensions. The stability of the suspension is a major problem in this form of fertilizers. Gelling type clays (e.g., bentonite, aluminosilicates) are added in order to prevent the settling of solids and to keep the suspension stable. Nevertheless, prolonged storage of several months is not recommended for these type of fertilizers (Hagin & Tucker, 1982). One critical, although hard-to-predict, determinant of a successful foliar fertilization is the amount of ions taken up by the leaf *via* cuticular and stomatal pathways (Fernandez & Brown, 2013; Kaiser, 2014). In recent years, studies have shown that aqueous stomatal uptake under certain conditions is possible (Eichert & Burkhardt, 2001; Burkhard & Hunsche, 2013; Kaiser, 2014). Recently, new products for foliar applications containing suspended mineral microparticles have emerged on the market (Kaiser, 2014). The latest direction of research on the intentional formation of fertilizer composition to obtain better quality characteristics of crops, is a search for a very specific composition of foliar fertilizers, which would act stimulatingly in the desired direction of changes in yield characteristics (Tripolskaja *et al*., 2017).

The aim of the study was to compare the effect of different fertilizer treatments (standard NPK fertilization (control), standard NPK fertilization plus NPK foliar fertilizer, standard NPK fertilization plus NPK micronutrient-enriched foliar fertilizer, standard NPK fertilization plus calcium micronized suspension foliar fertilizer, and standard NPK fertilization plus the mixture of Cu, Mn, Zn, Ca micronized suspension foliar fertilizers) on grain yield and yield components of spring wheat (*Triticum aestivum* L.). Liquid NPK micronutrient-enriched fertilizer was applied once at the tillering phase of wheat, and other liquid fertilizers were applied at the tillering and stem elongation phases. These fertilizers were tested for the first time in field experiments.

Materials and Methods

The new innovative formulas of liquid fertilizers were used: liquid NPK fertilizer, liquid NPK micronutrient-enriched fertilizer, and Ca, Cu, Mn, Zn suspension fertilizers obtained at the Fertilizer Research Centre of New Chemical Syntheses Institute, Poland.

A field experiment was carried out in 2017 at the Institute of Soil Science and Plant Cultivation (IUNG-PIB) Experimental Site in Puławy, Poland. A spring wheat cultivar 'Harenda' was used in the experiment. A trial was set up in a randomized complete block design with five different fertilizer treatments with three replications. Treatments were as follows:

1. T_1 – Control – standard NPK fertilization: 50 kg $N\cdot ha^{-1}$ as 34% ammonium nitrate (AN), 80 kg $P_2O_5\cdot ha^{-1}$ as granular triple superphosphate, 100 kg $K_2O\cdot ha^{-1}$ as potassium salt before sowing and 40 kg $N\cdot ha^{-1}$ as 34% ammonium nitrate at the stem elongation phase (BBCH 32);
2. T_2 – standard NPK fertilization plus liquid NPK (10-11-11) fertilizer at doses of 10 $L\cdot ha^{-1}$ at the tillering (BBCH 20) and 5 $L\cdot ha^{-1}$ at the stem elongation phase (BBCH 32) (foliar application);
3. T_3 – standard NPK fertilization plus liquid NPK (10-11-11) fertilizer with microelements (0.01% B, 0.03% Fe- EDTA, 0.01% Mn-EDTA, 0.001% Mo, 0.004% Zn-EDTA, 0.004% Cu-EDTA) at one dose of 5 $L\cdot ha^{-1}$ at the tillering phase (BBCH 20) (foliar application);
4. T_4 – standard NPK fertilization plus calcium micronized suspension fertilizer (19.5% Ca) at two

Table 1

Soil properties (layer 0-30 cm) at the IUNG-PIB experimental site

Parameter	Method	Unit	Value
pH(KCl)	potentiometrically	-	6.6
Nmin, DM	gravimetric method	%	85.9
$N\text{-}NO_3$	CFA with spectrophotometric detection	$mg \cdot kg^{-1}$	5.0
$N\text{-}NH_4$	CFA with spectrophotometric detection	$mg \cdot kg^{-1}$	2.4
available phosphorus (P_2O_5)	spectrophotometric method	$mg \cdot 100g^{-1}$	26.9
available potassium (K_2O)	FAES	$mg \cdot 100g^{-1}$	18.3
available Mg	FAAS	$mg \cdot 100g^{-1}$	7.4
Ca	FAAS	$mg \cdot kg^{-1}$	921
Corg	titration method	%	0.59
organic matter	by calculation Corg x 1.724	%	1.02

doses of 5 kg Ca ha^{-1} (26 kg of Ca suspension per ha, respectively) at the tillering (BBCH 20) and at the stem elongation phase (BBCH 32) (foliar application);

5. T_5 – standard NPK fertilization plus Cu, Mn, Zn, Ca micronized suspension fertilizers (33% Cu, 23% Mn, 51%Zn, 19.5% Ca) at two doses of 100 g $Cu \cdot ha^{-1}$, 300 g $Mn \cdot ha^{-1}$, 400 g $Zn \cdot ha^{-1}$, and 5 kg Ca ha^{-1} (a mixture of 0.303 kg of Cu suspension + 1.305 kg of Mn suspension + 0.785 kg of Zn suspension + 26 kg of Ca suspension per ha, respectively) at the tillering (BBCH 20) and at the stem elongation phase (BBCH 32) (foliar application).

Foliar solutions were sprayed with a hand held spray bottle at the rate of 400 $L \cdot ha^{-1}$ on plant foliage. Spring wheat was sown in an amount ensuring a density of 450 plants per m^2. The area of each plot was 1 m^2. The soil chemical characteristics at experimental site can be seen in Table 1. Data on the yield and yield components were recorded. Plants with roots were collected from each plot (1 m^2) by hand, then labelled and plant number per 1 m^2 was counted. After harvest, productive tillers from each plot were cut using scissors and then counted. Grain yield per plant, grain yield per ear, the number of kernels per plant, and the number of kernels per ear were mathematically calculated using Excel formulas. Exactly 100 kernels from each plot were counted and weighted in three replications and the results were multiplied by 10 in order to calculate thousand grain weight.

The spring wheat vegetation period in 2017 was characterized by much higher average monthly temperatures compared to long term averages (Figure

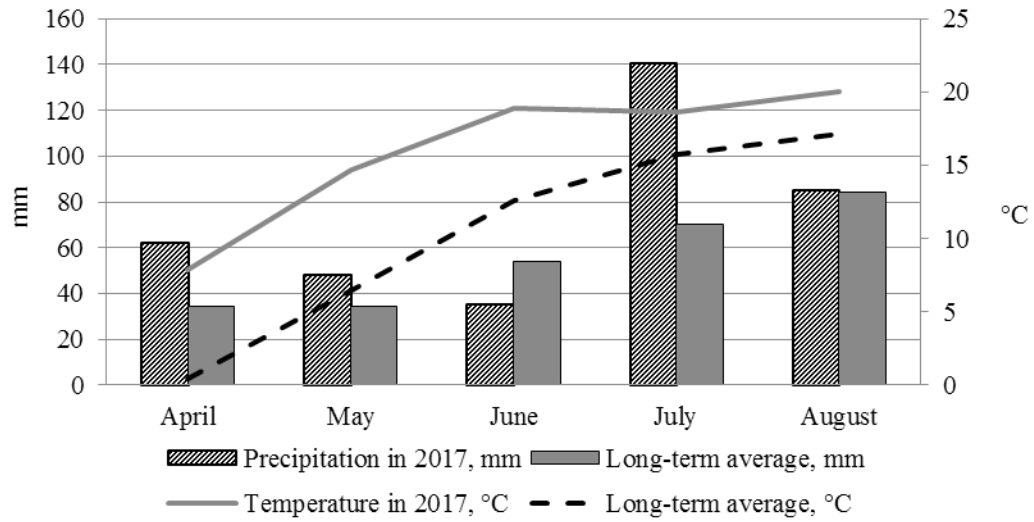

Figure 1. Weather conditions in 2017 and the long term average data (1971 – 2007).

1). In the growing season, the average temperature was 16 °C, and the sum of precipitation was 371 mm. In June, precipitations were lower (35.4 mm) than the long-term average precipitation data (54.2 mm). In contrast, the sum of precipitation in July (140.5 mm) was two-fold higher than the long term average value (70 mm).

The productive tillering coefficient (PTC) was calculated by the following formula:

$$PTC = \frac{number\ of\ produvtive\ tillers \cdot m^{-2}}{number\ of\ overwintered\ plants \cdot m^{-2}}$$

Statistical evaluation was carried out using the Statgraphics Centurion v. XVI. Analysis of variance was performed with Tukey's confidence interval at a significance level of α=0.05.

Results and Discussion

Analysis of the results showed a significant beneficial effect of micronized suspension and liquid clear fertilizers on grain yield of spring wheat. The highest grain yield was observed under applications of Ca and the mixture of Cu, Mn, Zn, Ca micronized suspension fertilizers (831.6 and 751.9 $g \cdot m^{-2}$, respectively) increasing respectively by 369.9 $g \cdot m^{-2}$ (44.5%) and by 290.2 $g \cdot m^{-2}$ (38.6%) with respect to control. Between T_1, T_2, and T_3 treatments there were no statistically significant differences ($p \geq 0.05$). But, there was only a tendency of higher grain yield after the application of NPK liquid and NPK micronutrient-enriched liquid fertilizer compared to control (by 15.7 and 11.7%, respectively) (Fig. 2). This may be due to a better crop nutrition through foliar application of suspension and clear liquid fertilizers, and also due to important roles of macro- (N, P, K, Ca) and micronutrients (Cu, Mn, Zn, B, Fe, Mn, Mo) in plant growth and development which may result in improved crop growth and increased production. Jarecki, Buczek & Bobrecka-Jamro (2017) reported that three foliar fertilizations increased grain yield in comparison with control. Ali (2012) reported that foliar application of Fe enhanced grain yield as compared to control. The highest grain yield per plant was observed under the application of the mixture of Cu, Mn, Zn, Ca micronized suspension fertilizers (T_5), followed by T_4, T_3, and T_2 treatments. Between T_1, T_2, T_3, and T_4 treatments, there were no statistically significant differences in grain yield per plant ($p \geq 0.05$). The highest grain yield per ear was observed under Ca micronized suspension fertilizer treatment (T_4), followed by T_5, T_3, and T_2 treatments.

Leszczyńska *et al*. (2007) reported that spring wheat cultivars require sowing of approximately 450 grains per m^2, because of their poor tillering. According to our study, the fertilizer treatments did not significantly affect the plant number of spring wheat per m^2 ($p \geq 0.05$). The plant number ranged from 251 to 313 plants per m^2 (Table 2) whereas the sowing density was 450 grains per m^2.

Analysis of the results showed a significant beneficial effect of micronized suspension and NPK liquid fertilizers on the ear number of spring wheat. The highest ear number was stated under T_5 and T_4 fertilizer treatments (micronized suspension fertilizers) as compared to control. Between the control (standard NPK fertilization), NPK fertilizer (T_2) and NPK micronutrient-enriched fertilizer treatments (T_3), there were no statistically significant differences in the ear number of spring wheat ($p \geq 0.05$) (Table 2). Bobrecka-Jamro, Jarecka & Jarecki (2015) confirmed that a higher NPK dose significantly increases the ear number per 1 m^2. Seadh *et al*. (2009)

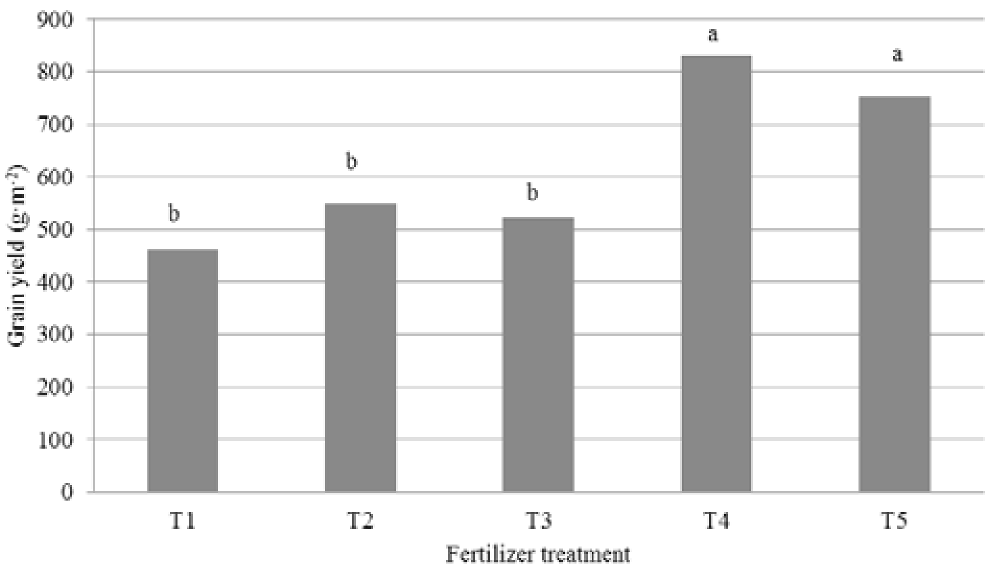

Figure 2. Grain yield ($g \cdot m^{-2}$) of spring wheat in 2017.

Table 2

Yield components and a productive tillering coefficient of spring wheat

Treatment	PN	EN	TGW (g)	GYP ($g \cdot plant^{-1}$)	GYE ($g \cdot ear^{-1}$)	NKP	NKE	PTC
T1	251	442b	38.2c	1.87bc	1.04b	49	27	1.79
T2	312	473ab	41.5b	1.76bc	1.16ab	42	28	1.52
T3	262	453b	42.0b	2.01ab	1.17ab	48	28	1.73
T4	313	605a	45.7a	2.67ab	1.37a	58	30	1.94
T5	310	611a	46.2a	2.49a	1.23ab	55	27	2.01

Notes: PN – plant number per m^2, EN – ear number per m^2, TGW – thousand grain weight, GYP – grain yield per plant, GYE – grain yield per ear, NKP – number of kernels per plant, NKE – number of kernels per ear, PTC – productive tillering coefficient. For each variable, means followed by the same letter are not significantly different at $p \geq 0.05$ (Tukey HSD test).

reported that the application of a high nitrogen dose and a multi component foliar fertilizer has the most favourable effect on the number of ears per 1 m^2. The study by Tahir *et al*. (2009) did not indicate the effect of foliar application of boron on the ear density. Arif *et al*. (2006), in turn, after the application of three-time foliar spraying, obtained a significant increase in the number of ears per 1 m^2. Jarecki, Buczek & Bobrecka-Jamro (2017) reported that the use of higher NPK dose resulted in an increase in the number of ears of spring wheat per area unit in comparison with the lower dose.

The fertilizer treatments significantly affected thousand grain weight (TGW) (Table 2). The highest TGW was observed under micronized suspension fertilizer treatments (T_4, T_5), followed by NPK liquid fertilizer (T_2) and NPK with microelement liquid fertilizer (T_3) applications, and the lowest TGW was observed under standard NPK fertilization (T_1). Arif *et al*. (2006), Rawashdeh & Sala (2016) and Jarecki, Buczek, & Bobrecka-Jamro (2017) confirmed that foliar fertilization increases TGW in wheat, but on the condition of performing several sprayings during the growing season. Nadim *et al*. (2013) did not indicate the effect of microelements applied to soil or on leaves on TGW.

The fertilizer treatments had no significant effect on the number of kernels per plant ($p \geq 0.05$) (Table 2). The number of kernels per plant increased linearly with increased N availability (Oscarson, 2000).

Number of kernels per ear is one of the most important yield determinants. The fertilizer treatments had no significant effect on the number of kernels per ear ($p \geq 0.05$) (Tab. 2). On the contrary, Arif *et al.* (2006) and Zain *et al.* (2015) reported that foliar application of nutrients had a significant effect on the number of kernels per ear. Esfandiari *et al.* (2016) reported that the foliar zinc application at the stage of grain development significantly increased grain yield by increasing the number of kernels per ear.

The fertilizer treatments had no significant effect on the productive tillering coefficient ($p \geq 0.05$) (Table 2). But the tendency of having the highest productive tillering coefficients was observed only under T_4 and T_5 treatments (1.94 and 2.01, respectively).

Conclusions

The present research revealed that different fertilizer treatments had a significant effect on the grain yield and some of the yield components of spring wheat. The use of micronized suspension foliar fertilizers (T4 and T5) significantly enhanced grain yield and yield components of spring wheat as compared to control. Liquid NPK and micronutrient-enriched NPK fertilizers (T2 and T3, respectively) had a significant effect on thousand grain weight as compared to control (T1). To confirm the results of the study, the field trials are being continued in 2018.

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