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EFFECT OF FOLIAR FERTILIZATION WITH SILICON ON THE CHOSEN PHYSIOLOGICAL FEATURES AND YIELD OF SUGAR BEET

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Abstract. In 2013–2014, in the south-eastern region of Poland, in Sahryń (50°41′ N and 23°46′ E) 6 variants of sugar beet foliar fertilization with silicon, comparing to the control were investigated. The effect of foliar fertilization on some physiological features of sugar beet plants like: LAI (leaf area index), PAR (absorption of photosynthetic active radiation); and after leaves' adaptation to the light chlorophyll a fluorescence parameters like: F_s (stationary fluorescence), F_m' (maximum fluorescence) and PSII – ΦPSII (effective quantum efficiency) were the main goal of the experiment. All variants of silicon foliar fertilization had the positive effect on LAI and PAR absorption. Yields of roots and technological sugar were significantly positive correlated with PAR absorption and LAI. At the same time those yields were negatively correlated with fluorescence parameters like F_s (stationary fluorescence) and F_m' (maximum fluorescence).

Key words: foliar fertilization, leaf area index, photosynthesis, silicon, technological sugar yield

INTRODUCTION

The silicon is known as the beneficial nutrient for plants. It's positive effect on most plants' species growth and development has been noticed by the researchers last time [Guntzer et al. 2012, Marschner 2002]. Silicon is especially important for better plants' resistance to biotic and anabiotic stresses like drought, low temperature, salinity with heavy metals, some plants' diseases and pests [Cai et al. 2009, Fauteux et al. 2005, Gunes et al. 2007, Henriet et al. 2006, Ma et al. 2004, Raven 2003, Sacała 2009].

The abolition of the production quotas for sugar in the EU in 2017 will create the necessity to increase sugar beet yields while reducing costs. The silicon foliar fertilization of sugar beet can become the one option of its greater productivity, as indicated a few studies carried out in recent years [Artyszak et al. 2014, 2015, 2016]. In the literature there is a lack of current research findings on the effects of foliar fertilization with silicon on the sugar beet plants physiological parameters.

As the research hypothesis, the authors established that the foliar fertilization with silicon affects positively some physiological parameters of sugar beet plants.

The main goal of the presented study was to determine what the physiological parameters related to the operation and the size of the assimilation apparatus affect the quantity and quality of sugar beet yielding under the conditions of foliar fertilization with the silicon.

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MATERIALS AND METHODS

In 2013–2014 the experiment was carried out in the southeastern part of Poland in Sahryń village (50°41′ N and 23°46′ E). Weather and soil conditions as well as agronomical methods were described in the paper Artyszak et. al. [2015].

The soil was classified as Chernozem [FAO 2006]. During the experiment (two years) the average C_{org} content in the soil was 9.5 g·kg^{-1} and pH_{KCl} 7.0. The average contents (mg·kg^{-1}) of the macro and micronutrients were as follows: NO_3-N – 8.1, NO_4^+-N – 2.7, P – 62.4, K – 91.4, Mg – 80.5, B – 4.3, Cu – 4.9, Fe – 675, Mn – 162, Zn – 6.1. In the whole experiment the doses of soil fertilization (kg·ha^{-1}) with macronutrients were: N – 135, P - 39, K – 112.

In the experiment the silicon as two fertilizers Herbagreen Basic and Optysil were used.

Herbagreen Basic (26.2% Ca and 7.99% Si) in doses as follows:

A) 1.5 kg·ha^{-1} at the stage of 4-6 sugar beet leaves (26 DAE);

B) 1.5 kg·ha^{-1} at the stage of 4-6 sugar beet leaves (26 DAE), and then 1.5 kg·ha^{-1} –7 days later (33 DAE);

C) 1.5 kg·ha^{-1} at the stage of 4-6 sugar beet leaves (26 DAE), then 1.5 kg·ha^{-1} – 7 days later (33 DAE), and 1.5 kg kg·ha^{-1} – 14 days later (40 DAE);

Optysil (94.1 g Si·dm^3, 24 g Fe·dm^3) in doses as follows:

D) 0.5 dm^3·ha^{-1} at the stage of 4-6 sugar beet leaves (DAE 26);

E) 0.5 dm^3·ha^{-1} at the stage of 4-6 sugar beet leaves (DAE 26), and then 0.5 dm^3·ha^{-1} – 7 days later (DAE 33);

F) 0.5 dm^3·ha^{-1} at the stage of 4-6 sugar beet leaves (DAE 26), then 0.5 dm^3·ha^{-1} – 7 days later (DAE 33), and 0.5 dm^3·ha^{-1} – 14 days later (DAE 40).

All fertilization treatment were compared with the control treatment – 0, where instead of fertilizers' solution pure water was used in dose 250 dm^3 water·ha^{-1}. Both fertilizers for each application were used as the water solution in dose of 250 dm^3·ha^{-1} of water. Single plot area was 43.2 m^2 (6 rows), for harvest – 21.6 m^2 (3 rows) and the number of replication 4. Such of the physiological parameters like: leaf area index (LAI) and photosynthetic active radiation (PAR) in the upper (Iu) and lower (Il) layer of the leaf canopy were measured by using an AccuPar ceptometer (Hansatech Instruments, UK). Absorption of PAR was calculated with using the following formula: PAR absorption = ((Il− Iu)/Il) × 100 [%]. For the measurement of chlorophyll a fluorescence parameters in leaves adapted to the current irradiance fluorimeter FMS-2 from Hansatech Instruments Ltd was used. Such chlorophyll a fluorescence parameters like: stationary fluorescence (F_s); maximum fluorescence ($F_m^{'}$) and effective quantum efficiency PSII (ΦPSII) were measured. The measurements of physiological parameters were carried out five times: in the day before the first spraying (26 days after emerging – DAE), then 7 days after the first, second and third application (33, 40 and 47 DAE) and 4 weeks after the third application (75 DAE). PAR and LAI measurements were carried out in 9 randomly selected locations in the 3 central rows per plot, and the fluorescence of chlorophyll a on 3 randomly selected plants from the 3 central rows (9 fully grown leaves per plot). From each fertilization variant 36 plants were measured. Sugar beet yielding and technological root quality were published by Artyszak et al. [2015]. The experimental data were statistically analyzed using one way and two way analysis of variance and means were compared using LSD, with the level of significance α=0.05. Statistical analyses were performed in the SAS 9.1 program (Cary, USA) using the GLM procedure. The evaluation of the correlation between the parameters was made based on value of simple Pearson correlation coefficients. The significance of cross-compliance was assessed at $P \leq 0.05$ and $P \leq 0.01$.

RESULTS AND DISCUSSION

Solar radiation interception is mainly determined by leaf expansion, the efficiency of photosynthetic apparatus and leaf area duration. A LAI of around 3.3–4.0 is necessary to maximize photon interception and yield of sugar beet crop [Chołuj et al. 2014, Scott and Jaggard 1993]. Another one of the major component of yield determination in sugar beet plants is the amount PAR absorbed by leaf area [Scott and Jaggard 1993].

During both vegetation periods such physiological parameters like LAI as well as PAR absorption increased successively reaching the highest values at 75 days after the emergence (Table 1). The effects of all silicon fertilization variants on higher LAI and PAR absorption values

Table 1. Effect of foliar fertilizers on physiological features of sugar beet plants (means in 2013–2014)

Measurement DAE	Variants of fertilization						
	0*	A	B	C	D	E	F
PAR absorption %							
26	36.4 abc*	38.8 ab	33.2 c	41.0 a	35.5 bc	36.4 abc	31.3 c
33	44.5 bc	49.2 ab	44.6 bc	51.9 a	47.6 ab	47.8 ab	41.5 c
40	60.1 c	67.5 ab	64.7 abc	69.1 a	68.2 ab	67.0 abc	61.3 bc
47	75.0 b	81.3 a	81.7 a	82.5 a	83.2 a	81.7 a	84.4 a
LAI							
26	0.62 bc	0.66 ab	0.56 bc	0.73 a	0.60 bc	0.59 bc	0.51 c
33	0.79 bc	0.89 ab	0.77 bc	0.99 a	0.83 bc	0.81bc	0.69 c
40	1.17 b	1.50 a	1.35 ab	1.54 a	1.42 ab	1.39 ab	1.30 ab
47	1.81 c	2.13 ab	2.04 bc	2.12 ab	2.16 ab	2.05 b	2.29 a
75	3.00 c	3.68 b	3.76 ab	3.67 b	3.83 ab	4.03 a	3.94 ab
Stationary fluorescence F_s							
26	635 a	646 a	677 a	692 a	664 a	680 a	681 a
33	607 a	619 a	649 a	661 a	635 a	651 a	653 a
40	546 b	576 ab	636 a	591 ab	594 ab	583 ab	634 a
47	509 a	515 a	525 a	523 a	532 a	541 a	511 a
75	513 a	516 a	523 a	516 a	541 a	558 a	521 a
Maximum fluorescence F_m'							
26	2268 a	2145 a	2237 a	2630 a	2457 a	2433 a	2436 a
33	2089 a	1926 a	2087 a	2265 a	2190 a	2188 a	2245 a
40	1899 a	1943 a	2073 a	2108 a	2101 a	2024 a	2020 a
47	1906 a	1947 a	2018 a	1966 a	1980 a	2080 a	2006 a
75	2471 b	2498 ab	2579 ab	2538 ab	2614 ab	2710 a	2551 ab

Table 1. cont

Effective quantum efficiency PSII – ΦPSII							
26	0.75 a	0.70 b	0.69 b	0.71 ab	0.71 ab	0.72 ab	0.71 ab
33	0.69 a	0.67 a	0.66 a	0.68 a	0.69 a	0.69 a	0.68 a
40	0.70 a	0.71 a	0.70 a	0.71 a	0.71 a	0.72 a	0.69 a
47	0.72 b	0.73 ab	0.73 ab	0.73 ab	0.72 b	0.73 ab	0.74 a
75	0.78 b	0.79 ab	0.79 ab	0.79 ab	0.79 ab	0.79 ab	0.80 a

*variants of fertilization – explanations in "materials and methods"; DAE – days after emerging
The same letters in rows indicate no significant differences

were observed from the first measurement time (26 DAE) and maintained to the last measurement at 75 DAE. At that time, the LAI values in variants with foliar nutrition with silicon exceeded the minimum recommended value (3.3), and were ranged of 3.67–4.03, while in the control variant it was 3.00. Similarly the PAR absorption values were ranged of 94.4–95.5% in the silicon foliar fertilization variants, while for the control it was 91.6%. LAI is one of the factor determining the yields of crops due to the dry matter production. Similarly to presented results, Manivannan et al. [2002] reported that foliar fertilization of rice with macronutrients and some chelated micronutrient affected the higher LAI, dry matter production.

The effect of foliar fertilization with silicon on such photosynthetic apparatus's parameters like F_s (stationary fluorescence), F_m' (maximum fluorescence) and PSII – ΦPSII (effective quantum efficiency) were ambiguous, however the tendency of higher F_s compared to the control variant as the effect of silicon nutrition in every variants was observed at every measuring time (Table 1). The significantly higher F_m' value compared to the control variant was observed only in fertilization variant E at 75 DAE. At the beginning of vegetation (26 DAE) the lover values of effective quantum efficiency PSII – ΦPSII were observed at variants with silicon fertilization compared to the control variant, while at 75 DAE the lowest PSII – ΦPSII value at the control variant was observed. Although there are not many studies on the effect of silicon on photosynthetic apparatus, Kalaji [2011] observed ambiguous effect of silicon fertilization in the experiment with two varieties of spring barley cultivated under stress conditions. He observed the systemic decrease of the values of the parameters characterizing the chlorophyll fluorescence due to the macro- and micronutrients deficiencies. More evident results Borawska-Jarmułowicz et al. [2014] observed in their study on the effect of grass hardening on the photosynthetic apparatus efficiency. The authors noted that temperature stress affected the decrease of PSII – ΦPSII, F_s and F_m' values. Similarly to Borawska-Jarmułowicz et al. [2014], the reduction of the PSII maximum quantum efficiency in wheat as the effect of high temperature was observed by Graham and Mc Donald [2001]. This negative temperature stress effect was cancelled by additional micronutrient fertilization.

In presented results the highest CV values were observed for PAR absorption and LAI, and the lowest for effective quantum efficiency PSII (ΦPSII) (Table 2).

Roots' yields in the experiment, related to the fertilization variants were as follows ($t \cdot ha^{-1}$): 0 – 90.6; A – 105.3; B – 100.7; C – 100.0; D – 103.3; E – 105.0; F – 103.0. Technological sugar yields ($t \cdot ha^{-1}$) were as follows: 0 – 14.7; A – 17.3; B – 16.7; C – 16.5; D – 17.0; E – 16.8; F – 16.5

Table 2. Variability of physiological features in 2013–2014

Measurement DAE	Physiological feature	Mean	Minimum	Maximum	SD	CV (%)
26	PAR absorption	36.1	15.4	61.8	13.7	38.0
	LAI	0.61	0.23	1.07	0.23	37.9
	F_s	668	273	881	122	18.3
	F_m`	2372	570	3281	524	22.1
	ΦPSII	0.71	0.50	0.81	0.06	7.9
33	PAR absorption	46.7	21.0	67.7	11.4	24.5
	LAI	0.83	0.32	1.34	0.25	29.7
	F_s	639	250	873	128	20.1
	F_m`	2141	518	2906	467	21.8
	ΦPSII	0.68	0.49	0.78	0.06	8.1
40	PAR absorption	65.4	35.0	87.7	13.5	20.7
	LAI	1.38	0.53	2.50	0.53	38.3
	F_s	594	435	798	97	16.4
	F_m`	2024	1367	2965	381	18.8
	ΦPSII	0.71	0.60	0.76	0.04	5.3
47	PAR absorption	81.4	58.3	91.9	7.7	9.5
	LAI	2.09	1.07	2.99	0.48	23.0
	F_s	522	438	651	63	12.2
	F_m`	1986	1327	2828	428	21.5
	ΦPSII	0.73	0.66	0.78	0.03	4.5
75	PAR absorption	94.5	85.4	98.7	3.6	3.8
	LAI	3.70	1.85	5.01	0.90	24.2
	F_s	527	336	716	114	21.7
	F_m`	2566	1618	3874	727	28.3
	ΦPSII	0.79	0.73	0.84	0.03	3.1

SD – Standard deviation; CV – Coefficient of variation

[Artyszak et al. 2015]. The root yield and technological sugar yield were strongly positive correlated with such photosynthetic parameters like PAR absorption and LAI in every measurement time (Table 3). It confirmed earlier results of Chołuj at al. [2014] where the authors suggest that such parameters like ΦPSII, LAI, PAR are strongly correlated with the yields of roots and sugar.

The results obtained in the experiment shows that sugar beet foliar fertilizations with silicon have long-time positive effect on LAI and PAR absorption. In contrast to Chołuj at al. [2014] the correlations between yields and ΦPSII values was ambiguous, and at two last measurements (45 DAE and 75 DAE) were strongly negative. Similarly the correlation between yields of roots

Table 3. Correlation coefficients between physiological parameters and roots yield and technological sugar yield in 2013–2014 (n = 56)

Measurement DAE	Parameter	Roots yield ($t{\cdot}ha^{-1}$)	Technological sugar yield ($t{\cdot}ha^{-1}$)
26	PAR absorption	0.64**	0.65**
	LAI	0.61**	0.61**
	F_s	-0.23	-0.21
	F_m'	-0.14	-0.10
	ΦPSII	0.28*	0.31*
33	PAR absorption	0.62**	0.63**
	LAI	0.55**	0.55**
	F_s	-0.34**	-0.33*
	F_m'	-0.13	-0.09
	ΦPSII	0.37*	0.40**
40	PAR absorption	0.65**	0.65**
	LAI	0.64**	0.63**
	F_s	-0.42**	-0.43**
	F_m'	-0.52**	-0.51**
	ΦPSII	0.07	0.09
47	PAR absorption	0.55**	0.56**
	LAI	0.59**	0.61**
	F_s	-0.56**	-0.57**
	F_m'	-0.59**	-0.60**
	ΦPSII	-0.48**	-0.49**
75	PAR absorption	0.64**	0.63**
	LAI	0.65**	0.64**
	F_s	-0.58**	-0.57**
	F_m'	-0.61**	-0.61**
	ΦPSII	-0.48**	-0.51**
Mean	PAR absorption	0.67**	0.67**
	LAI	0.68**	0.67**
	F_s	-0.53**	-0.52**
	F_m'	-0.51**	-0.50**
	ΦPSII	0.09	0.12

**significant correlation at p≤0.01; *significant correlation at p≤0.05

and technological sugar and F_s were significantly negative with the exception at 26 DAE (first measurement). Similarly those yields were negatively correlated with F_m', but this negative correlation was observed a little later on. It started from 33 DAE.

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CONCLUSIONS

1. Foliar fertilization with silicon has the beneficial effect for such physiological parameters of sugar beet plants like LAI and PAR absorption, and this effect lasts until the end of the sugar beets' growing season.
2. Yields of sugar beet roots, and technological sugar are strongly positive correlated with PAR absorption and LAI while their correlations with F_s (stationary fluorescence) and F_m' (maximum fluorescence) are significantly negative.
3. Silicon foliar fertilization can be useful as agronomic tool for mitigating the sugar beet plants' stress that limiting growth of photosynthetic apparatus and loss of yields in consequence.
4. However there is a permanent need to continuation of the research on the effect of silicon nutrition, especially in order to clarify the mechanism of its activity in plants and optimization of silicon fertilizers' use.

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WPŁYW DOKARMIANIA DOLISTNEGO KRZEMEM NA WYBRANE CECHY FIZJOLOGICZNE I PLONOWANIE BURAKA CUKROWEGO

Synopsis. W latach 2013–2014, w południowo-wschodnim rejonie Polski, w Sahryniu (50°41′ N and 23°46′ E) było badanych 6 wariantów dokarmiania dolistnego krzemem buraka cukrowego i porównywane z kontrolą. W doświadczeniu oceniano wpływ dokarmiania dolistnego na kilka cech fizjologicznych roślin buraka cukrowego, takich jak: wskaźnik powierzchni liści (LAI), absorpcję fotosyntetycznie aktywnej radiacji (PAR) oraz parametry fluorescencji chlorofilu, a po adaptacji liści na świetle - fluorescencję stacjonarną ($F_{s)}$, fluorescencję maksymalną (F_m') oraz efektywną wydajność kwantową (PSII – ΦPSII). Wszystkie warianty dokarmiania dolistnego krzemem miały korzystny wpływ na wartość LAI i absorpcję PAR. Plon korzeni i technologiczny plon cukru były istotnie i dodatnio skorelowane z absorpcją PAR oraz wartością LAI. Jednocześnie plony te były istotnie ale ujemnie skorelowane z F_s oraz F_m'.

Słowa kluczowe: dokarmianie dolistne, wskaźnik powierzchni liści, fotosynteza, krzem, plon technologiczny cukru

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