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EFFECT OF DIFFERENTIATED FOLIAR FERTILIZATION ON CHOSEN PHYSIOLOGICAL FEATURES OF SUGAR BEET

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Abstract. In 2013–2014, in the south-eastern region of Poland, in productive fields in Sahryń (50°41′ N and 23°46′ E) 6 variants of sugar beet foliar fertilization with macro- and micronutrients, comparing to the control were investigated. The effects of foliar fertilization on some physiological parameters of sugar beet plants such as: LAI (leaf area index), PAR absorption (absorption of photosynthetic active radiation); and after leaves adaptation to the light chlorophyll a fluorescence parameters such as: F_s (stationary fluorescence), F_m' (maximum fluorescence) and ΦPSII (effective quantum efficiency PSII) were the main aim of the experiment. All variants of foliar fertilization had the positive effect on LAI and PAR absorption. However the highest values of these both parameter were observed at F fertilization variant. Foliar fertilization of sugar beet significantly improved ΦPSII at the first three measurements (from 26 to 40 days after emerging). The effect of foliar fertilization on other fluorescence parameters of chlorophyll a were not observed. PAR absorption and LAI from every measurements were positively correlated with the root yield and the technological sugar yield.

Key words: foliar fertilization, leaf area index, photosynthesis, sugar beet.

INTRODUCTION

Among the methods of fertilizer application, foliar nutrition is recognized as very important. Usually nutrients from foliar fertlizers penetrate the leaf cuticle or stomata and enter to the cells facilitating their easy and rapid utilization. Many authors observed positive effects of foliar fertilization on yielding of many crops [Shehzad and Maqsood 2015], including sugar beet [Artyszak et al. 2015a, 2015b, Mekki 2014]. For the best effect, fertilizers should contain well balanced content of microelements, whose availability and concentration in the soil is often inadequate for proper plants growth and development. Micronutrients are an integral components of enzyme structures and have the following functions: catalytic, coactive or structural, therefore they regulate many metabolic processes related to the energy changes [Hänsch and Mendel 2009]. They also affect the oxidation-reduction state of cells, gene expression, hormone perception and signal transduction. In the photosynthesis and respiration processes, where balance is primarily responsible for the accumulation of biomass in the plant such micronutrients like copper [Kopsell and Kopsell 2007], iron [Rochaix 2011] and zinc [Hänsch and Mendel 2009] are involved.

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In the case of crop yield, boron is important. It regulates root growth, the metabolism of proteins, nucleic acids, nitrogen and carbohydrates as well as cell wall [Gupta 2007]. Sugar beet is very sensitive to boron deficiency [Armin and Asgharipour 2011, Artyszak 2014]. Moreover, only under conditions of optimal nutrition with macro and micronutrients plant can run on an effective defence mechanisms against abiotic [Graham and McDonald 2001] and biotic stresses [Grzebisz et al. 2010]. Plants supply of in zinc [Graham and McDonald 2001], which increases the resistance of the photosynthetic apparatus to heat stress and also has provided effective protection against fungi, or even snails and viruses is especially important as well [Poschenrieder et al. 2006]. Zinc activates enzymes involved in chlorophyll biosynthesis and maintains the proper structure of the thylakoid membranes in the chloroplasts and regulates electron transport at Hill reaction in light stage of photosynthesis also which affects the PAR absorption by the photosynthetic apparatus [Fageria 2009].

The aim of the research was to answer the question: does foliar fertilization with macro- and micronutrients affect the photosynthetic apparatus activity and its size, and finally the root and technological sugar yield.

MATERIALS AND METHODS

In 2013–2014 the experiment was carried out in the south-eastern 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 of Artyszak et al [2015b]. Foliar fertilizers were applied in once, twice or three times, in different plant growth stages (Tables 1 and 2). For each application 250 dm^3 of water ha^{-1} was used. Chemical content of the fertilizers is placed in Table 3 and total dose of applied mineral nutrients is placed in Table 4.

Single plot area was 43.2 m^2 (6 rows), for harvest – 21.6 m^2 (3 rows) and 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 (Decagon Devices, USA). 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 fluorometer FMS-2 from Hansatech Instruments Ltd was used. Such chlorophyll a fluorescence parameters

Table 1. Terms of physiological measurements and applications of foliar fertilizers

Specification	Days after emerging (DAE)
I measurement	26
I application	26
II measurement	33
II application	33
III measurement	40
III application	40
IV measurement	47
V measurement	75

Table 2. Scheme of the experiment

Variants of fertilization	Terms of applications					
	26 DAE		33 DAE		40 DAE	
	No of fertilizer	Dose, $dm^3 \cdot ha^{-1}$	No of fertilizer	Dose, $dm^3 \cdot ha^{-1}$	No of fertilizer	Dose, $dm^3 \cdot ha^{-1}$
Control (0)						
A	1	2				
	2	3				
B	1	2	3	1		
	2	3	4	1		
C	1	2	3	1	5	2
	2	3	4	1		
D	1	3				
	4	1.5				
E	1	3	4	1.5		
	4	1.5	6	3		
F	1	3	4	1.5	5	2
	4	1.5	6	3		

Description of fertilizers in Table 3

Table 3. Compositions of the fertilizers used in the experiment ($g \cdot dm^{-3}$)

Name of fertilizer	No of fertilizer	N	K	Ca	S	B	Cu	I	Fe	Mn	Zn	Mg	Mo
FoliQ Ascovigor	1	317	158	129	102	38.1	0.004	0.04	0.06	10.2	6.4		
FoliQ Mg	2	56.0			56.0							127	
FoliQ Mikromix	3	78	130		34.8	4.7	7.9		15.7	23.6	15.7	28.3	0.15
FoliQ Bor	4					150							
FoliQ Zn	5	54.8				54.8					54.8		
FoliQ Kombimax	6	300	187		10.0	0.30	0.75		1.5	0.75	0.75	36.2	0.15

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; Table 1). 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

Table 4. Total doses of macro and micronutrients applied in the foliar fertilizers ($g \cdot ha^{-1}$)

Variants of fertilization	N	K	Ca	S	B	Cu	I	Fe	Mn	Zn	Mg	Mo
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A	802	316	258	372	76.2	0.008	0.08	0.12	20.4	12.8	381	0.0
B	880	446	258	407	231	7.91	0.08	15.8	44.0	28.5	409	0.15
C	990	446	258	407	341	7.91	0.08	15.8	44.0	138	409	0.15
D	951	474	387	306	339	0.012	0.12	0.18	30.6	19.2	0.0	0.0
E	1851	1035	387	336	565	2.26	0.12	4.68	32.9	21.5	109	0.45
F	1961	1035	387	336	675	2.26	0.12	4.68	32.9	131	109	0.45

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 [2015b]. 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 $\alpha=0.05$. 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

PAR absorption is one of the main factors determining the light phase of photosynthesis efficiency and therefore the production of ATP and NADPH. Mainly, interception of solar radiation is determined by leaf expansion, the efficiency of photosynthetic apparatus and leaf area duration. PAR absorbed by leaf area is one of the major component of yield determination in sugar beet plants [Scott and Jaggard 1993]. The second factor determining the yield is LAI which should achieve value of around 3.3–4.0. Such value is necessary to maximize photon interception and yield of sugar beet crop [Chołuj et al. 2014, Scott and Jaggard 1993]. During the vegetation of sugar beet plants from the control variant the values of their parameters like PAR and LAI were increasing successively (Fig. 1 and 2), and they got the maximum at 75 DAE (89.9% for PAR and 2.61 for LAI). According to Scott and Jaggard [1993] the minimal LAI value should exceed 3.3 at this time of vegetation. In 75 DAE, in the control variant plants LAI did not reach the minimal value from optimum range. The fertilizers combinations used in the experiments had positive significant effects on PAR absorption and LAI of sugar beet plants. The significant growths of values PAR and LAI were noticed at 47 DAE and this beneficial effect survived until to the last measurement which was conducted four weeks later (Fig. 1 and 2). The changes of PAR absorption values were similar to the changes of LAI. The significant positive effects of all fertilization variants in compare to the control were observed from 47 DAE and survived to the 75 DAE. The highest PAR absorption (96%) was observed as the effect of F – fertilization variant. This value was significantly higher than PAR absorption observed as the

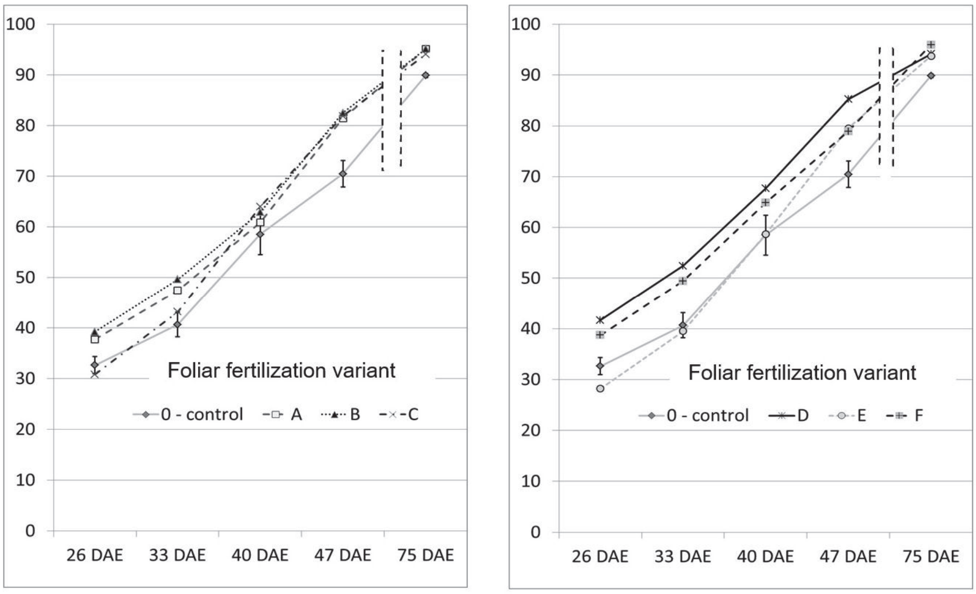

Fig. 1. Changes of PAR absorption values of sugar beet plants fertilized with 6 different foliar fertilization variants during vegetation (means and LSD in 2013–2014)

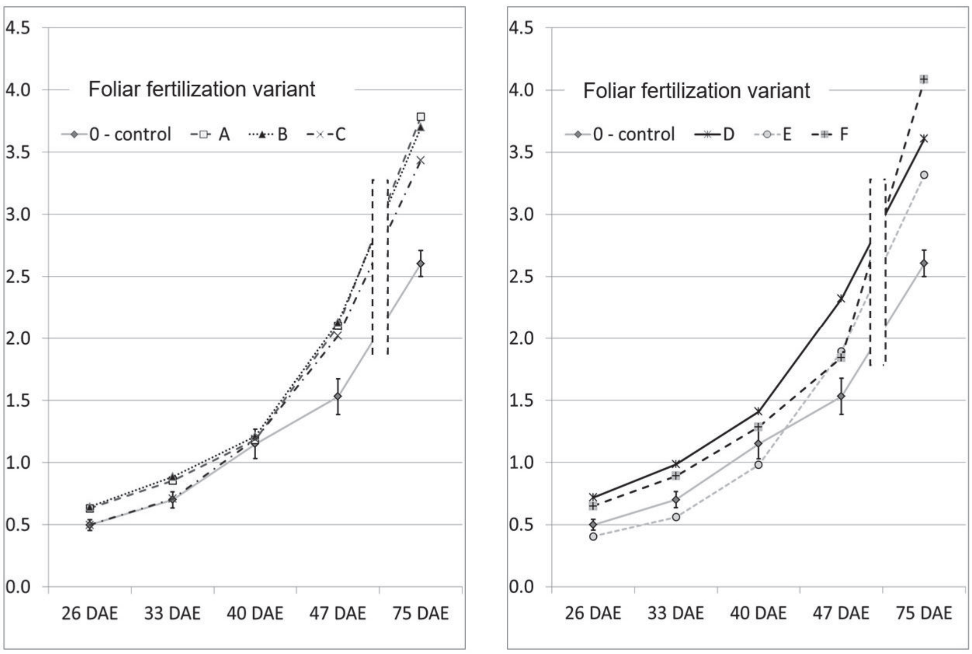

Fig. 2. Changes of LAI values of sugar beet plants fertilized with 6 different foliar fertilization variants during vegetation (means and LSD in 2013–2014)

effect of the other five fertilization variants. The plants form all variants with foliar fertilization ranged LAI value of 3.32 to 4.08. The highest LAI value exceeding 4, was noticed at the variant F and similarly to the PAR absorption changes it was significantly higher than observed at the control variant as well as at the other five fertilization variants.

LAI is an important factor determining the dry matter production of crops and subsequently the yield. Similarly to presented results, Manivannan et al. [2002] reported that foliar application of N, P, K and chelated micronutrient recorded markedly high LAI, dry matter production and crop growth rate in rice-fallow urdbean. Zayed et al. [2011] found that dry matter production, LAI and chlorophyll content as well as plant height and panicle length were significantly higher when rice plant received the micronutrients (Zn, Fe, Mn) in compare to the control.

The values of F_s (stationary fluorescence of chlorophyll a) and F_m' (maximum fluorescence of chlorophyll a) in the leaves adapted to the natural irradiance decreased steadily in subsequent terms of measurements in all variants, but with a few exceptions (Table 5). However there was no significant effect of foliar fertilization on both fluorescence values of chlorophyll a.

The effects of foliar fertilization variants on the effective quantum efficiency PSII (ΦPSII) were significant in compare to the control variant at first three measurements (from 26 to 40 DAE). The lowest values were observed at the control variant and the highest for variants C and F where 3 applications of foliar fertilizers were used.

Table 5. Effect of foliar fertilizers on chlorophyll a fluorescence parameters of sugar beet plants (means in 2013–2014)

Measurement/ DAE	Variants of fertilization						
	0	A	B	C	D	E	F
Stationary fluorescence F_s							
26	732 a	669c	721 ab	673 bc	653 c	673 bc	651 c
33	703 a	627 b	679 ab	628 c	636 bc	659 abc	631 c
40	644 a	610 ab	611 ab	592 b	601 ab	607 ab	618 ab
47	529 b	580 ab	567 ab	554 ab	607 a	583 ab	577 ab
75	531 a	540 a	567 a	558 a	552 a	599 a	563 a
Maximum fluorescence F_m'							
26	2536 ab	2242 c	2314 c	2663 a	2406 bc	2379 bc	2441 bc
33	2281 ab	2048 c	2150 bc	2418 a	2220 abc	2190 bc	2237 abc
40	2192 ab	2117 b	2082 b	2196 ab	2218 ab	2237 ab	2409 a
47	1890 c	2002 bc	2069 abc	2077 ab	2120 ab	2213 a	2046 abc
75	2340 a	2357 a	2482 a	2445 a	2479 a	2520 a	2433 a
Effective quantum efficiency PSII – ΦPSII							
26	0.650 b	0.711 a	0.697 a	0.731 a	0.714 a	0.708 a	0.723 a
33	0.609 b	0.683 a	0.672 a	0.709 a	0.695 a	0.693 a	0.712 a
40	0.691 b	0.701 ab	0.695 b	0.730 ab	0.719 ab	0.722 ab	0.743 a
47	0.704 b	0.707 b	0.723 b	0.729 b	0.703 b	0.732 b	0.709 b
75	0.763 b	0.756 b	0.753 b	0.759 b	0.761 b	0.752 b	0.761 b

a, b, c – different letters in rows indicate homogenous groups of means based on LSD at 0.05 significance level

Deficiency of iron, magnesium and zinc in tropical plants caused the reduction of the effective quantum efficiency PSII (ΦPSII)) measured in leaves adapted to the darkness [Balakrishnan et al. 2000]. According to these authors, zinc deficiency inhibits the PSI and PSII activity and iron or magnesium deficiency have a negative effect on chlorophyll biosynthesis, activity and synthesis of cytochromes what reduces the excitation degree of electrons in photosystems and energy transfer between them. Reduction of the PSII maximum quantum efficiency in wheat was observed as the effect of high temperature and it was cancelled by additional zinc fertilization [Graham and McDonald 2001].

CV value for PAR absorption and LAI decreased systematically with each measurement date (Table 6) which means that variability between plants increased in later growth stages. For F_s and F_m' decreased up to 40 DAE, and then increased. CV values for ΦPSII were the highest at 26 and 33 DAE, and the lowest at 75 DAE.

Table 6. Variability of physiological parameters in 2013–2014

Measurement/DAE	Parameter	Mean	Min.	Max.	SD	CV, %
26	PAR absorption	35.6	12.8	59.0	14.4	40.4
	LAI	0.58	0.07	0.99	0.24	41.5
	F_s	682	551	881	77.9	11.4
	F_m'	2426	1496	3085	384	15.8
	ΦPSII	0.705	0.523	0.789	0.070	10.0
33	PAR absorption	46.0	17.5	64.3	12.0	26.0
	LAI	0.80	0.12	1.23	0.27	33.7
	F_s	652	532	858	71.3	10.9
	F_m'	2221	1409	2805	335	15.1
	ΦPSII	0.682	0.472	0.761	0.072	10.5
40	PAR absorption	62.5	29.1	81.3	12.0	19.1
	LAI	1.20	0.17	1.99	0.39	32.5
	F_s	612	510	780	55.0	9.0
	F_m'	2207	1453	2786	279	12.6
	ΦPSII	0.714	0.508	0.779	0.058	8.1
47	PAR absorption	80.0	56.1	90.6	7.0	8.7
	LAI	1.98	0.95	2.80	0.40	20.2
	F_s	571	462	723	57.8	10.1
	F_m'	2060	1475	2509	286	13.9
	ΦPSII	0.715	0.630	0.776	0.039	5.4
75	PAR absorption	94.0	84.9	97.0	3.1	3.3
	LAI	3.51	1.73	4.28	0.67	19.0
	F_s	559	425	891	121	21.6
	F_m'	2437	1393	4041	783	32.1
	ΦPSII	0.758	0.681	0.820	0.042	5.5

SD – standard deviation, CV – coefficient of variation

Roots' yields (t·ha^{-1}) in the experiment, related to the fertilization variants were as follows: control – 98.3; A – 111.3; B – 119.8; C – 118.3; D – 120.1; E – 115.7; F – 118.6. Technological sugar yields (t·ha^{-1}) were as follows: control – 16.5; A – 17.9; B – 19.6; C – 19.2; D – 19.7; E – 18.7; F – 19.7 [Artyszak et al 2015b].

PAR absorption and LAI from every measurements were positively correlated with the root yield and the technological sugar yield (Table 7). However the negative correlations of Fs with

Table 7. Correlation coefficients between physiological parameters, roots yield and technological sugar yield in 2013–2014 (n = 56)

Measurement/DAE	Parameter	Roots yield, t·ha^{-1}	Technological sugar yield, t·ha^{-1}
26	PAR absorption	0.657**	0.639**
	LAI	0.609**	0.588**
	F_s	-0.557**	-0.497**
	F_m'	0.449**	0.426**
	ΦPSII	0.648**	0.599**
33	PAR absorption	0.592**	0.580**
	LAI	0.500**	0.487**
	F_s	-0.587**	-0.538**
	F_m'	0.468**	0.439**
	ΦPSII	0.655**	0.601**
40	PAR absorption	0.564**	0.548**
	LAI	0.576**	0.552**
	F_s	-0.347**	-0.313*
	F_m'	0.449**	0.417**
	ΦPSII	0.474**	0.442**
47	PAR absorption	0.386**	0.375**
	LAI	0.398**	0.387**
	F_s	-0.230	-0.213
	F_m'	-0.479**	-0.475**
	ΦPSII	-0.319*	-0.336*
75	PAR absorption	0.679**	0.641**
	LAI	0.636**	0.595**
	F_s	-0.526**	-0.490**
	F_m'	-0.661**	-0.627**
	ΦPSII	-0.710**	-0.692**
Mean	PAR absorption	0.647**	0.628**
	LAI	0.663**	0.633**
	F_s	-0.637**	-0.583**
	F_m'	-0.248	-0.247
	ΦPSII	0.469**	0.414**

**significant correlation at $P \leq 0.01$; *significant correlation at $P \leq 0.05$

those yields were significant in every measurements with the one exception of measurement at 47 DAE. The root yield and the technological sugar yield were positively correlated with F_m' at first, second and third measurement and then negatively in the next two measurements.

As average for every measurements the root yield and the technological sugar yield were positively correlated with PAR absorption and LAI value. Then, the significant, but slightly lower correlations between those yields and ΦPSII were noticed. However the correlations of the root yield and technological sugar yields with F_s were significantly negative. Chołuj at al. [2014] suggest that such features like ΦPSII, LAI, PAR are strongly correlated with the roots' yield, as well as with the yield of sugar.

The results obtained in the experiment shows that foliar fertilizations with macro and micronutrients have long-time positive effect on LAI and PAR absorption.

Sugar beet foliar fertilization improves the quantum efficiency of PSII (ΦPSII) also. However it is difficult to notice a significant effect foliar fertilization on stationary (F_s) and maximum fluorescence (F_m'). The increase of roots' and sugar yields as the effect of foliar fertilization are primarily caused by the increase of photosynthetic apparatus surface area which is correlated with the increase of PAR absorption. Both of these physiological features have the effect on photosynthesis process as well as on the sugar beet plants productivity.

CONCLUSIONS

PAR absorption and LAI were increasing successively during the vegetation period of sugar beet plants, and the maximum value was observed at 75 DAE. The highest PAR absorption and LAI was observed for F – fertilization variant. It was significantly higher in comparison to other fertilization variants.Application of macro- and micronutrients in F variant allow to in the highest degree to ensure nutritional requirements of sugar beet. PAR absorption and LAI were positively correlated with the root yield and the technological sugar yield. Moreover positively correlated traits with sugar yield were F_m' and ΦPSII, while for F_s correlation was negative.

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WPŁYW ZRÓŻNICOWANEGO DOKARMIANIA DOLISTNEGO NA WYBRANE CECHY FIZJOLOGICZNE BURAKA CUKROWEGO

Synopsis. W latach 2013–2014, w południowo-wschodnim regionie Polski, na polu produkcyjnym w Sahryniu (50°41′ N, 23°46′ E) badano wpływ 6 wariantów dokarmiania dolistnego buraka cukrowego makro- oraz mikroelementami i porównywano z kontrolą. Oceniano wpływ dokarmiania dolistnego na wybrane cechy fizjologiczne roślin buraka cukrowego: 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 miały korzystny wpływ na wartość LAI i absorpcję PAR. Jednakże największą wartość obu parametrów zaobserwowano w wariancie F. Podobnie dokarmianie dolistne buraka cukrowego istotnie poprawiało efektywną wydajność kwantową PSII (ΦPSII) w pierwszych trzech terminach pomiarów (od 26. do 40. dnia po wschodach). Dokarmianie dolistne nie miało istotnego wpływu na pozostałe parametry fluorescencji chlorofilu a. Absorpcja PAR i LAI w każdym terminie pomiaru były istotnie dodatnio skorelowane z plonem korzeni i plonem technologicznym cukru.

Słowa kluczowe: dokarmianie dolistne, wskaźnik powierzchni liści, fotosynteza, burak cukrowy

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