USING THE SPRAY OF MACRO- AND MICRONUTRIENTS OF FERTILIZERS TO INCREASE THE PRODUCTIVITY OF POTATO TUBERS (*SOLANUM TUBEROSUM* L.)

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Abstract: *The experiment carried out on the field in 2015-2017 in the conditions of south-eastern Poland (The Experimental Station, Uhnin in Province Lublin) (51°34 ', 23°02'E), on the fawn soil, slightly acidic. The study to determine the effects of foliar fertilizers used in the form of spraying on the productivity of the tubers potatoes. In the research hypothesis, it was assumed that macro- and microelements contained in foliar fertilizers will affect the intensity of process of photosynthesis and transpiration in the field conditions, which in consequence may affect the yield of potato tubers. The experiment was performed in randomized subblocks, in triplicate. In the study was evaluated the effect of the spray of macro- and micronutrient fertilizers on the productivity of potato cultivars Jelly and Satina. Were tested four fertilization variants: three technologies foliar fertilization and standard object, without foliar fertilization. Technologies foliar fertilization had had a significant effect on the Total yield of tubers, the commercial yield of tubers, the yield of seed potato tubers. The technology of foliar fertilization using: Basfoliar Extra 36, per 400 dm water on 1 hectare had significantly increased of the total yield of tubers, the commercial yield of tubers, and yield of seed potato tubers. In the case of cultivars, Satina had a significant increase in share and yield of total yield, commercial yield and yield of seed potato tubers over than Jelly cultivar.*

Keywords: POTATOES, FOLIAR FERTILIZERS, JELLY, COMMERCIAL YIELD, SEED YIELD, SATINA, YIELD OF TUBERS

1. Introduction

The potato (Solanum tuberosum L.) has a place with the most important arable yields for the global economy. Potato is the third largest food crop in the world regarding human consumption, and the fourth place for production after maize, rice, and wheat (FAOSTAT 2014). Potato is food for humans and animals, and crude material necessary for the manufacture of food (e.g., French fries, potato chips, and dehydrated potatoes) and starch industries (Spooner and Knapp 2013). The present production of potato in the worldwide adds up to more than 320 million tons, and for a long time, it has been shown an upward trend (Kuta and Golab 2014; CIP 2014). More than a billion people worldwide consume potatoes (Orozco-Cardenas et al. 2014; FAOSTAT 2014). According to Alva et al. (2012), Kolodziejczyk (2013), Pszczolkowski and Sawicka (2017), yields of potato tubers are variable, depending on a variety (genotype) and production factors such as climate, soil, water availability, agronomic practices, and nutrient management. One of the most effective factors in plant growth and yield of potato tubers is fertilization; without using it (chemical or organic) profitable cultivars of potato cannot be produced and developed. Recently, foliar fertilization of elements nutrients has become an important technique in crop production, while soil fertilization is the basic method (Alam et al. 2010). That is why to use foliar fertilization to correct nutritional deficiencies in plants, which has potential advantages over soil application; it may increase the efficacy of fertilizer use (Silberbush 2002). Foliar fertilization is more efficient than soil fertilization for both macro and micronutrients in different soil types regarding yield (Arif et al. 2006). Liew (1988) found that the foliar fertilization of micronutrients to be 6-20 times more efficient than soil fertilization, depending on a soil type. Use of Mixed liquid fertilizers will provide to crops the primary (N, P, K) and secondary nutrients (Mg, Ca, S) and micronutrients (B, Mn, Zn, Fe, Mo, Cu) (Wadas and Dziugiel 2013). Therefore, the main part of a modern potato cultivation technology is foliar fertilization in form of multi-component fertilizers.

The study to determine the effects of foliar fertilizers used in the form of spraying on the productivity of the tubers potatoes. In the research hypothesis, it was assumed that macro- and microelements contained in foliar fertilizers will affect the intensity of process of photosynthesis and transpiration in the field conditions, which in consequence may affect the yield of potato tubers.

2. Materials 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 was 2cultivars of potatoes belonging to different classes of earliness: Satina − medium early and Jelly − medium late. The second order factor were 4 foliar fertilization technologies: A) Suplofol mikro ZM + Suplofol mono Mn + Suplofol mono B + Magnesium sulphate; B) Suplofol mikro ZM + Suplofol mono Mn + magnesium sulphate; C) Basfoliar Extra 36; D) standard object − without foliar spraying, treated with clean water. The forecrop of potato in 2015-2017 was: barley, rape and triticale. In the autumn of each year preceding planting, winter plowing was carried out to a depth of about 27 cm. In the spring 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 ha^{-1}, 112.1 kg K ha^{-1} and 15.8 kg S.ha^{-1}. The amount of mineral fertilization was determined on the basis of soil fertility in these components. Nitrogen fertilizers were sown in the spring too in the amount of 90 kg N 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, in the third decade of April, at the spacings of 67.5 x 37 cm, according to the scheme of experience. 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 amount of usable liquid was 400 $dm \cdot ha^{-1}$. No adhesion promoters were used. A battery sprayer equipped with flat spray nozzles with an outflow of 0.35-0.65 dm was used to perform the treatments. min-1 and a pressure of 0.1-0.2 MPa. 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. The harvests of potato tubers were made in the period of technical maturity, at the mid of September. At the time of harvest, the potato tuber crop, as well as its structure, was determined. Statistical analysis of the results was based on the model of three-factor analysis (ANOVA) and also using the multiple t-Tukey's tests.

3. Soil and meteorological conditions

The results of soil granulometric analysis and some physicochemical properties of soil are presented in Table 6. 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). The soil content in assimilable components was as follows: phosphorus and magnesium very high (21.0 mg P_2O_5·100 g^{-1} soil, 7.03 mg Mg·100 g^{-1} soil), medium in potassium (11.9 mg K_2O·100 g^{-1} soil), in copper medium (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 (Table 2). 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 acid soils in 2017 had 6.6 pH. The humus content in the arable layer was low and formed at 0.94 - 1.06%.

***Table 1**. Physical and chemical properties of soil in Uhnin, (2015 – 2017)*

Year	Content of assimilable Macronutrients [mg·100 g^{-1} Soil]			Humus content [%]	pH [KCL]	Micronutrients content [mg·100 kg^{-1} soil]				
	P_2O_5	K_2O	Mg			Cu	Mn	Zn	Fe	B
2015	20.1	13.1	7.8	0.94	5.92	7.51	318	40.1	3760	7.24
2016	18.9	10.9	7.0	1.06	5.77	4.92	337	56.7	3925	5.28
2017	24.0	11.8	6.3	1.03	6.6	8.99	166	41.1	3600	6.04
Mean	21.0	11.9	7.03	1.02	6.09	7.02	273.8	45.96	3762	6.17

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

In order to characterize the thermal and humidity conditions, the data from the Meteorological Station in Uhnin were used to characterize the thermal and humidity conditions in Uhnin (Table 10). The values of hydrothermal coefficient of Sielianinov are given by the formula (Skowera et al. 2014): $k = \frac{10p}{\sum t}$, where: P − sum of the monthly precipitation in mm, Σt − monthly total of air temperature >0ºC

Monthly totals of temperature were obtained by multiplying the average air temperature by the number of days in a month. The month classification was based on the Sielianinov coefficient suggested by Skowera et al. (2014). This made it possible to isolate extremely dry and extremely wet conditions.

***Table 2.** Rainfalls, air temperature and hydrothermal coefficient of sielianiniv, during the growing season of potato, according to the meteorological station in Uhnin (2015-2017)*

Month	Rainfalls [mm]			Air temperature [°C]			Sielianinov's coefficients		
	2015	2016	2017	2015	2016	2017	2015	2016	2017
IV	62	47	52	8.8	10.0	8.1	2.3	1.6	2.1
V	120	46	66	12.8	15.3	13.7	3.0	1.0	1.5
VI	47	87	23	16.7	19.1	18.3	0.9	1.5	0.4
VII	45	114	132	19.4	20	19.4	0.8	1.8	2.2
VIII	6	41	27	21.4	19.5	20.3	0.1	0.7	0.4
IX	130	12	83	15.5	15.5	14.8	2.8	0.3	1.9
Mean	-	-	-	15.8	16.7	15.8	1.7	1.2	1.4

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 − $k > 3.0$. .*

4. Results and discussions

4.1 Yield of tubers

The average yield of tubers in the experiment was 44.90 t.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 (Table 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 analysed experimental results, was low (CV = 1,32%), which means that these results are credible and great confidence can be given to experimental data (Table 4).

Table 3. Influence of foliar fertilization, cultivars and years of cultivation on total yield of potato tubers

Foliar fertilization	Cultivars		Years			Average
	Satina	Jelly	2015	2016	2017	
A	48.79	44.96	40.28	50.39	49.95	47.09_c
B	48.53	46.90	41.17	51.17	50.81	47.67_b
C	49.76	48.27	41.61	53.77	51.68	49.61_a
D	48.53	44.77	38.74	51.00	50.22	46.86_d
Average	48.90a	46.23b	40.45c	51.58a	50.66b	47.81
$HSD_{0.05}$	Fertilization (F) – 0.37; cultivars (C) – 0.18; Years (Y) – 0.29 F x C – 0.74; Y x F – 1.11					

*A – Suplofol micro ZM + Suplofol mono Mn + Suplofol mono B + Magnesium sulphate; B – Suplofol micro ZM + Suplofol mono Mn + Magnesium sulphate; C - Basfoliar Extra 36; *D – standard object without foliar fertilization*

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 Basfoliar Extra 36, for which the yield of tubers was higher than in the standard object (Table 3). Another application that caused significantly increase: Suplofol micro ZM + Suplofol mono Mn + Magnesium sulphate and the lowest increase in yield were observed with Suplofol micro ZM + Suplofol mono Mn + Suplofol mono B + Magnesium sulphate . Objects with foliar fertilizers Suplofol micro ZM + Suplofol mono Mn and Suplofol mono B + Magnesium sulphate proved to be homogeneous in terms of the value of this feature (Table 3).

The genetic characteristics of the cultivars examined were the most important factors influencing the yield. Satina was the most fertile one, the least Jelly cultivar (Table 3). Atmospheric conditions in the years of research significantly determined the yield. The highest yield was obtained in 2016, while the lowest in 2015 (Table 3).

The cultivars tested showed a differentiated response to foliar fertilization (Table 3). Satina cultivar responded most favorably to foliar fertilizers. Application of Basfoliar Extra 36 increased higher than the standard object, then Suplofol micro ZM + Suplofol mono Mn + Suplofol mono B + Magnesium sulphate increased 0.5%. In the case of the combination of Suplofol micro ZM + Suplofol mono Mn + Magnesium sulphate fertilizers, a decrease in total yield was observed compared to the standard object (figure 1). In the case of Jelly cultivar, the application of foliar fertilizers contributed to a significant increase in yield, with Basfoliar Extra 36, then Suplofol micro ZM + Suplofol mono Mn + Suplofol mono B + Magnesium sulphate, but the total yield of this cultivar was decreased when used with fertilizers of Suplofol micro ZM + Suplofol mono Mn + Magnesium sulphate compared to the standard object.

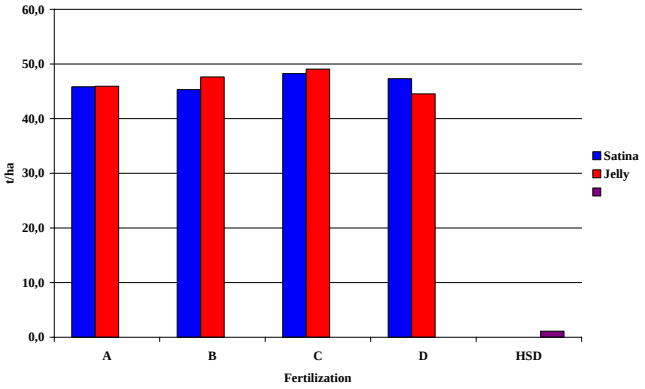


***Figure 1.** Influence of foliar fertilization and cultivars on total yield of tubers; Explanations as in table 3*

4.2. Share and yield of commercial potato tubers

The tuber yields in the experiment were high and amounted to 41.88 t·ha^{-1} an average and the share of commercial tubers was 93.19%. 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 (Table 4). All foliar fertilizers significantly altered the share of commercial tubers in the total yield of potato tubers. Fertilizer Basfoliar Extra 36 resulted in 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 sulphate and Suplofol micro ZM + Suplofol mono Mn + Suplofol mono B + Magnesium sulphate and standard object were homogenous referring to this feature (Table 4).

Table 4. *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 [t· ha^{-1}]
Foliar fertilization	A	92.60 $_b$	41.15 $_b$
	B	92.42 $_b$	41.32 $_b$
	C	95.20 $_a$	44.47 $_a$
	D	92.53 $_b$	40.60 $_c$
	HSD 0.05	0.18	0.34
Cultivars	Satina	93.62 $_a$	45.52 $_a$
	Jelly	93.27 $_b$	43.21 $_b$
	HSD $_{0.05}$	0.18	0.34
Years	2015	92.69 $_b$	36.20 $_c$
	2016	94.62 $_a$	46.22 $_a$
	2017	92.25 $_c$	43.23 $_b$
	HSD $_{0.05}$	0.14	0.27
Average		93.19	41.88
RSD [%]		0.32	1.32

*A – Suplofol micro ZM + Suplofol mono Mn + Suplofol mono B + Magnesium sulphate; B – Suplofol micro ZM + Suplofol mono Mn + Magnesium sulphate; C - Basfoliar Extra 36; *D – standard object without foliar fertilization*

The smallest share of commercial yield was produced by Lord cultivar, while the highest value was obtained by Satina cultivar, followed by Jelly and Vineta cv. The highest value of this feature was obtained in 2016 and the lowest in 2017 (Table 4). Application of foliar fertilization had significant positive effect on the share of commercial tubers in the total yield. The greatest positive effect on commercial yield was due to the fertilization with Basfoliar Extra 36, which brought an increase in the value of this feature by 9.5%, in relation to the standard object. The effect of fertilization with foliar fertilizers Suplofol micro ZM + Suplofol mono B + Suplofol Mono Mn + Magnesium sulphate was homogeneous, meanwhile foliar fertilization with Suplofol micro ZM + Suplofol mono Mn + Magnesium sulphate turned out to be homogenous. Among tested cultivars, Satina produced the largest yield of commercial tubers, then Jelly. 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 2015 (Table 4).

Satina cultivar reacted with a significant increase in the yield of commercial tubers due to fertilizers Suplofol micro ZM + Suplofol mono Mn + Suplofol mono B + Magnesium sulphate (1.7%), as compared to the standard object (where foliar fertilization was not used). Suplofol micro ZM + Suplofol mono Mn + Magnesium sulphate has significantly increased the commercial yield of Jelly by 4.6%. The response of cultivars to the Basfoliar Extra 36 fertilizers was the most significant increase than other fertilizers: Satina 5.7% and Jelly 11.2% (Figure 2).

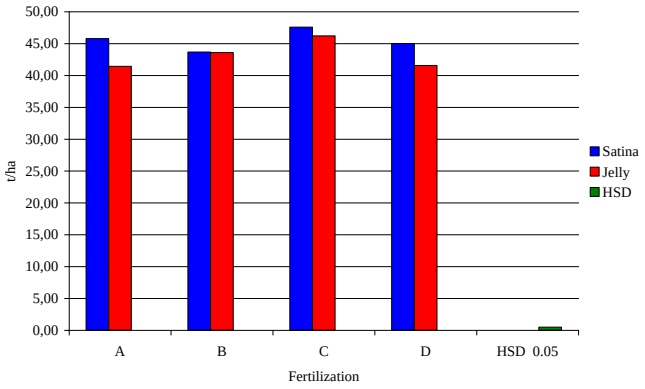


Figure 2 *Influence of foliar fertilization and cultivars on the commercial yield; Explanations as in table 3*

4.3. Share and yield of seed potato tubers

The share of seed potatoes in the total yield was 91.38%, with an average yield of 41.03 t·ha^{-1} (Table 5). Foliar fertilization significantly increased the share of seed potatoes in the total yield. The greatest positive impact of foliar fertilization on the participation of seed potato fraction was found with fertilizer Basfoliar Extra 36. Application of fertilizers Suplofol micro ZM + Suplofol mono Mn + Suplofol mono B + Magnesium sulphate and Suplofol micro ZM + Suplofol mono Mn + Magnesium sulphate, have affected the reduced fraction of tubers in the yield as compared to the standard object; the effect of using these fertilizers was homogeneous. The genetic traits of cultivars tested had significant effect on the share of seed potatoes in the total yield. The largest share of tubers of this fraction was recorded in Jelly cultivar. The smallest share of seed potatoes was characterized by Satina cultivar (Table 5).

Table 5. *Effect of foliar fertilization, cultivars and years on the share of seed potatoes in the total yield and their yield*

Factors of the experiment		Share of seed potato in the total yield [%]	The yield of seed potato [t·ha^{-1}]
Foliar fertilization	A	90.49 $_c$	40.18 $_{b,c}$
	B	90.74 $_{b,c}$	40.53 $_b$
	C	93.28 $_a$	43.53 $_a$
	D	91.02 $_b$	39.89 $_c$
	HSD $_{0.05}$	0.45	0.38
Cultivars	Satina	90.26 $_c$	43.86 $_a$
	Jelly	92.46 $_a$	42.75 $_b$
	HSD $_{0.05}$	0.45	0.38
Years	2015	91.63 $_b$	35.80 $_c$
	2016	92.21 $_a$	44.98 $_a$
	2017	90.31 $_c$	42.31 $_b$
	HSD $_{0.05}$	0.36	0.30
Average		91.38	41.03
RSD [%]		0.80	1.49

*A – Suplofol micro ZM + Suplofol mono Mn + Suplofol mono B + Magnesium sulphate; B – Suplofol micro ZM + Suplofol mono Mn + Magnesium sulphate; C - Basfoliar Extra 36; *D – standard object without foliar fertilization*

Meteorological conditions during the study period significantly influenced the share of seed potatoes. The highest share was observed in 2016, while the lowest in 2017 (Table 5).The highest yield of seed potatoes was found in plants using fertilizers Basfoliar Extra 36, followed by Suplofol micro ZM + Suplofol mono Mn + Magnesium sulphate and Suplofol micro ZM + Suplofol mono Mn + Suplofol mono B + Magnesium sulphate. The yield of the seed fraction in all combinations was significantly higher than on the standard object (without foliar fertilization), except the application of Suplofol micro ZM + Suplofol mono Mn + Suplofol mono B, which was homogeneous with standard object . Among the cultivars tested, the highest yield of seed potatoes was produced by Satina cultivar, followed by Jelly. In 2016, the highest yield of seed potatoes was recorded, while the lowest in 2015 season (Table 5).

Application of foliar fertilization had a significant effect on the

yield of seed potatoes for potato cultivars. Fertilizer Suplofol micro ZM + Suplofol mono Mn + Suplofol mono B + Magnesium sulphate gave rise to the yield of seed potatoes, Satina whereas in Jelly cultivar, value of this feature decreased. Suplofol micro ZM + Suplofol mono Mn + Magnesium sulphate for Jelly cultivar, resulted in an increase, but negative effect was observed for Satina cultivar. In case of application using fertilizer Basfoliar Extra 36, the highest yield of seed potatoes for all tested cultivars was recorded, and the highest production of seed from these cultivars was shown by Satina cv. (Figure 3).

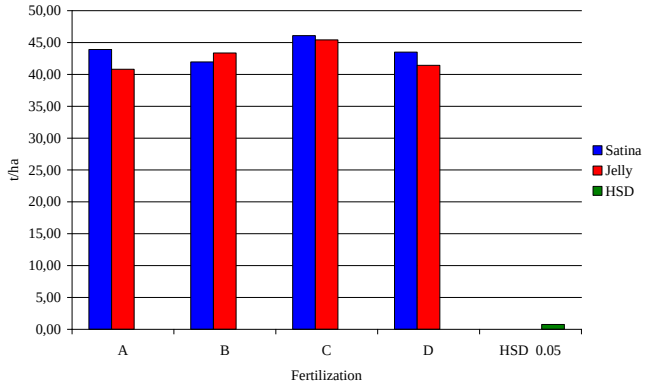


Figure 3. *Influence of foliar fertilization and cultivars on the seed potato yield; Explanations as in table 3*

The foliar fertilizers used in the experiment had varied impact on total and commercial yield of tubers. Average potato yield in Poland, according to Winnicki and Bogucka (2017), is 27.0 t·ha^{-1}. In the experiment, the average yield was 44.90 t·ha^{-1} and can be considered high, as it exceeded the average national yield by 64.4%. The commercial yield of tubers was 41.88 t·ha^{-1} and represented 93.19% 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 t·ha^{-1} in the organic system to 31.7 t·ha^{-1} in the integrated system; the share of commercial tubers accounted respectively: 63.1% and 70.7% of total tuber yield, while Trawczynski (2014) reported that potato tubers yield in light soils conditions, at 32.5-37.9 t·ha^{-1}, depended on the year. The total yield of tubers on light soil, in amount of 25.1 t·ha^{-1} and on heavy soil 26.4 t·ha^{-1}, was obtained by Rozylo and Palys (2007). According to Michalek et al. (2000), potential yields of very early cultivars potato, on light soils, are much higher: 51.3 t·ha^{-1}, but in conditions of medium soils, they yield up to 100 t·ha^{-1} (Pszczolkowski et al. 2016).

5. Conclussions

1. Technologies foliar fertilization had had a significant effect on the Total yield of tubers, the commercial yield of tubers, the yield of seed potato tubers.
2. The technology of foliar fertilization using: Basfoliar Extra 36, per 400 dm water on 1 hectare had significantly increased of the total yield of tubers, the commercial yield of tubers, and yield of seed potato tubers.
3. In the case of cultivars, Satina had a significant increase in share and yield of total yield, commercial yield and yield of seed potato tubers over than Jelly cultivar.
4. Meteorological conditions during the research modified the yield of tubers. in 2017, potato plants have produced high total yield of tubers with the largest share of the marketable tubers and seed potatoes. while, in 2016, plants produced high total yield.

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