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Foliar fertilization in shaping the potato yield in the conditions of south-eastern Poland

Dolistne nawożenie w kształtowaniu plonu ziemniaka w warunkach Polski południowo-wschodniej

Summary. The study aimed at determining the effect of macro- and microelements contained in foliar fertilizers on potato productivity of tubers. The field experiment was conducted in 2015–2017 in Uhnin using the random blocks method. The first order factor were 2 cultivars of potatoes, the second order factor were 3 foliar fertilization technologies and standard object − without foliar spraying. Mineral fertilizers were constant. Foliar fertilization contributed to the increase in overall and commercial potato tuber yield. Varieties and weather conditions in the years of research also had a significant impact on the tuber yields obtained.

Key words: potato, foliar fertilization, cultivars of potato, yield of tubers, structure of tubers

INTRODUCTION

Foliar fertilization is the spraying of liquid fertilizer (a mineral salt solution or a chelate with a surface tension reducing agent) on plant leaves and stems and the absorption of nutrients at these sites. It is a supplying complementary dose of minor or major nutrients to plants [Mousavi et al. 2007, Villa et al. 2011, Shitole et al. 2012, Singh et al. 2013, Fernández et al. 2013, Trawczyński 2014, 2015, Al-Juthery and Saadoun 2018]. It can be used in the situation of difficult nutrient uptake from soil, representing an alternative way to supply plants with missing macronutrients and micronutrients [Sawicka and Skiba 2009, Pszczółkowski and Sawicka 2017]. It is the most efficient way to deliver trace elements and micronutrients to a plant. Timing of foliar fertilization should be applied to coincide with specific growth periods, using specific fertilizer fittings depending on crops and location [Fageria et al. 2009, Al-Juthery and Saadoun 2018]. It has been shown that foliar fertilization is an excellent way to supply plant requirements with secondary nutrients (magnesium, calcium, and sulfur) and micronutrients (manganese, zinc, copper, iron, molybdenum, and boron), while completing NPK needs for critical periods of growth. Foliar fertilization affects the yield, both quantitatively and qualitatively [Kozera et al. 2006, Khil et al. 2011, Trawczyński 2016, Parmar et al. 2016]. Mixed, liquid fertilizers began to be used in the United States in the early fifties. Moreover, it is now used worldwide [Wiley-Vch 2007], because it is the most effective in plant growth and development [Mona et al. 2012] and the most economical way of fertilization in order to achieve high quality crop production and yield [Singh 2007, Wadas and Dziugieł 2015]. This type of fertilization will ensure the cultivation of basic nutrients (N, P, K) and secondary nutrients (Mg, Ca, S) as well as microelements (B, Mn, Zn, Fe, Mo, Cu) [Wadas and Dziugieł 2015]. Therefore, currently, the main part of modern potato cultivation technology is foliar fertilization of multicomponent fertilizers. Foliar fertilization has recently been used extensively to correct nutritional deficiencies in plants, having potential advantages over the soil use, and may increase the effectiveness of fertilizer use [Silberbush 2002, Rawczyński 2015]. Similarly, regarding yields, this method is more efficient than soil fertilization for both macronutrients and micronutrients in different types of soil [Trawczyński 2016]. However, when the soil conditions are unfavorable, and the plant needs micronutrients, foliar fertilization can correct the level of nutrients in plants. The most important function of foliar fertilization is the supplementary intervention; it allows for correction of the poor nutritional status of plants [Fernández et al. 2013, Singh et al. 2013, Jawad and Al-Fadhly 2016]. Fernández et al. [2013] and Al-Juthery and Saadoun [2018] and Moinuddin et al. [2017] reported that the use of foliar fertilizers is the most appropriate and is used as insurance to minimize the potential unpredictable effects of nutrient deficiencies. Foliar micronutrient fertilization affects the yield [Sawicka and Skiba 2009] and quality [Kozera et al. 2006] of potato tubers. Sawicka and Krochmal-Marczak [2009] reported that foliar fertilizer intensifies resistance to pathogens infections in potato plant. Moreover, it influences on the formation of species of fungal groups colonizing potato tubers [Wierzbowska et al. 2015, Kapsa et al. 2014]. Foliar fertilizers are best used during intensive growth and development of plants; as older plants are more tolerant of higher salt concentrations compared to younger plants. Foliar fertilization causes the increased leaf activity stimulating the need for water intake by vascular plants, and as a result increases nutrient absorption from the soil [Mona et al. 2012, Singh et al. 2013]. Shitole and Dhumal [2012] found that foliar application of micronutrients increased the number of major metabolites, photosynthesis and organic components. Hence, the study is aimed at determining the effect of macro- and microelements contained in foliar fertilizers on potato productivity of tubers. The problem of foliar fertilization was a subject of many studies. Still, there is no enough information on the effect of foliar fertilization on microelements in the form of chelates and amino acids and vitamins on yield, and structure of potato tubers. In addition, the research aimed at evaluating the effectiveness of foliar fertilization of selected potato cultivars in soil and climatic conditions of south-eastern Poland.

MATERIAL AND METHODS

The field experiment was conducted in 2015–2017 in The Experimental Station for Cultivars Evaluation in Uhnin, Lublin Province [51°34'N, 23°02'E). The experiment was set up following the randomized blocks method in a subsidiary system [split-split-plot) in three replicates. The first order factor were 2 cultivars of potatoes belonging to different classes of earliness: 'Lord' − very early, 'Satina' − medium early. The second order factor were 4 foliar fertilization technologies: A) Suplofol Micro ZM + Suplofol Mono Mn + Suplofol Mono B + Magnesium Sulfate, B) Suplofol micro ZM + Suplofol Mono Mn + Magnesium Sulfate, C) Basfoliar Extra 36, D) standard object − without foliar spraying, treated with distilled water.

Techniques of foliar fertilization in the field experiment: A) fertilization with: Suplofol Micro ZM − 1 $dm^3 \cdot ha^{-1}$, with the volume of tank 400 $dm^3 \cdot ha^{-1}$, Suplofol Mono Mn − 1 $dm^3 \cdot ha^{-1}$, with the volume of tank 400 $dm^3 \cdot ha^{-1}$, Suplofol Mono B − 1 $dm^3 \cdot ha^{-1}$, with the volume of tank 400 $dm^3 \cdot ha^{-1}$, Magnesium Sulfate − 5 $kg \cdot ha^{-1}$, with the volume of tank 400 $dm^3 \cdot ha^{-1}$; B) fertilization with: Suplofol micro ZM − 2 $dm^3 \cdot ha^{-1}$, with the volume of tank 400 $dm^3 \cdot ha^{-1}$, Suplofol Mono Mn − 1 $dm^3 \cdot ha^{-1}$, with the volume of tank 400 $dm^3 \cdot ha^{-1}$, Magnesium Sulfate − 5 $kg \cdot ha^{-1}$, with the volume of tank 400 $dm^3 \cdot ha^{-1}$; C) fertilization with fertilizer Basfoliar Extra 36 − concentration of 6% of the liquid spray, 2–3 times during the growing season, 12 $dm^3 \cdot ha^{-1}$, with the volume of tank 400 $dm^3 \cdot ha^{-1}$; D) standard fertilization – without foliar spraying, with distilled water (400 $dm^3 \cdot ha^{-1}$ of water).

Basfoliar Extra 36 – is a fertilizer containing nutrients in the following amounts: nitrogen (N) 27%, magnesium (MgO) 3.2%, boron (B) 0.02%, copper (Cu) 0.2%, iron (Fe) 0.02%, manganese (Mn) 1.0%, molybdenum (Mo) 0.005%, zinc (Zn) 0.01%. It is widely used in agriculture and horticulture. Basfoliar 36 Extra is characterized by high content of nitrogen (N) and magnesium (MgO). All micronutrients are chelated with biodegradable IDHA chelate [Basfoliar Extra 36 2015].

Magnesium Sulfate – is a fertilizer containing nutrients in the following amounts: (MgO) 16%, Mg 9.7%, So3 32%, S 12.8%. This fertilizer is used with all crops, especially when magnesium is needed, preparation of production of liquid fertilizers [Magnesium Sulfate 2015].

Suplofol Mikro ZM – foliar fertilizer, suitable for all potato cultivars. Contains high amounts of manganese (Mn), boron (B) and zinc (Zn). It ensures optimum development of plants, as potatoes are very sensitive to deficiencies of these elements. It is a fertilizer containing nutrients in the following amounts: nitrogen (N) 15%, magnesium (MgO) 2%, sulphur (SO_3) 5.0%, boron (B) 0.31%, copper (Cu) 0,065%, iron (Fe) 0.08%, manganese (Mn) 1.80%, molybdenum (Mo) 0,016%, zinc (Zn) 0.73% [Suplofol Mikro ZM 2015].

Suplofol Mono B – modern boron fertilizer – boroethanolamine. Particularly useful for plants most sensitive to boron deficiency, such as sugar beet, rapeseed, potato. Composition: Boron (B) 8% m / m [Suplofol Mono B 2015].

Suplofol Mono Mn – it is fertilizer-containing manganese (Mn) 8%, it is particularly recommended for feeding cereals, especially oats, where the manganese deficiency causes gray spots. Very susceptible to manganese deficiency are also potatoes, sugar beet and fodder beet and canola [Suplofol Mono Mn 2015].

The forecrop of potato in 2015–2017 was spring barley. In the autumn of each year preceding planting, winter plowing was carried out to a depth of about 27 cm. In the spring, the field harrowing was carried out, and then NPK fertilizers were sown and mixed with a cultivating aggregate to a depth of 12 cm. Mineral fertilizers: potassium, phosphorus and sulfur were applied to the soil in quantities: 39.3 kg $P \cdot ha^{-1}$, 112.1 kg $K \cdot ha^{-1}$ and 15.8 kg $S \cdot ha^{-1}$. The amount of mineral fertilization was determined on the basis of soil fertility in these components. Nitrogen fertilizers were also sown in the spring in the amount of 90 kg $N \cdot ha^{-1}$ (27 kg Polifoska + 63 kg Urea). Reproductive material of potato in the class degree C/A was manually planted, annually in the spring, at the end of April at the spacing of 67.5 × 37 cm, according to the scheme of experiment. During the potato vegetation, treatments were according to principles of Good Agricultural Practice. Plant protection against diseases, pests and weeds was carried out in accordance with the IOR-PIB recommendations and the principles of Good Agricultural Practice. There were used chemical plant protection agents to fight: weeds, Colorado potato beetle, potato pests and late blight, as well as the doses, timing of application and the choice of products were in line with the recommendations of Polish Institute of Plant Protection − State Research Institute (IOR-PIB) (Tab. 1).

Foliar fertilizers were used in accordance with the recommendation of the producers 3 or 4 times starting from phase BBCH 39 (crop cover complete: about 90% of plants meet between rows) to BBCH 79 (nearly all berries in the Nth fructification have reached full size or have been shed). The harvests of potato tubers were made in the period of technical maturity at the end of August (‘Lord’ − very early) and in the mid of September (‘Satina’ − medium early). At the time of harvest, the potato tuber crop, as well as its structure was determined.

The work verified the alternative hypothesis, which assumes that foliar fertilization has a positive effect on the total and commercial yield of tubers, its structure, in connection with the null hypothesis that there is no difference between the objects with foliar fertilization and the standard combination without foliar fertilization.

Statistical analyses were based on three-factor analysis of variance (ANOVA) and multiple T-Tukey tests, with the assumed significance level $\alpha = 0.05$. The models of variance analysis with the main effects of the factors studied and their interactions were used. The detailed analysis only dealt with the main effects. The calculations were made with the help of SAS Enterprise 4.2 program [SAS 2008]. T-Tukey’s multiple comparison tests enabled detailed comparative analyses of averages, by isolating statistically homogeneous medium groups (homogeneous groups) and determining the so-called the smallest significant mean differences, which in Tukey’s tests are marked by HSD (Tukey’s honest significant difference).

Table 1. The agricultural treatments and equipment used in the experiment (2015–2017)

Autumn 2015–2017		
Tillage		
Winter plowing to a depth of about 27 cm		
Herbicides		
Bizon – 1 $dm^3 \cdot ha^{-1}$ (Autumn 2016) Lentipur flo 500 SC – 1 $dm^3 \cdot ha^{-1}$ (Autumn 2017) Glean 75 WG – 0.01 $kg \cdot ha^{-1}$ (Autumn 2017)		
Spring 2015	Spring 2016	Spring 2017
Tillage and agricultural processes		
Harrowing NPK fertilization Planting of seeds-potato manually Earthing up Spray herbicides Harvest with potato elevator digger	Harrowing NPK fertilization Planting of seeds-potato manually Earthing up Spray herbicides Harvest with potato elevator digger	Harrowing NPK fertilization Planting of seeds-potato manually Earthlng up Spray herbicides Harvest with potato elevator digger
Fungicides		
Infinito 867.5 SC – 1.6 $dm^3 \cdot ha^{-1}$	Infinito 867.5 SC – 1.6 $dm^3 \cdot ha^{-1}$ Acrobat MZ 69 WG – 2 $kg \cdot ha^{-1}$	Infinito 867.5 SC – 1.6 $dm \cdot ha^{-1}$ Acrobat MZ 69 WG – 2 $kg \cdot ha^{-1}$
Insecticides		
	Actara 25 WG – 0.08 $kg \cdot ha^{-1}$ Nuprid 200 SC – 0.15 $dm^3 \cdot ha^{-1}$	Actara 25 WG – 0.08 $kg \cdot ha^{-1}$ Apacz 50 WG – 0.04 $kg \cdot ha^{-1}$ Proteus OD 110 – 0.4 $dm^3 \cdot ha^{-1}$ Fastac O50 ME – 0.2 $dm^3 \cdot ha^{-1}$

Meteorological conditions in the years of research were varied. The year 2015 was characterized by dry June and July with extremely dry August, during the period of maximum yield of tubers. In 2016, the April was cold and optimum for rainfall, in May relatively hotter and dry, June and July were quite warm, and July was characterized by humid weather due to large precipitation. In August, the temperature was still high and very dry, while the temperature decreased in September and this month was extremely dry. The year 2016 was characterized by an excess of precipitation in the important stages of potato growing, in relation to the water requirements of potato. In the year 2017, April was cold and wet, especially at the end, in May the air temperature was increased than previous month with optimum rainfall. While in June, July and August, the level of air temperature continued to increase and referring to the rainfall, June and August were extremely dry, but July was wet, September was moderate in respect of the air temperature and fairly humid (Tab. 2).

Table 2. Rainfalls, air temperature and the hydrothermal coefficient of Sielianinov, during the growing season of potato, according to the meteorological station in Uhnin 2015–2017

Year	Month	Sum of Rainfall (mm)	Average temperature (°C)	Hydrothermal coefficient of Sielianinov*	Classification of the month according to Skowera et al. (2014)
2015	April	61.8	8.8	2.3	wet
	May	120.3	12.8	3.0	very humid
	June	46.7	16.7	0.9	dry
	July	45.2	19.4	0.8	dry
	August	6.1	21.4	0.1	extremely dry
	September	130.2	15.5	2.8	very humid
	Average	–	–	1.7	–
2016	April	47.1	10.0	1.6	optimum
	May	46.3	15.3	1.0	dry
	June	87.3	19.1	1.5	optimum
	July	114.1	20.5	1.8	fairly humid
	August	41.0	19.5	0.7	very dry
	September	11.8	15.5	0.3	extremely dry
	Average	–	–	1.2	–
2017	April	51.8	8.1	2.1	wet
	May	65.5	13.7	1.5	optimum
	June	23.1	18.3	0.4	extremely dry
	July	132.0	19.4	2.2	wet
	August	27.0	20.3	0.4	extremely dry
	September	83.3	14.8	1.9	fairly humid
	Average	–	–	1.4	–

Source: the meteorological station in Uhnin
Ranges of values of this index were classified according to Selianinov***** as: extremely dry − $k \le 0.4$; very dry − $0.4 < k \le 0.7$; dry − $0.7 < k \le 1.0$; fairly dry − $1.0 < k \le 1.3$; optimum − $1.3 < k \le 1.6$; fairly humid − $1.6 < k \le 2.0$; wet − $2.0 < k \le 2.5$; very humid − $2.5 < k \le 3.0$; extremely humid − $k > 3.0$

The soil. The experiment was carried out on sandy loam soil type. According to percentage content of sand, silt and loam fraction, this is a granulometric subgroup – clay sand (light soil). Soil granulometric composition was determined by means of the aerometric method by Prószyński [Ryżak et al. 2009]. The fraction of sand was 67%, the dust fraction was 30.6% and the loam was 2.4%. This proportion of individual fractions corresponds to the composition of loamy dust. In terms of agricultural suitability, these soils belong to slightly acidic good rye complex. This soil is classified to agronomic category as light mineral [Mocek 2015]. The soil content in available components was as follows:

phosphorus and magnesium very high (9.2 mg P·100 g^{-1} soil, 4.2 mg Mg·100 g^{-1} soil), medium in potassium (9.9 mg K·100 g^{-1} soil), medium in copper (7.02 mg Cu·kg^{-1} soil), in manganese, iron and zinc also medium and was respectively 273.8 mg Mn·kg^{-1} of soil, 3761.7 mg Fe·kg^{-1} of soil, and zinc the average was 45.96 mg Zn · kg^{-1} of soil. In case of boron, the average was high, about 6.17 B·kg^{-1} of soil (Tab. 3). The average acidity of the soil in a solution of KCl in 2015 and 2016 was 5.92 pH – 5.77 pH; these values allowed the classification of the experimental soil as slightly acidic soil, while natural acidic soils in 2017 had 6.6 pH. The humus content in the arable layer was low and formed at 0.94–1.06%.

Table 3. Physical and chemical properties of soil in Uhnin (2015–2017)

Year	Content of available macronutrients [mg·kg^{-1} soil]			Humus content (%)	pH_{KCL} (mol·dm^{-1})	Micronutrients content (mg·kg^{-1} soil)				
	P	K	Mg			Cu	Mn	Zn	Fe	B
2015	88.0	109.0	47.0	0.94	5.92	7.51	318	40.1	3760	7.24
2016	82.0	90.0	42.0	1.06	5.77	4.92	337	56.7	3925	5.28
2017	105.0	98.0	38.0	1.03	6.60	8.99	166	41.1	3600	6.04
Average	210.0	99.0	42.0	1.02	6.09	7.02	274	46.0	3762	6.17

Source: Own experiment results, which made in the Laboratory Central of Agro-Ecological (LCAE), the University of Life Science in Lublin

RESULTS

Yield of tubers. The average yield of tubers in the experiment was 46.92 Mg·ha^{-1}, and it can be considered high, because it exceeds twice the national yield. This feature was influenced by all factors of the experiment (Tab. 4). The use of multifactorial variance analysis also allowed for calculating the combined coefficient of variation (CV) or relative standard deviation (RSD) [%] for each variable potato in total. The coefficient of variability (CV or RSD), that is the measure of a random variability in analyzed experimental results, was low (CV = 1,32%), which means that these results are credible and great confidence can be given to experimental data (Tab. 4). Application of foliar fertilization significantly differentiated the yield of tubers. The highest effect of this treatment, in the form of tuber yield increase, was achieved in the object with foliar fertilization using Basfoliar Extra 36, for which the yield of tubers was 3.5% higher than in the standard object (Tab. 4). Another application that caused significantly increase: – Suplofol micro ZM + Suplofol Mono Mn + Suplofol Mono B + Magnesium Sulfate Suplofol micro ZM + Suplofol Mono Mn + Magnesium Sulfate (increase by 2.1%) and the lowest increase in yield were observed with – Suplofol Micro ZM + Suplofol Mono Mn + Magnesium Sulfate (1.9%). Objects with foliar fertilizers Suplofol proved to be homogeneous in terms of the value of this feature (Tab. 4).

Table 4. Influence of foliar fertilization, cultivars and years of cultivation on total yield of potato tubers ($Mg \cdot ha^{-1}$)

Technologies	‘Lord’				‘Satina’				Average			Average
	2015	2016	2017	Average	2015	2016	2017	Average	2015	2016	2017	
A	40.69	47.97	46.42	45.03	40.73	55.76	50.56	49.02	40.71	51.87	48.49	47.02
B	39.96	48.79	46.19	44.98	38.40	55.24	53.04	48.89	39.18	52.02	49.62	46.94
C	41.27	52.40	43.71	45.79	40.16	56.62	51.82	49.53	40.72	54.51	47.77	47.66
D	42.80	48.18	44.83	45.27	39.82	51.00	49.62	46.81	41.31	49.59	47.23	46.04
Average	41.18	48.56	45.64	45.13	39.95	54.66	51.04	48.55	40.48	47.60	49.90	46.92
$HSD_{0.05}$	technology – 0.37; cultivars – 0.19; years – 0. 29; technology × years – 1.11; technology × cultivars – 0.74; cultivars × years – ns											
RSD (%)	1.32											

A – Suplofol Micro ZM + Suplofol Mono Mn + Suplofol Mono B + Magnesium Sulfate; B – Suplofol Micro ZM + Suplofol Mono Mn + Magnesium Sulfate; C – Basfoliar Extra 36; D – standard object without foliar fertilization; ns – not significant

Genetic characteristics of the cultivars examined were the most important factors influencing the yield. ‘Satina’ was the most fertile one, then ‘Lord’. ‘Satina’ produced almost 6.6%, then ‘Lord’ (Tab. 4).

Atmospheric conditions in the years of research significantly determined the yield. The highest yield was obtained in 2017, while the lowest in 2015 (Tab. 4).

In 2016, the highest effect of foliar fertilization was obtained in object fertilized with Basfoliar Extra 36, in comparison with the standard object. In 2017, with the dry June and very wet July, the highest yield of tubers was obtained in the facilities with fertilizers Suplofol, both combinations of these fertilizers were homogeneous in terms of the size of this characteristic and in 2015, a dry year, the highest tuber yield was obtained in the control facility, without foliar fertilization with micronutrient fertilizers (Tab. 4).

The cultivars tested showed a differentiated response to foliar fertilization (Tab. 4). The ‘Lord’ with the application of foliar fertilizers contributed to significant increase in the yield, as compared with fertilization fertilize Suplofol (Technology A and B). The highest yield was obtained using Basfoliar Extra 36. ‘Satina’ responded most favorably to foliar fertilizers. Application of Basfoliar Extra 36 increased by 5.8% higher than the standard object, then Suplofol Micro ZM + Suplofol Mono Mn + Suplofol Mono B + Magnesium Sulfate increased the yield about 4.7% and the combination of Suplofol Micro ZM + Suplofol Mono Mn + Magnesium Sulfate fertilizers increased the yield of potato about 4.4%, comparison to standard object with distilled water (Tab. 4).

Share weight of tubers in yield. The largest share in the total yield had tubers with a diameter of 36–50 mm (67.4%), while the smallest – tubers with a caliber >60 mm (2,4%) (Tab. 5). The coefficient of variability (CV or RSD) was very low to low (CV = 0.8–9.7%), which means that these results are credible and great confidence can be given to experimental data (Tab. 5).

Table 5. Effect of foliar fertilization, cultivars and growing years on the contribution of particular fractions of tubers in the total yield

Factors of the experiment		Share fractions of tubers (%)			
		<35 mm	36–50 mm	51–60 mm	>60 mm
Foliar fertilization	A	7.4 a	66.8 b	23.3 c	2.5 a
	B	7.6a	66.2 c	23.9 b	2.4 b
	C	4.8 b	68.4 a	24.3 a	2.5 a
	D	7.5 a	68.2 a	22.2 d	2.1 c
	$HSD_{0.05}$	0.2	0.3	0.3	0.1
Cultivars	‘Lord’	7.1 a	71.1 a	20.2 b	1.5 b
	‘Satina’	6.6 b	63.7 b	26.6 a	3.3 a
	$HSD_{0.05}$	0.2	0.3	0.3	0.1
Years	2015	7.3b	72.0 a	17.9 c	2.8 a
	2016	5.4 c	62.6 c	29.6 a	2.4 b
	2017	7.8 a	67.6 b	22.7 b	1.9 c
	$HSD_{0.05}$	0.1	0.3	0.2	0.1
Average		6.8	67.4	23.4	2.4
RSD (%)		4.3	0.8	1.8	9.7

A – Suplofol Micro ZM + Suplofol Mono Mn + Suplofol Mono B + Magnesium Sulfate; B – Suplofol Micro ZM + Suplofol Mono Mn + Magnesium Sulfate; C – Basfoliar Extra 36; D – standard object without foliar fertilization

Application of foliar fertilization modified the share of weight of tubers of all crop yield fractions. The foliar application of Basfoliar Extra 36 contributed to a significant reduction in the proportion of tubers with a diameter <35 mm, and increased participation of tubers of other size fractions, except for the 36–50 mm fraction, in comparison with the standard object (Tab. 5).

Foliar applications of foliar fertilizers in object (A) (Suplofol Micro ZM + Suplofol Mono Mn + Suplofol Mono B + Magnesium Sulfate) and in object (B) (Suplofol Micro ZM + Suplofol Mono Mn + Magnesium Sulfate) it did not significantly affect the weight of tubers <35 mm in diameter. The application of fertilizers in the object A is not affected by mass small tubers and medium-sized (diameter <35 mm in diameter and 36–50), but significantly increased the share of the weight of large tubers with a diameter of 51–60 and >60 mm in diameter. The addition of foliar fertilizers at object B was reduced the share of tuber weight with a diameter of 36–50 mm and increased the weight of large tuber with a diameter of 51–60 and >60 mm in diameter (Tab. 5).

Structure of the crop was determined by genetic factor. The most beneficial structure, i.e. the highest share of large tubers with a diameter >51 mm and the smallest share of fine and medium tubers (<35 and 36–50 mm) in the general yield revealed 'Satina', the least favorable – 'Lord' (Tab. 5).

The most favorable yield structure was observed in 2016, the average in terms of rainfall and air temperatures, because plants produced the largest proportion of tuber mass with a diameter of 51–60 mm. The least favorable in this respect was fairly year 2015, which was characterized by drought in June–August and the air temperature above the long-term average (Tab. 5).

Table 6. Influence of foliar fertilization, cultivars and years of cultivation on the commercial yield and the share of commercial potato tubers

Factors of the experiment		Share of commercial tubers (%)	Commercial yield of tubers ($Mg \cdot ha^{-1}$)
Foliar fertilization	A	92.58 b	43.27 b
	B	92.08 c	43.00 b
	C	95.15 a	46.18 a
	D	92.37 b	41.65 c
	$HSD_{0.05}$	0.18	0.34
Cultivars	'Lord'	92.47 b	41.50 b
	'Satina'	93.61 a	45.62 a
	$HSD_{0.05}$	0.18	0.34
Years	2015	92.99 b	37.57 c
	2016	94.53 a	48.82 a
	2017	91.62 c	44.28 b
	$HSD_{0.05}$	0.14	0.27
Average		93.04	43.54
RSD (%)		0.32	1.31

A – Suplofol Micro ZM + Suplofol Mono Mn + Suplofol Mono B + Magnesium Sulfate; B – Suplofol Micro ZM + Suplofol Mono Mn + Magnesium Sulfate; C – Basfoliar Extra 36; D – standard object without foliar fertilization

Share and yield of commercial potato tubers. The tuber yields in the experiment were high and amounted to 43.54 $Mg \cdot ha^{-1}$ on average and the share of commercial tubers was 93.04% (Tab. 6). The coefficients of variation (RSD – relative standard deviation) for the share of commercial tubers in yield and commercial yield were very low (0.32% and 1.32%, respectively, which indicates very small variability of results in the conducted experiment (Tab. 6). All foliar fertilizers significantly altered the share of commercial tubers in the total yield of potato tubers. Fertilizer Basfoliar Extra 36 resulted in a significant increase in the share of commercial tubers yield as compared to the standard object. In the remaining combinations of fertilizers, share of commercial yields of tubers were significantly higher than standard object, but Suplofol Micro ZM + Suplofol Mono Mn + Magnesium Sulfate and Suplofol Micro ZM + + Suplofol Mono Mn + Suplofol Mono B + Magnesium Sulfate and standard object were homogenous, referring to this feature (Tab. 6).

Genetic traits shaped both the share of commercial bulbs in the total yield and the volume of commercial yield. The higher share of commercial tubers and their greater yield characterized the medium early cultivar of 'Satina' then very early cultivar 'Lord' (Tab. 6). Meteorological conditions during the study period significantly influenced the mass of commercial tubers. The highest share of tubers of this caliber was observed in 2016, while the lowest in 2017. The highest yield of commercial tubers was in 2016, optimal in the precipitations of the year, and the lowest – in dry 2015 (Tab. 6).

DISCUSSION

Foliar fertilizers used in the experiment had varied impact on total and commercial yield of tubers and its structure. Average potato yield in Poland, according to Winnicki and Bogucka [2017], is 27.0 Mg·ha^{-1}. In the experiment, the average yield was 46.92 Mg·ha^{-1} and can be considered high, as it exceeded the average national yield by 73.8%. The commercial yield of tubers was 43.54 Mg·ha^{-1} and represented 93.04% of the total yield. Results obtained by other researchers in this field varied depending on the potato variety and different experimental conditions. According to Nowacki [2008], potato yield in the field experiments, depending on the cultivation system, ranged from 23.6 Mg·ha^{-1}, in the organic system to 31.7 Mg·ha^{-1} in the integrated system; the share of commercial tubers accounted respectively: 63.1% and 70.7% of total tuber yield, while Trawczyński [2014] reported that potato tubers yield in light soils conditions at 32.5–37.9 Mg·ha^{-1}, depending on the year. The total yield of tubers on light soil, in amount of 25.1 Mg·ha^{-1} and on heavy soil 26.4 Mg·ha^{-1}, was obtained by Różyło and Pałys [2007]. According to Michałek et al. [2000], potential yields of very early cultivars potato, on light soils are much higher: 51.3 Mg·ha^{-1}, but in conditions of medium soils, they yield up to 100 Mg·ha^{-1} [Pszczółkowski et al. 2016].

According to many authors [Boligłowa 2003, Sawicka and Skiba 2009, Jabłoński 2009, Trawczyński 2014, Al-Juthery and Saadoun 2018], the use of foliar fertilizers causes a significant increase in the yield of potato tubers. This is confirmed by own research, in which the application of foliar fertilization significantly differentiated the yield of tubers. The highest effect of this treatment, in the form of total and commercial yield increase, was achieved in the object with foliar fertilization using Basfoliar Extra 36. It was higher than in the standard object, while another application that caused significant increase: Suplofol Micro ZM + Suplofol Mono Mn + Suplofol Mono B + Magnesium Sulfate and the lowest increase in yield, were observed after application fertilizers: Suplofol micro ZM + Suplofol Mono Mn + Magnesium Sulfate.

This finding is consistent with those of past studies of many authors, such as Jaskulski and Gałęzowski [2009], who found an increase in yield by only 4%, compared to the control object after applying fertilizers Sonata and Symbol-Vita, while in Jabłoński's studies [2009], the use of Sonata Z and Alkalin PK fertilizers 10 : 20 contributed to the increase in the total yield by 16.1–19.5%, depending on the cultivar. Also, in many studies of Trawczyński [2013, 2014, 2015], an increase in yield by 5–20%, after application of foliar fertilizers, depending on the fertilizer used, was reported.

After applying the foliar fertilizers of manganese in the conditions of Colombia, Villa et al. [2011] obtained significant results depending on the cultivar increasing the yield of potato tubers. The increase of yield was varied depending on the cultivars and conditions of experiments, the increase as compared with the standard object was 10% due to Szewczuk [2009], 7% due to Trawczyński and Korycki [2008] after using fertilizers Campofort, 3% due to Rizk et al. [2013], when using 3% urea solution to a foliar application. Rastogi et al. [2017] report about impact of metal and metal oxide nanoparticles on plant. According to Sawicka [2003], who investigated the effect of preparation Insol 7, in the conditions of Poland, for yielding the potato, a significant but differentiated yield production effect was obtained, depending on the cultivars. Moreover, study by Jawad and Al-Fadhly [2016] examining application of foliar manganese and zinc (together or separately), revealed significant increase in the tubers yield. In addition, results are in line with earlier literature by other authors [Mousavi et al. 2007, Jabłoński 2007, 2009, Jakiene et al. 2008, Rasool et al. 2010, Mona et al. 2012, Jasim 2013, Keutgen et al. 2014], who found significant, beneficial effects of fertilization of potato tubers.

Al-Juthery and Saadoun [2018], showed that nano-applied (Cu + Zn + Fe + Mn) treatment as well as triple, double and single spray combinations, these formulations were significantly better on the yield of fresh and dry tubers compared to traditional micronutrient fertilizers and a control object, sprayed only with distilled water. Mona et al. [2012] argued, using the elements supplied to the plant in the form of spraying, that it affects the efficiency of potato plants, because it will be the cause of more intensive vegetative growth, more intensive photosynthesis, increased carbohydrate production. Also, the effect of tuber yield increase after the application of urea solution was caused by loosening the potato leaf tissues by this solution, which allows more intense penetration of fertilizer components [Janmohammadi et al. 2015].

However, soil mineral reserves and soil fertilization are not always sufficient to satisfy the needs of crops. Disorders in potato nutrition occur in acidic and alkaline soils. In acidic soils, there is a lack of calcium, magnesium and phosphorus for growing the crops, and in alkaline ones, there is lack of boron, manganese and zinc [Janmohammadi et al. 2015]. The alternative approach is the application of these nutrients to plant leaves and stems through foliar fertilization. Foliar fertilization is a supplemental nutrition with macro and micronutrients. Foliar nutrition is ideally designed to provide many elements in conditions that may limit the production at a time when nutrient uptake from the soil is inefficient or nonexistent.

On the market, there are different foliar fertilizers, that are often mixtures of micronutrients and secondary nutrients [Mousavi et al. 2007, Al-Juthery and Saadoun, 2018]. Their application is recommended to increase the yield and quality of crops. Observed effects include an increase in crop yield and quality of potato crop [Bednarek et al. 2006, Jasim 2013, Trawczyński 2016].

However, some studies could not confirm the positive results of foliar fertilization in potato. There is considerable lack of scientific results based on effectiveness of foliar fertilizers on plant metabolism. In a preliminary study, Horvat et al. [2014] did not find any positive effect of foliar fertilizer Megagreen (44.1% CaO) on chlorophyll content in potato leaf. Chapagain and Wiseman [2004] determined a significant increase of chlorophyll content in tomato leaves after foliar application of Nutri-Vent-PeaK (95% monocalcium-phosphate). Physiological response of potato to the application of foliar fertilizers is not sufficiently known. Moreover, Horvat et al. [2014] in all the other days after planting, observed no significant differences in the intensity of photosynthesis between treatments and control. Effect of foliar fertilizers on the concentration of chlorophyll pigments and concentration of total carotenoids in potato leaves was not significant. However, the highest tuber dry matter yield under conditions of higher than optimum temperature was obtained with the foliar fertilizer Mega green, that contains calcium.

The use of foliar fertilizers depends on the soil acidity and its abundance in nutrients, because acidic soil pH promotes the presence of trace elements in more mobile forms and creates conditions for greater accumulation of these elements in plants, which is the reason for the increased amount of trace metals in tubers and may be the cause of some diseases [Bednarek et al. 2006]. It is worth adding here that the Polish soil is mostly characterized by the natural content of trace metals [Lipiński 2005]. On the other hand, there are also many studies that do not confirm a significant increase in yield under the influence of foliar fertilization, such as Bogucka et al. [2010], Bogucka and Cwalina-Ambroziak [2016] and Wróbel [2012] did not observe the increase in yield, but found similar results after using foliar fertilizers: Actisil and Yara Vita. Also, Boligłowa [2003] did not find any significant effect on the total yield of potato tubers after using foliar urea and Agrosol-K and fertilizer concentrate (Ekosol K, Insol 7). In addition, Dkhil et al. [2011] reported that the use of increasing doses of potassium in the form of potassium nitrate did not make the increase in yield.

In the current market situation, edible potato producers have to care not only for the high overall yield, but above all, for the largest share of the commercial yield in it. The volume of commercial yield is an important factor determining the profitability of growing potatoes, both edible and for direct consumption, as well as other directions of use. Until now, it was assumed that the commercial yield of edible potato harvested after ripening is a part of the total yield, in which the size of tubers is over 4 cm in transverse diameter. Currently, they are increased requirements as to the quality of edible potatoes, which forced the definition to be tightened: the commercial yield of edible potato harvested after the end of vegetation is part of the total yield of tubers over 3.5 cm in diameter, with the largest possible leveling of tubers of this caliber in the batch (share of tubers of specific fractions in the yield), with no external defects [Trawczyński 2013].

The foliar fertilizers applied in our study contributed to the increase of commercial yield by 3.3–10.9%, depending on the type of fertilizer. The research by Jabłoński [2009] showed an increase in the tuber yield by 11.2% after using Florovit, while applying fertilizers Sonata with Alkalin PK 10 : 20, it gained an increase in this attribute by 8.0–22.6%, depending on the cultivar. The research by Rizak et al. [2013] also found increased commercial yield by approximately 9%, when applying 6% solution of urea and Ekosol K fertilizer. Furthermore, Boligłowa [2003] concluded that significant increase in the commercial yield of tubers after the application of 6% aqueous urea solution, as well as Trawczyński and Korycki [2008] studies proved that using the foliar Campofort increases the commercial yield by an average of 13%. The beneficial effect of foliar fertilization on the volume of commercial yield was also demonstrated by Jakiene et al. [2008], Jabłoński [2009], Rasool et al. [2010], and Trawczyński [2013, 2014]. Trawczyński and Korycki [2008] pointed out that foliar fertilization causes an increase in the commercial yield in the very dry year by up to 24.1%, compared to the control object, in adverse water and thermal conditions. Trawczyński [2013] obtained higher yielding effect after applying fertilizer Herbagreen, which proved that the period of drought makes it difficult for plants to take up the ingredients from the soil, and their use in the form of spraying allows for quick action and high efficiency.

In the conducted studies, the application of foliar fertilizers had significant impact on increasing the share of tuber mass with a diameter of 51–60 mm and >60 mm. That finding is consistent with those of past studies carried out by other authors [Boligłowa 2003, Jabłoński 2007, 2009, Jakiene et al. 2008, Dkhil et al. 2011, Wróbel 2012, Trawczyński 2013, 2014, 2015, Jawad and Al-Fadhly 2016]. Trawczyński and Korycki [2008] also showed similar results and obtained an increase in the share of tubers fraction 4–5 cm and 5–6 cm by 1% and 6 cm tubers by 2%, as compared to the control object. Furthermore, Jabłoński [2009] observed an increase about 12.4–27.0% in the fraction of tubers of 5 cm in diameter, depending on the cultivar. Wróbel [2012], using the Actisil silicon formulation and Yara Vita Potato, obtained an increase in the weight of tubers with a diameter of 6 cm, respectively, by 23.0% and 10.0%. The results of Boligłowa [2003], who considered applying foliar fertilizer Ekolist K, noted significant reduction in the share of large potato tubers with a diameter of 60 mm. According to El-Zohiri and Asfour [2009], the use of foliar fertilization (in the form of potassium nitrate) and magnesium (in the form of magnesium sulfate) proved that it leads to an increase in the proportion of tubers with a diameter of 36–45 mm and >45 mm, while reducing the share of small tubers (28–35 mm). In another study, Trawczyński [2013] examined foliar fertilization using a multi-ingredient Herbagreen and found a 2% increase in the proportion of tubers with a diameter of 50–60 mm and 4% tubers with a diameter of >60 mm. Similarly, Dkhil et al. [2011], using foliar potassium, noted significant increase in the weight of tubers. Moreover, they found similar results to those obtained by Jawad and Al-Fadhly [2016], and recorded an increase in the average weight of tubers under the influence of foliar application of zinc and manganese. Jabłoński [2009], using Florovit, obtained an increase in the seeds potato by 33.3%, while applying foliar fertilizers Sonata z and Alkalin PK 10 : 20 showed increased this fraction by 11.8–27,6%, with lower level of soil fertilization.

Own research confirms these results, as the foliar fertilizers used in the experiment significantly increased the share of seed potatoes. The greatest positive impact of foliar fertilization on the share and yield of seed potato in the total yield was due to the use of fertilizers Basfoliar Extra 36. The issue of the seed potatoes is important for seed production, because their share and yield are of great importance due to their insufficient replacement of seed potatoes in Poland.

Research of many authors such as: Boligłowa [2003], Jasim [2013], Fernandez et al. [2013], Trawczyński [2013, 2014, 2016], Pszczółkowski et al. [2016], have confirmed that genetic traits of cultivars have significant impact on yield and quality traits. They also differentiate the yield structure, which is confirmed by the results of own study and other authors [Boligłowa 2003, Sawicka and Skiba 2009, Wadas and Dziugieł 2015]. Pszczółkowski and Sawicka [2017] found that varietal variability may result from different anatomical structure, morphological characteristics, chemical composition of potato tubers, as well as complexity of these traits. In the study carried out, the cultivars determined to the largest extent the yield of tubers. The highest yield of tubers was noted in 'Satina' (48.6 $Mg \cdot ha^{-1}$), but the lowest – 'Lord' (45.1 $Mg \cdot ha^{-1}$). Żołnowski [2013] recorded a yield of tubers at the level of 33.4 to 35.9 $Mg \cdot ha^{-1}$ depending on the cultivar. Potential of potatoes for yielding on medium soils is much higher, as reported by Michałek, et al. [2000] and Pszczółkowski et al. [2016]. The research by Pszczółkowski et al. [2016] also obtained in the soil and climatic conditions of the Lublin region, yields of tubers of some cultivars up to 100 $Mg \cdot ha^{-1}$.

The influence of the varietal factor on the application of foliar fertilization can be conditioned in two ways: as a result of genetic resistance or diversified morphological and anatomical structure of the leaves. Greater importance is played by diversified morphological structure of leaves, which in turn determines the retention of usable liquid on their surface [Fageria et al. 2009, Al-Jobori and Al-Hadithy 2014]. According to Urbanowicz [2012], the early use of foliar fertilizers, after emergence, may increase the penetration of nutrients into the interior of plants through the leaf blade and stomata. The number of stomata is a varietal feature. However, most varieties react negatively to the early introduction of foliar fertilizers. Therefore, it is not only the form and dose of foliar fertilizers that is important, but also the timing of their applications.

CONCLUSIONS

1. Basfoliar Extra 36 applied as a foliar fertilizer, due to the fact that it contains the biodegradable IDHA chelating agent, has contributed more than other micronutrient fertilizers to the increase in yield due to significant production in the crop of significantly higher tuber mass with a diameter of 51–60 mm, contributing to the highest share and yield of commercial tubers.

2. Foliar fertilizing has contributed to a significant increase in total and commercial yield. The use of Suplofol Micro ZM + Suplofol Mono Mn + Magnesium Sulfate reduced the share of tubers weight with diameter of 36–50 mm.

3. Application of Suplofol Micro ZM + Suplofol Mono Mn + Suplofol Mono B + Magnesium Sulfate contributed to the highest share of tubers with a diameter >60 mm, lowering share of tubers with a diameter of 51–60 mm,

4. Response of studied cultivars to the applied foliar fertilization varied: ‘Lord’ reacted by reducing the share of commercial tubers, the share of tubers with diameter <60 mm, while increasing the share of tubers with diameter <35 mm; ‘Satina’ was reacted to the foliar fertilization with an increased share in the large tubers yield (51–60 mm in diameter), with a reduced share of medium-sized tubers, which resulted in an increase in the total and marketable yield.

5. Meteorological conditions during the years of research modified the yield of tubers and its structure. The lowest overall and commercial yield was obtained in the dry, 2015. The highest total yield was generated by plants in optimal 2016, thanks to the production of the largest mass of large and very large tubers; the best economic effect, in the form of commercial yield, was obtained in 2017, when very heavy rainfall fell in July and contributed to the production of more tubers.

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Streszczenie. Celem pracy było określenie wpływu makro- i mikroelementów zawartych w nawozach dolistnych na wydajność bulw ziemniaka. Doświadczenie polowe przeprowadzono w latach 2015–2017 w Uhninie metodą losowanych podbloków. Czynnikiem pierwszego rzędu były 2 odmiany ziemniaków a drugim czynnikiem były 3 technologie nawożenia dolistnego i obiekt kontrolny (oprysk wodą destylowaną). Nawozy mineralne stosowano na stałym poziomie. Nawozy dolistne stosowano zgodnie z zaleceniami producentów. Nawożenie dolistne przyczyniło się do wzrostu ogólnego i handlowego plonu bulw ziemniaka. Na uzyskane plony bulw istotny wpływ wywarły również odmiany oraz warunki pogodowe w latach badań.

Słowa kluczowe: ziemniak, nawożenie dolistne, odmiany ziemniaka, plon bulw, struktura

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