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The bio-organic nano fertilizer improves sugar beet photosynthesis process and productivity

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Abstract

Applications of biological agents intensify the growth of crops, so they more quickly form a maximum leaf area, optimize photosynthesis, increase plant productivity and quality. Chemical producers offer a new generation of bio-organic fertilizers based on nano technologies. Such fertilizers have not been well investigated yet; therefore, the aim of this study was to ascertain the influence of the fertilization rates by bio-organic nano fertilizer, made from cattle manure on the effectiveness of sugar beet crop photosynthesis and productivity parameters. The investigations were carried out in 2011–2012 at Aleksandras Stulginskis University's Research Station, Kaunas district, Lithuania (54º52′ N, 23º49′ E) on a silty loam *Luvisol* (*Calcari-Epihypogleyic Luvisol*, *LVg-p-w-cc*). Sugar beet plants were sprayed with the fertilizer at doses of 0.5 or 1.0 L ha^{-1} at the BBCH 18 and/or BBCH 31 stages. Single application of the bio-organic fertilizer at single 1 L ha^{-1} dose was more effective than at single 0.5 L ha^{-1} or double 0.5 + 0.5 L ha^{-1} doses. At the beginning of intensive sugar beet development (BBCH 37–38), single 1 L ha^{-1} dose increased the number of leaves by 19.6%, leaf area by 13.4%, root diameter by 11.1%, canopy dry biomass by 29.1%, root biomass by 42.6%, net photosynthetic productivity by 15.8%, root yield by 12.6%, sucrose content by 1.03 percentage points and yield of white sugar by 19.2% in comparison with the untreated beets. Double 1 + 1 L ha^{-1} dose of fertilizer was slightly more effective but economically less suitable than single (1 L ha^{-1}). In general, the application of bio-organic fertilizer revealed a great potential for optimization of sugar beet development, productivity and quality parameters.

Key words: *Beta vulgaris*, biometric and growth parameters, sucrose content, yield.

Introduction

In order to optimize the productivity of field crops, optimal conditions for the growth of plants need to be created that will accelerate the vital processes occurring in plants and affect crop productivity. However, plants are affected by negative factors that cause stress. Negative factors affecting sugar beet growth can lead to the stress caused by drought, diseases, pests and weeds (herbicides). It should be noted that stress tolerant sugar beet varieties are less fertile under optimal growth conditions (Pidgeon et al., 2006). Shen et al. (2013) confirmed that application of bio-organic fertilizers could more effectively control Fusarium wilt disease. In Lithuanian climate conditions, sugar beets are affected by more than one hundred different species of pests. Due to pest damage, sugar beet seed germination can be reduced by 47–74% and yield by up to 24% (Pekarskas, 2008). Sugar beets cannot tolerate shading by weeds because they grow slowly during the early stages (6–8 weeks after sowing) of development. However, growth of weeds should be suppressed until harvest (Dewar et al., 2006). Sugar beets can be damaged by herbicides from direct spraying, be susceptible to herbicides brought by the wind or sprayed on adjacent crops or even by cultivating sugar beet after other plants that had been sprayed with herbicides, because they remain in the soil for a long time. Various stresses can be mitigated by applying macro-and micronutrient solutions, biological preparations or bio-organic fertilizers (Jakienė et al., 2009; Ghormade et al., 2011).

Optimization of photosynthetic parameters by technological measures also directly determines productivity (Lawlor, 1995). The photosynthetic productivity of sugar beet mainly depends on varietal differences, leaf assimilation area and spatial distribution, the inclination angle of the sunshine, photosynthetic pigment content (Suojala, 2000; Jakienė et al., 2008). Farmers have mostly tried to increase plant productivity by applying abundant nitrogen fertilization, and unreasonable amounts of plant protection products (Šiuliauskas et al., 2008). Eventually, the soil starts to degrade. Biological agents may promote soil biological processes and increase plant productivity and production quality because they more quickly attain a maximum leaf area, have more intensive photosynthesis; rapid assimilate transport from the leaves to the roots (Staugaitis, Laurė, 2008; Romaneckas, Romaneckienė, 2009). The efficiency of bio-organic fertilizers is especially apparent under adverse growth conditions. However, the application of bio-organic or bio-organic nano fertilizers is not well documented. So, the aim of our research was to estimate the influence of fertilization rates of such bio-organic fertilizer on sugar beet development, photosynthetic parameters, yield and quality of roots.

Material and methods

Description of experimental site and soil Investigations were carried out in 2011–2012 at Aleksandras Stulginskis University's Research Station, Kaunas district, Lithuania (54º52′ N, 23º49′ E) on silty loam *Luvisol* (*Calcari-Epihypogleyic Luvisol*, *LVg-p-w-cc*). The pH_{KCl} of the arable soil layer was 7.1–7.3, available phosphorus (P_2O_5) – 238–315 mg kg^{-1}, available potassium (K_2O) – 154–172 mg kg^{-1}, humus – 17.0–24.5 g kg^{-1}. In the experiment, sugar beet plants were sprayed with different doses of bio-organic nano fertilizer. Treatments consisted of: 1) C-0 – control, without bio-organic fertilizer, 2) N-0.5-1 – bio-organic fertilizer 0.5 L ha^{-1} at BBCH 18, 3) N-0.5-2 – bio-organic fertilizer 0.5 L ha^{-1} at BBCH 18 and 31, 4) N-1-1 – bio-organic fertilizer 1 L ha^{-1} at BBCH 18 and 5) N-1-2– bio-organic fertilizer 1 L ha^{-1} at BBCH 18 and 31.

The initial experimental plot area was 12.6 m^2. The experiment was carried out in four replications; a randomized plot design was applied. The pre-crop of sugar beet was winter wheat. In the spring, the soil was cultivated and all experimental plots were primarily fertilized by fertilizer NPK 8:20:30 at 300 kg ha^{-1} rate ($N_{24+38}P_{60}K_{90}$). The herbicide Pyramin Turbo (5.0 L ha^{-1}, a.i. chloridazon 520 g L^{-1}) was applied before sowing. The soil was tilled repeatedly by a complex cultivator. A sugar beet variety 'Ernestina' (by KWS, Germany) was sown. In early May, upon renewed weed germination, the field was sprayed with the herbicide Betanal Expert (1.30 L ha^{-1}, a.i. ethofumezate 112 g L^{-1}, phenmedipham 91 g L^{-1} and desmedipham 71 g L^{-1}). The sugar beet crop was additionally fertilized with ammonium nitrate (N_{34}) 112 kg ha^{-1} before leaves covered 70–80% of the ground. Bio-organic fertilizer was applied according to the scheme of the experiment. The amount of water for fertilizer solution was 250 L ha^{-1}. Weeds were repeatedly controlled using a herbicide mixture: Betanal Expert (1.1 L ha^{-1}) + Lontrel (0.3 L ha^{-1}, a.i. clopyralid 300 g L^{-1}). Samples for sugar beet productivity and quality evaluation were collected at the beginning of October.

Methods. Sugar beet leaf area was measured using a leaf area measurement system *WinDIAS 3* (Delta-T Devices, UK). The dry matter of sugar beet plants was determined by drying them at 105°C temperature to a constant weight. Net photosynthetic efficiency during sugar beet vegetation was calculated according to the formula:

$$F_{pr} = M_2 - M_1 / ½ (L_0 + L_1) \times T,$$

where F_{pr} is photosynthesis productivity, g cm^{-2} per 24 h, M_2 and M_1 – dry weight gain over a period of time, g, L_0 and L_1 – leaf area at the beginning and end of a period, cm^2, and T – period in days. Sugar beet yield was determined by weighing the roots from each plot and was converted to Mg ha^{-1}. Sugar beet roots were counted, weighed and the number of plants per hectare was estimated. Samples (25 roots) for estimation of sucrose content were taken from each experimental plot. Sucrose content was evaluated at the Marijampolė sugar factory, Lithuania. Quantity of white sugar (Ws, Mg ha^{-1}) was calculated according to the formula:

Ws = Y × Sa, where Y is yield of roots Mg ha^{-1}, Sa − sugar output, %;

Sa = Sc − 0.9 − 3.76, where Sc is sucrose content, %, 0.9 − average sugar losses before molasses, %, 3.76 − average sugar loses in molasses, %.

Research data was analyzed with a statistical computer program *ANOVA* from the package *SELECTION*. The treatment effect was tested by the *P* test. If $P \leq 0.050 > 0.010$, the differences from the control treatment are significant at 95% probability level, and if $P > 0.050$, there are no significant differences.

The bio-organic universal nano fertilizer Nagro was investigated. It is an ecologically safe fertilizer made from cattle manure (by the method of cold synthesis) with micro-, macro- and mezo-elements and bioactive materials. It is suitable for fertilization of all types of agricultural crops, ornamental crops, forests and parks, and green plots in various types of soils. According to the producers (Russian Federation), the use of the fertilizer increases yields, enhances plant immunity, protects against stress (drought, frost, pesticide effects), and disease, shortens the ripening period and improves product quality. It is used as a water solution for seed treatment before sowing, or as foliar application. The composition of the fertilizer is: humus extract, humic and fulvic acids – not less than 0.2%, total nitrogen (N) – not less than 0.015%, total potassium (K_2O) – not less than 0.02%, total phosphorus (P_2O_5) – not less than 0.002%. The microelements boron (B), copper (Cu), zinc (Zn), cobalt (Co), magnesium (Mg), manganese (Mn), molybdenum (Mo), and iron (Fe) are included too.

Meteorological conditions. The weather conditions during the growing season affect the chemical composition of sugar beet: a lack of moisture slows down fat synthesis and increases the protein quantitatively; increasing rainfall, when the air temperature lowers, produces more intense carbohydrate synthesis in the leaves. The meteorological conditions during sugar beet vegetation were mostly warmer than usual (Table 1).

Table 1. Average air temperatures and rainfall during sugar beet vegetation (the data of Kaunas Meteorological Station)

Index / month	April	May	June	July	August	September	October
2011							
Temperature °C	8.9	13.1	18.1	19.6	18.1	13.6	7.7
Rainfall mm	25.2	46.9	82.7	144.0	152.4	73.9	21.6
2012							
Temperature °C	7.7	13.7	15.3	19.4	17.1	13.3	7.6
Rainfall mm	72.3	50.3	93.4	112.8	69.2	67.2	75.0
Long-term (since 1974) average							
Temperature °C	6.7	12.6	15.6	17.6	17.1	12.2	7.1
Rainfall mm	38.1	47.2	66.7	83.0	73.2	53.8	54.7

The precipitation rate was variable and uneven during the two experimental years. In 2011, April was drier than the long-term average and May was similar to typical conditions; however, the summer months and September were too wet (especially July and August). These factors had a negative effect on beet growth. October was dry and there was a favourable period for sucrose accumulation in the roots. In 2012, the entire growing season was more humid than usual. The only exception was in August. Under those conditions in heavy soils some sugar beet plants died because of too high water content in the soil.

Results and discussion

Sugar beet biometric ***parameters***. Sabir et al. (2014) indicated that application of the nano Ca-based fertilizer led to a significant increase in foliar development and chlorophyll concentration of the vines. In Moghaddasi et al. (2013) experiments, Zn nano-particles were produced from ground rubber and they were more effective than Zn-sulphate for cucumber. In our experiment, the bio-organic fertilizer with nano multi microelement complex mostly had a significant positive impact on sugar beet growth and development processes. Biometric measurements, carried out at the BBCH 34–35 growth stages, showed that sugar beet leaf growth was increased by a higher level of fertilization (1–2 L ha^{-1}). Fertilized seedlings had significantly more (by the 12.6–23.2%) leaves than untreated plants (Table 2).

The greatest effect was obtained by applying N-1-2 treatment. Similarly Kumar et al. (2014) found, that double dose of bio-fertilizers increased wheat root and shoot length, number of roots and leaves, green and dry mass of roots and canopy. The biometric measurements in BBCH 37–38 stages showed similar results (Table 2). Fertilization level of bio-organic fertilizer from 1 to 2 L ha^{-1} significantly increased the number of sugar beet leaves by 17.4–27.6%. As in BBCH 34–35, treatment N-1-2 was the most effective. In the BBCH 34–35 growth stage, foliar fertilization significantly increased the diameter of roots by 5.4–16.3% (Table 2). The highest root diameter was obtained in the treatment N-1-2. In the later sugar beet growth stages (BBCH 37–38) we found analogous results.

Table 2. Effect of different fertilization rates on sugar beet biometric parameters (the average data of 2011–2012)

Treatment	Quantity of leaves			Diameter of root		
	number per plant	± from control		cm	± from control	
		number	%		cm	%
BBCH 34–35 stages						
C-0	19.8	–	–	9.2	–	–
N-0.5-1	20.6	0.8	4.0	9.7*	0.5	5.4
N-0.5-2	23.5*	3.7	18.7	10.3*	1.1	12.0
N-1-1	22.3*	2.5	12.6	10.0*	0.8	8.7
N-1-2	24.4*	4.6	23.2	10.7*	1.5	16.3
LSD_{05}	1.13			0.50		
BBCH 37–38 stages						
C-0	27.5	–	–	11.7	–	–
N-0.5-1	29.7*	2.2	8.0	12.7*	1.0	8.6
N-0.5-2	32.3*	4.8	17.4	13.1*	1.4	12.0
N-1-1	32.9*	5.4	19.6	13.0*	1.3	11.1
N-1-2	35.1*	7.6	27.6	13.6*	1.9	16.2
LSD_{05}	1.57			0.64		

C-0 – control, without bio-organic fertilizer, N-0.5-1 – bio-organic fertilizer 0.5 L ha^{-1} at BBCH 18, N-0.5-2 – bio-organic fertilizer 0.5 L ha^{-1} at BBCH 18 and 31, N-1-1 – bio-organic fertilizer 1 L ha^{-1} at BBCH 18, N-1-2– bio-organic fertilizer 1 L ha^{-1} at BBCH 18 and 31; * – significant difference from control treatment (C-0) at $P \leq 0.05$

Sugar beet growth parameters. The application of bio-organic fertilizer significantly increased leaf area of sugar beet plants (Table 3). In BBCH 34–35 growth stages, single or double application of fertilizer in lower concentrations (N-0.5-1 and N-0.5-2) increased average leaf area by 7.7–8.4%. More effective was fertilizer application at the higher concentrations (N-1-1 and N-1-2). Sugar beet leaf area increased by 12.2–13.7% compared to the control treatment (Table 3).

Table 3. Effect of different fertilization rates on sugar beet leaf area and dry biomass (the average data of 2011–2012)

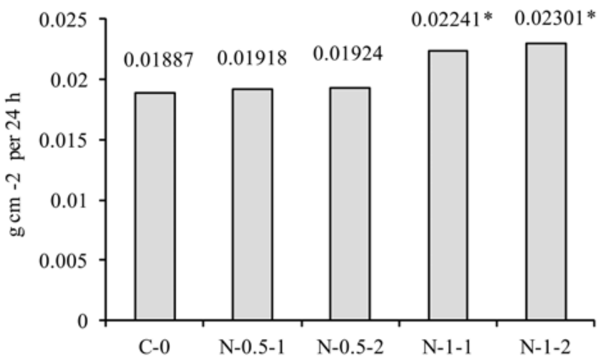
Treatment	Leaf area			Canopy biomass			Root biomass		
	cm^2 per plant	± from control		g per plant	± from control		g per plant	± from control	
		cm^2	%		g	%		g	%
BBCH 34–35 stages									
C-0	3793.9	–	–	34.4	–	–	21.5	–	–
N-0.5-1	4086.8*	292.9	7.7	36.6*	2.2	6.4	24.8*	3.3	15.4
N-0.5-2	4111.0*	317.1	8.4	37.1*	2.7	7.8	26.4*	4.9	22.8
N-1-1	4257.7*	463.8	12.2	43.9*	9.5	27.6	30.4*	8.9	41.4
N-1-2	4313.8*	519.9	13.7	44.7*	10.3	29.9	32.0*	10.5	48.8
LSD_{05}	209.23			2.08			1.40		
BBCH 37–38 stages									
C-0	7365.9	–	–	66.3	–	–	40.8	–	–
N-0.5-1	7951.4*	585.5	8.0	69.1	2.8	4.2	47.3*	6.5	15.9
N-0.5-2	8134.2*	768.3	10.4	69.8	3.5	5.3	48.9*	8.1	19.8
N-1-1	8354.7*	988.8	13.4	85.6*	19.3	29.1	58.2*	17.4	42.6
N-1-2	8452.4*	1086.5	14.8	87.5*	21.2	32.0	61.5*	20.7	50.7
LSD_{05}	404.38			4.45			2.70		

Explanations under Table 2

Application of bio-organic fertilizer solutions also resulted in significantly greater accumulation of dry matter in the beet canopy and roots (Table 3). 14 days after spraying with fertilizer solutions, the dry matter content in sugar beet leaves increased by 6.4–7.8% in those sprayed with single or double doses of fertilizer at lower concentrations (N-0.5-1 and N-0.5-2), and by 27.6–29.9% in those sprayed at higher concentrations (N-1-1 and N-1-2) compared to the dry matter content in untreated leaves. The bio-organic fertilizer initiated a higher dry matter quantity in the sugar beet roots too. Concentrations N-0.5-1 and N-0.5-2 resulted in an increase in the dry matter content in roots by 15.4–22.8%, and N-1-1 and N-1-2 – by 41.4–48.8% compared to the control treatment. So the concentrations N-1-1 and N-1-2 were the most effective. Investigations repeated after three weeks (BBCH 37–38) showed similar results.

Photosynthesis productivity. In Sortino et al. (2012) experiment, bio-organic fertilizer from municipal wastes (kitchen wastes, home gardening residues and public park trimmings) with alkali demonstrated the best results in leaf chlorophyll content, plant growth and tomato fruit ripening rate and yield. In our experiment, application of the bio-organic fertilizer solutions also intensified photosynthesis in sugar beets. Application of investigated fertilizer at lower concentrations (N-0.5-1 and N-0.5-2) increased net photosynthesis productivity insignificantly – by about 2%, compared to the control treatment (Fig.).

Significantly higher net photosynthesis productivity was estimated after spraying higher concentrations (N-1-1 and N-1-2) of fertilizer. It increased by 15.8% and 18.4% compared to that in the control sugar beet plots. It should be noted that double application of higher doses



Explanations under Table 2; LSD_{05} = 0.00125

Figure. Effect of different fertilization rates on the sugar beet net photosynthesis productivity (the average data of 2011–2012)

(N-1-2) of fertilizer significantly increased photosynthesis productivity compared with single (N-1-1).

Sugar beet productivity parameters. The bio-organic fertilizer had a significant positive effect on sugar beet root yield (Table 4). The most effective were N-1-1 and N-1-2 treatments; however, the differences between them were insignificant.

In our experiment, the sugar beet crop density was similar – from 83.5 to 85.3 thousand plants per ha or varied from −0.6 to 1.3%. Despite that, the average mass of root increased significantly by 3.9% to 14.6%. Solutions of higher concentration (N-1-1 and N-1-2) were the most effective (Table 4).

Sugar beet root quality parameters. Salama et al. (2015) found the best quality parameters of fennel plants, when they were processed with 50% NPK + 50% organic fertilizer and bio-fertilizer. Similar results were

Table 4. Effect of different fertilization rates on sugar beet productivity parameters (the average data of 2011–2012)

Treatment	Root yield			Crop density			Average mass of root		
	Mg ha^{-1}	± from control		t ha^{-1}	± from control		kg	± from control	
		Mg ha^{-1}	%		t ha^{-1}	%		kg	%
C-0	64.50	–	–	84.2	–	–	0.766	–	–
N-0.5-1	67.92*	3.42	5.3	85.3	1.1	1.3	0.796*	0.030	3.9
N-0.5-2	70.38*	5.88	9.1	83.7	−0.5	−0.6	0.841*	0.080	9.8
N-1-1	72.63*	8.13	12.6	83.5	−0.7	−0.8	0.878*	0.110	14.6
N-1-2	73.79*	9.29	14.4	84.8	0.6	0.7	0.878*	0.110	14.6
LSD_{05}	1.803			3.45			0.0213		

Explanations under Table 2

found in investigations with broccoli (Naguib et al., 2012). In our experiment, application of bio-organic nano fertilizer at different doses increased the sucrose content in sugar beet roots significantly by 0.81–1.14 percentage units (Table 5). The best treatment was N-1-2, but N-0.5-1 also showed similar results.

Table 5. Effect of different fertilization rates on sugar beet root quality parameters (the average data of 2011–2012)

Treatment	Sucrose content		Yield of white sugar		
	%	± from control % units	Mg ha^{-1}	± from control Mg ha^{-1}	± from control %
C-0	16.65	–	8.28	–	–
N-0.5-1	17.46*	0.81	9.42*	1.14	13.7
N-0.5-2	17.64*	0.99	9.84*	1.56	18.8
N-1-1	17.68*	1.03	9.89*	1.61	19.2
N-1-2	17.79*	1.14	10.18*	1.90	22.9
LSD_{05}	0.446		0.234		

Explanations under Table 2

The application of different doses of the bio-organic fertiliser increased white sugar yield by 13.7–22.9%. The best result was found after application of the highest dose of fertilizer (2 L ha^{-1}, N-1-2). Yield of white sugar increased by 22.9% and was significantly higher compared with other treatments. Differences between N-0.5-2 and N-1-1 treatments (1 L ha^{-1}) were little. So, single application of 1 L ha^{-1} (N-1-1) was the most economically effective treatment compared with double application (N-0.5-2 or N-1-2). In N-1-1 incomes were greater than in N-0.5-2 by 90 € ha^{-1} and only by 20 € less than in N-1-2 (data are not presented).

Conclusions

1. A single application of the bio-organic fertilizer at 1 L ha^{-1} dose (N-1-1) was more effective than 0.5 L ha^{-1} or 0.5 + 0.5 L ha^{-1} doses (N-0.5-1 or N-0.5-2 treatments). At the beginning of intensive sugar beet development (BBCH 37–38), the concentration N-1-1 increased the number of leaves by 19.6%, leaf area by 13.4%, root diameter by 11.1%, canopy dry biomass by 29.1%, root biomass by 42.6%, net photosynthetic productivity by 15.8%, root yield by 12.6%, sucrose content by 1.03 percentage units and yield of white sugar by 19.2% in comparison with the control treatment.

2. Concentration N-1-2 (double 1 + 1 L ha^{-1} rate) showed slightly higher, but not economically suitable results than in singly treated (N-1-1) plots.

3. As a result, we suggest spraying of sugar beet plants with 1 L ha^{-1} dose of nano bio-organic fertilizer once at BBCH 18 growth stage.

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Bioorganinės nanotrąšos gerina cukrinių runkelių fotosintezės procesą ir produktyvumą

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Santrauka

Biologinių medžiagų panaudojimas intensyvina žemės ūkio augalų augimą, todėl jie sparčiau suformuoja maksimalų lapų plotą. Tai optimizuoja fotosintezės procesą, didina augalų produktyvumą ir gerina produkcijos kokybę. Cheminių medžiagų gamintojai sukūrė naujos kartos bioorganines trąšas, prisodrintas nanodalelių. Tokios trąšos nėra pakankamai gerai ištirtos, taigi šių tyrimų tikslas – nustatyti bioorganinių nanotrašų, pagamintų iš galvijų mėšlo, tręšimo normų efektyvumą cukrinių runkelių fotosintezės ir produktyvumo rodikliams. Tyrimai atlikti 2011–2012 m. Aleksandro Stulginskio universiteto Bandymų stotyje, Kauno r. (54º52′ N, 23º49′ E). Eksperimento dirvožemis – dulkiško lengvo priemolio giliau glėjiškas karbonatingas išplautžemis (IDg8-k). Cukrinių runkelių augalai buvo purkšti trąšų 0,5 arba 1,0 L ha^{-1} dozių tirpalu BBCH 18 ir/ar BBCH 31 vystymosi tarpsniais. Cukrinių runkelių augimo ir produktyvumo rodiklius efektyviau veikė didesnė 1 L ha^{-1} vienkartinė dozė trąšų nei vienkartinė 0,5 L ha^{-1} arba patręšus du kartus po 0,5 L ha^{-1}. Palyginus su netręštais runkeliais, cukrinių runkelių intensyvaus vystymosi pradžioje (BBCH 37–38) toks tręšimas esmingai padidino cukrinių runkelių augalų lapų skaičių (19,6 proc.) bei plotą (13,4 proc.), šakniavaisių skersmenį (11,1 proc.), augalų antžeminės dalies sausąją biomasę (29,1 proc.), šakniavaisių biomasę (42,6 proc.), suminį fotosintezės produktyvumą (15,8 proc.), šakniavaisių derlingumą (12,6 proc.) bei cukringumą (1,03 proc. vnt.) ir baltojo cukraus derlingumą (19,2 proc.). Dviguba dozė (1 + 1 L ha^{-1}) trąšų buvo šiek tiek efektyvesnė, tačiau ekonomiškai mažiau tinkama nei vienkartinė (1 L ha^{-1}). Apskritai, tręšimas tirta bioorganine nanotrąša yra efektyvus būdas optimizuoti cukrinių runkelių vystymosi, produktyvumo ir kokybinius rodiklius.

Reikšminiai žodžiai: *Beta vulgaris*, biometriniai ir augimo rodikliai, cukringumas, derlius.