Journal of Elementology ISSN 1644-2296

Prośba-Białczyk U., Sacała E., Wilkosz M., Cieciura M. 2017. *Impact of seed stimulation and foliar fertilization with microelements on changes in the chemical composition and productivity of sugar beet*. J. Elem., 22(4): 1525-1535. DOI: 10.5601/jelem.2017.22.1.1408

ORIGINAL PAPER

IMPACT OF SEED STIMULATION AND FOLIAR FERTILIZATION WITH MICROELEMENTS ON CHANGES IN THE CHEMICAL COMPOSITION AND PRODUCTIVITY OF SUGAR BEET*

Urszula Prośba-Białczyk[1], Elżbieta Sacała[2], Małgorzata Wilkosz[1], Małgorzata Cieciura[1]

[1]Department of Crop Production
[2]Department of Plant Nurition
Wrocław University of Environmental and Life Sciences, Poland

Abstract

The experiment was carried out in 2011-2013, under the climatic conditions of the Silesian Lowlands. It was set up in a split-plot design with three replications. The purpose was to analyse the effect of foliar fertilization with iron, copper, manganese on sugar beet plants grown from natural, standard seeds and from seeds conditioned through priming. Each year, seeds of sugar beet were sown between 10th and 20th of April, and harvested around 20th of October. The density of plants ranged from 95 to 98 thousand of specimens per ha and did not depend on the factors analysed throughout the experiment. Plants were fertilized with microelements in BBCH phases 15 and 18, and the content of N, P, K, Mg and Na was analysed in roots and leaves in BBCH phases 28, 35, 41 and 46. During BBCH phase 49, i.e. the phase of full maturity, the yield of sugar and some technological root quality characteristics, such as the content of sucrose, α-amino nitrogen and potassium and sodium cations, were analysed. Foliar fertilization with microelements such as iron, copper and manganese, and the stimulation of seeds by priming changed the level of concentration of nitrogen and mineral macro components of phosphorus, potassium, magnesium, and sodium during the vegetation season in the roots and leaves. In BBCH stages 28 and 35, plants grown from the primed seeds had a higher content of nitrogen, potassium, sodium and magnesium in leaves, and higher content of nitrogen, phosphorus, and potassium in roots. Foliar fertilization with these trace elements in interaction with the pre-sowing stimulation of seeds (priming*)* had an impact on the chemical composition of the plant during the vegetation season, the content of sucrose in the roots, and plants' performance.

Keywords: sugar beet*,* priming, foliar fertilization, iron, copper, manganese, sucrose.

prof. dr hab. Urszula Prośba-Białczyk, Department of Crop Production, Wrocław University of Environmental and Life Sciences, pl. Grunwaldzki 24a, 50-363 Wrocław, Poland.
* The study was supported financially by Wrocław University of Environmental and Life Sciences.

INTRODUCTION

Sugar beet is a very important crop plant and it accounts for about 35% of the world's sugar production (FAO 2014). It is also used as feedstock for the production of biofuels (Hoffmann 2010, Panella 2010), and the residue of sugar beet after sugar extraction may be utilized to improve the phytoremediation efficiency (Wiszniewska et al. 2016). Sugar beet has a large potential yield and its production is expanding in eastern Europe. Different practices are implemented in order to achieve its highest yield potential and to improve the quality of roots for sugar production. Obviously, a crucial factor is proper nutrition of sugar beets. Recently, more attention has been paid to the application of microelement fertilizer. Microelements, required for proper functioning, growth and development of plants, include iron, boron, zinc, chloride, manganese, copper, molybdenum and nickel. Among them Fe, Cu and Mn play a very important role in photosynthesis as activators of chlorophyll biosynthesis and components of the photosynthetic electron transport system, but they are also required in other physiological processes. Their deficiencies may induce various diseases in plants and consequently reduce both the quantity and quality of yield. Thus, micronutrient fertilization may not only ehance the growth and yield of plants, but they also protect plants from adverse effects of various biotic and abiotic stresses (Ciećko et al. 2004, Tripathi et al. 2015). Some reports showed that the technological quality of sugar beets roots and sucrose efficiency are connected with concentration of certain microelements in plant tissues (Prośba-Białczyk et al. 2000*a*,*b*,*c*, Masri, Hamza 2015). Another solution to improve the crop productivity and the quality of yield is a pre-sowing seed treatment (Ashraf, Foolad 2005, Aladjadjiyan 2007, Marinković et al. 2008). Priming is an important approach in pre-sowing seed technology (Ashraf, Foolad 2005, Conrath 2011, Jisha et al. 2013, Chen, Arora 2013). The most common technique is hydropriming that involves imbibition of seeds to a point where germination processes are begun but not completed. Treated seeds are usually redried before using and after rehydration they exhibit rapid germination and stand establishment (Ashraf, Foolad 2005, Jisha et al. 2013). Seeds of sugar beets obtained according to this technology are named energ'hill or quick beet. Our earlier experiments indicated that an application of this technology increases the physiological activity and productivity of sugar beets and improves the roots' quality (Sacała et al. 2012, 2016).

The aim of this study was to evaluate the interactive effect of the pre-sowing seed treatment (energ'hill) and foliar application of selected microelements (Fe, Cu, Mn) on the nutritional status of sugar beet at different growth stages and yield of roots and their quality in terms of some technological parameters.

MATERIAL AND METHODS

Field research and laboratory tests were carried out in 2011-2013, under the climatic conditions of the Silesian Lowlands. The experiment was set up in a split-plot designs with three replications. Seeds of the variety Ruweta: natural (standard – denoted in the work as non-stimulated NS) and stimulated (by *priming* – denoted as S), as well as foliar fertilization with iron, copper, and manganese were tested.

The field experiment was carried out in the experimental department of the Wrocław University of Environmental and Life Sciences, on lessive type of soil (FAO WRB 2014) with the grain-size composition of light clay on medium clay, defined as good wheat complex with slight acidity (pH 5.9-6.4) and an average content of absorbable forms of macronutrients: P, K and Mg. The content of trace elements applied through foliar application ranged from 3.5 to 6.0 mg kg^{-1} of iron , from 5 to 8 mg kg^{-1} of copper and from 0.5 to 15 mg kg^{-1} of manganese in the soil layer from 0 to 30 cm.

Phosphorus (44 P kg ha^{-1}) and potassium (132.8 K kg ha^{-1}) fertilization was performed in the autumn, while nitrogen was applied at a dose of 120 kg ha^{-1} before sowing. The plants received foliar fertilization in phases BBCH 15 and 18, with two doses in total, including 75 g ha^{-1} of Fe, 120 g ha^{-1} of Cu, and 400 g ha^{-1} of Mn in the form of liquid fertilizers with microelements: Suplo Mono Fe, Suplo Mono Cu and Mikrosol Mn.

Each year, seeds of sugar beet were sown between 10^{th} and 20^{th} of April, and harvested around 20^{th} of October. The density of plants ranged from 95 to 98 thousand of specimens per ha and did not depend on the factors analysed throughout the experiment.

The course of the weather, varied in the years of research, did not cause any major interference with the development of sugar beet, and the temperature conditions were beneficial for the growth of this species. Temperatures higher than the multi-year average (about 1.8) in the months from May to September, appeared in May, June, and September in 2011, from May to September in 2012, and from May to August in 2013. The sum of precipitation, in the same period, over the respective years was as follows: 452.3 mm, 392.2 mm, and 517.9 mm. During the beet growing season, which lasts 178-185 days, there were 63 days with rainfall in 2011, 66 days in 2012, and 61 days in 2013. Rainfall exceeding the mean annual rainfall occurred in June, July and August in 2011, and from May to September in 2012, and in May, June, August and September in 2013.

Chemical plant analyses were made at four development phases (BBCH 28, 35, 41 and 46) and the root yield and some quality attributes were determined at the end of the growing season (BBCH 49). Chemical analyses included determination of important nutrients (total nitrogen, phosphorus, potassium, magnesium and sodium) both in roots and leaves.

Plant material was dried and mineralised. Phosphorus and magnesium were determined using colorimetric assays with a vanadate-molybdate reagent for P and titan yellow for Mg. Potassium and sodium were measured with a flame photometer. Total nitrogen was determined using the Kjeldahl method.

Some quality attributes of the plants were assessed and the following parameters were determined (Buchholz et al. 1995, Artyszak et al. 2016): root yield, sucrose, α-amino-nitrogen, sodium and potassium content in roots in a Venema Automation beet analyzing system. Based on these parameters were calculated:

– biological sugar yield (t ha^{-1}) = root yield (t ha^{-1}) · sucrose content in roots (%);
– technological sugar yield (t ha^{-1}) = root yield (t ha^{-1}) · [sucrose content in roots (%) – loss of sugar productivity (%)];
– technological saccharose (%) = sucrose content in roots (%) – loss of sugar productivity (%).

The statistical evaluation was performed in accordance with the methodology of field experiments with two variable factors using variation analysis (Statistica 9.0) and by determining the least significant difference at a confidence level of $\alpha = 0.05$ with the Duncan's test. The modified method of sub -blocks was applied in the synthesis of the results from three years, taking into account the years of research as a dependent variable.

RESULTS AND DISCUSSION

Successful cultivation of sugar beet and ultimately desirable sugar yields depend on many different factors, of which the nutritional status in plants is very important. The content of macronutrients in the roots and leaves of beets, clearly different in subsequent growth stages BBCH 28, 35, 41 and 49, was also modified by the pre-sowing stimulation of seeds and foliar fertilization with microelements: iron, copper and manganese (Figures 1 and 2). The leaves of plants developed from seeds stimulated before sowing had a higher content of potassium and sodium in phases BBCH 28, 35 and 41, (from July to September). In stages BBCH 28 and 35, (in July and August), also the content of nitrogen and magnesium was higher in relation to the content of these elements in the leaves of plants grown from unstimulated seeds (Figure 1). In phases BBCH 28 and 35 during the rapid increase of roots weight, the roots of plants raised from stimulated seeds contained more nitrogen, phosphorus and potassium than non-stimulated ones (Figure 2). Higher levels of N, K, Na and Mg in leaves and N, P, K in roots accumulated in the plants from stimulated seeds, which indicates a stronger growth of plants owing to the priming of seeds. The positive impact of priming, as well

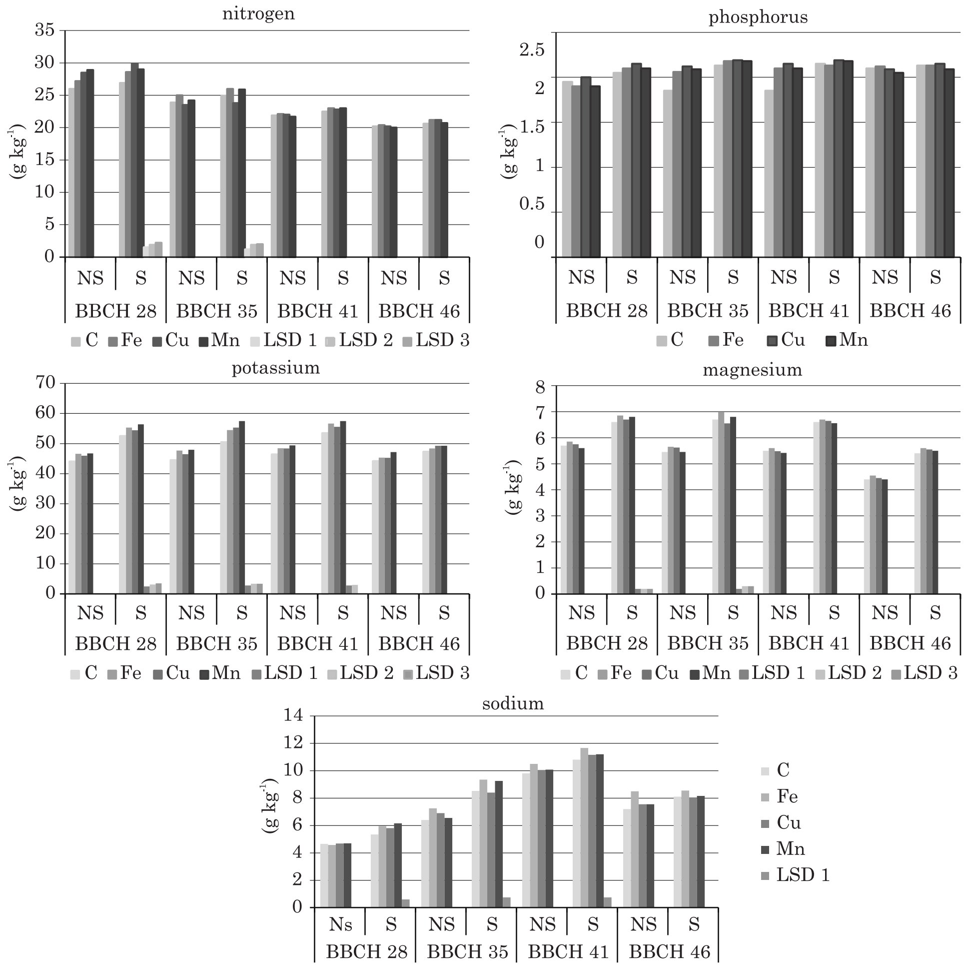

Fig. 1. Impact of seed stimulation and foliar fertilization with microelements on content of macroelements in leaves (g kg^{-1} d.m.): NS – non-stimulated, S – stimulated, C – control, Fe – iron, Cu – copper, Mn – manganese, LSD 1 – LSD seed stimulation, LSD 2 – LSD microelements, LSD 3 – interaction

as other methods of pre-sowing stimulation, is also confirmed by the research of Rochalska, Orzeszko-Rywka (2008), Sacała et al. (2012) and Prośba-Białczyk et al. (2012). Prośba-Białczyk et al. (2012) showed that the roots and embryonic beet leaves developed from stimulated seeds were longer and had a higher content of photosynthetic pigments compared to cotyledons of seedlings developed from unstimulated seeds. On the other hand, Sacała et al. (2016) reported that different seed treatments (laser irradiation and priming) either had a positive or no effect on the mineral composition of leaves and roots during the growing season. Modifications of the chemical composition of the sugar beet during the growing season induced by the pre-

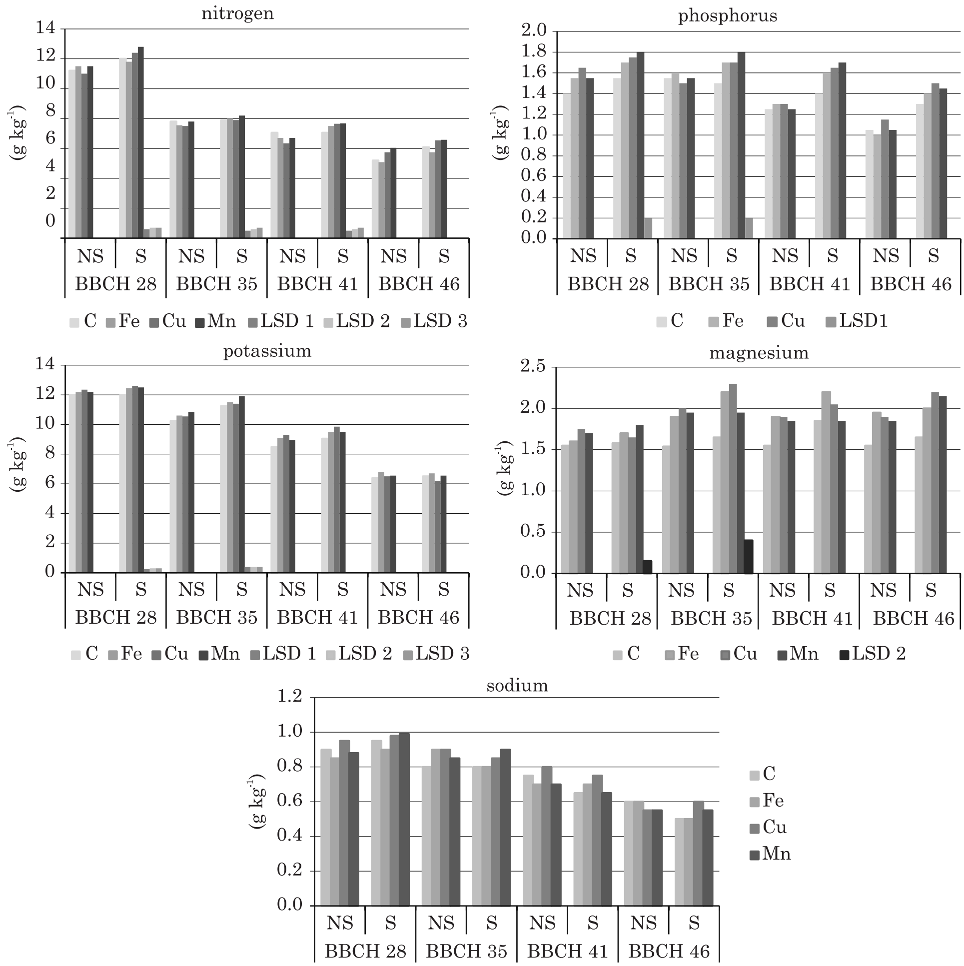

Fig. 2. Impact of seed stimulation and foliar fertilization with microelements on content of macroelements in roots (g kg^{-1} d.m.): Explanation see Figure 1.

sowing stimulation of seeds have been demonstrated in other studies, which reported a higher content of dry matter, nitrogen, potassium and sodium in the leaves and roots of plants developed from seeds stimulated with the energ'hill method and irradiated with laser light, during the phase of intensive weight build-up of leaves and roots, compared to plants developed from unstimulated seeds. Furthermore, the concentration levels of these elements significantly correlated with the content of sucrose in mature roots. The impact of pre-sowing stimulation of seeds with semiconductor laser light and the energ'hill program was also showed in the experiments of Sacała et al. (2012), which indicated a higher content of photosynthetic pigments and a higher concentration of nitrate and nitrate reductase activity in the leaves of beets developed from stimulated seeds, from July to September.

Pre-sowing stimulation of seeds also modified the level of developed crop and productivity of sugar (Figure 3). The plants developed from stimulated seeds produced yields higher by about 6 t ha^{-1} in comparison with unstimulated seeds, and the roots of the plants contained about 0.9% more sucrose and gave a yield of technological sugar higher by 1.2 t ha^{-1}. An increase in root yield, from 5.7 to 6.2 t ha^{-1} depending on a variety, under the influence of stimulation, with a magnetic field, and an increase in the sugar content were also reported by Wójcik (2006). The literature regarding the impact of pre-sowing stimulation on the yield of sugar beet indicates that it is possible to achieve expected results owing to such treatments, but they depend on a method of stimulation, genotype of a strain and environmental conditions (Pietruszewski, Wójcik 2000*a*,*b*).

The chemical composition of plants was also impacted through foliar fertilization with iron, manganese and copper – the microelements which, next to boron, significantly modify the productivity of sugar beet. Furthermore, the content of these micronutrients in plants can significantly correlate with the yield of technological sugar, the most important criterion for the assessment of agricultural technology of sugar beet (Prośba-Białczyk et al. 2000*a*,*b*,*c*, 2012). Our results showed that foliar fertilization with iron resulted in a significant increase in the nitrogen content in leaves in phases BBCH 28 and 35 (Figure 1) and magnesium, which, besides its function in chlorophyll, is also important and activates other processes. In studies of Borowski and Michałek (2011), foliar fertilization with organic salts of iron had a positive impact on the content of chlorophylls and carotenoids in bean leaves. In our study, we found that there is an increase in the potassium and magnesium content in beet roots also in phases BBCH 28 and 35 owing to fertilization with iron (Figure 2). As other studies show (Artyszak 2014, Sacała et al. 2016), these elements can significantly influence the sugar content.

Foliar fertilization with manganese contributed to a higher concentration of nitrogen in leaves and roots, compared to plants which were not fertilized. This relationship was found in the leaves in phases BBCH 28 and 35, and in the roots only in the BBCH 28 phase. Manganese applied onto leaves resulted also in an increase in the potassium and magnesium content in the roots and leaves. The content of potassium increased significantly in the roots from about 0.2 to 0.6 g kg^{-1} and from 3 to 7 g kg^{-1} in leaves under the influence of manganese, while the content of magnesium increased only in the roots by about 0.2-0.5 g kg^{-1} in comparison with non-fertilized plants (Figures 1 and 2).

Fertilization with copper also contributed to a higher content of nitrogen, potassium and magnesium in the roots and leaves (Figures 1 and 2). A higher nitrogen content in roots and leaves was reported in BBCH 28, and the potassium and magnesium content in the roots in BBCH 28, as well as in BBCH 35 phase.

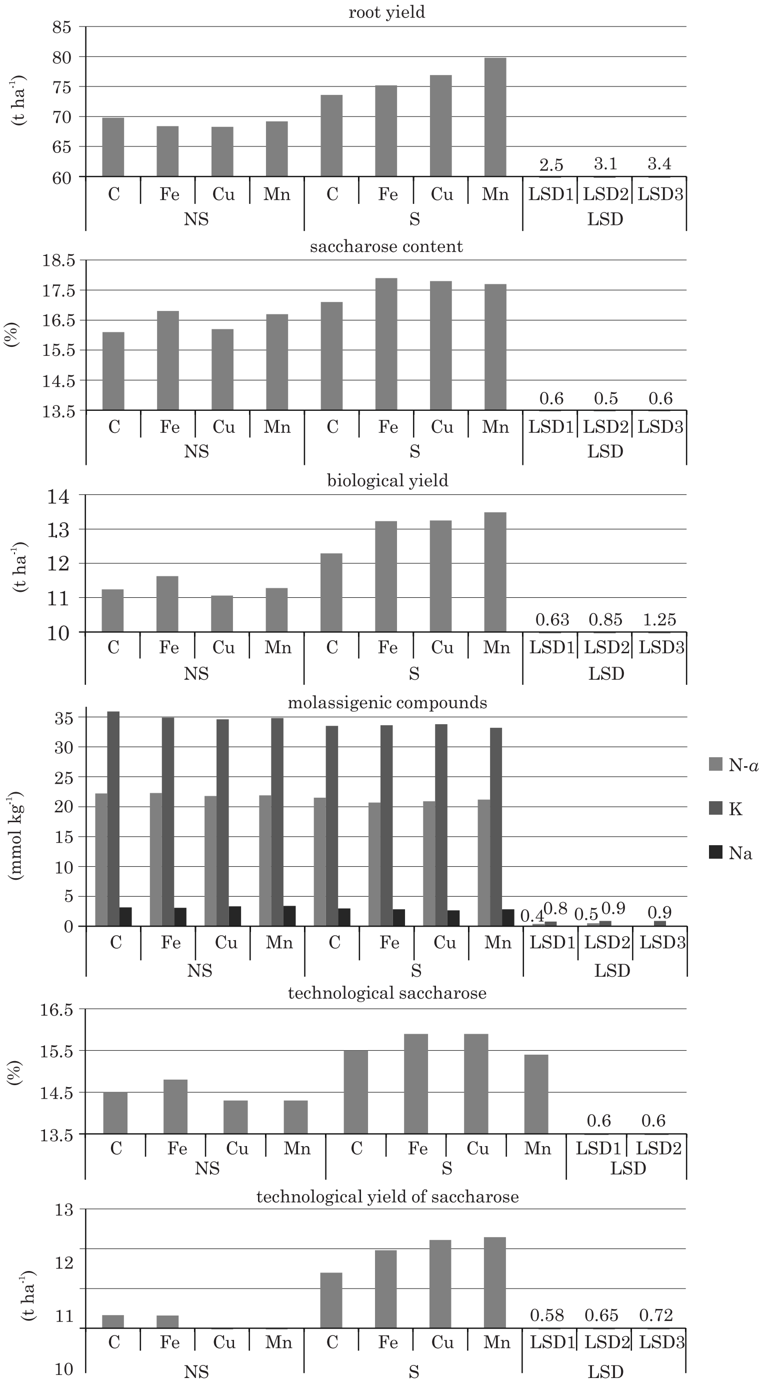

Fig. 3. Impact of seed stimulation and foliar fertilization with microelements on yields and technological quality of sugar beet. Explanation see Figure 1

The impact of foliar fertilization with Fe, Cu and Mn on the content of some of the determined elements in roots and leaves manifested during the growing period of sugar beet plants as well as in mature plants, interacting with the pre-sowing seed stimulation (Figures 1 and 2).

Foliar fertilization with iron, copper and manganese significantly modified the chemical composition of roots and leaves of plants developed from stimulated seeds. The nitrogen content in the roots and leaves of the plants developed from stimulated seeds was higher than in the roots and leaves of plants developed from non-stimulated seeds.

Fertilizing with trace elements affected the level of crop yield, but the interaction was confirmed only for copper and manganese fertilized plants developed from stimulated seeds (Figure 3). Plants developed from stimulated seeds and fertilized with manganese gave higher yield of roots and a higher sugar content. The yield-forming impact of manganese in the cultivation of sugar beet was also shown in the research of Kiepul and Gediga (2000). Kiepul and Gediga (2000) also stress the yield-forming effect of iron. In the course of our study, in addition to the level of yield under the influence of manganese, a higher yield of biological and technological sucrose was obtained (Figure 3). Fertilization with copper also contributed to a higher content and productivity of sucrose from plants developed from stimulated seeds (Figure 3).

CONCLUSIONS

1. Stimulating seeds by priming and foliar fertilization with trace elements: iron, copper and manganese, modified the concentration of nitrogen and mineral macronutrients: phosphorus, potassium, magnesium and sodium, during the plant growing period in the roots and leaves of plants.

2. Plants developed from the primed seeds in phases BBCH 28 and 35 were characterized by a higher content of nitrogen, potassium, sodium and magnesium in leaves and nitrogen, phosphorus and potassium in roots.

3. Foliar fertilization with trace elements: iron, manganese and copper, in combination with the pre-sowing stimulation of seeds (priming) had an impact on the chemical composition of the plants during the plant growing period and had a positive influence on the content and yield of sucrose in roots.

REFERENCES

Aladjadjiyan A. 2007. *The use of physical methods for plant growing stimulation in Bulgaria*. J. Central Europ. Agric., 8(3): 369-380.

Artyszak A., Gozdowski D., Kucińska K. 2016. *The effect of calcium and silicon foliar fertilization in sugar beet*. Sugar Tech., 18(1): 109-114.

Artyszak A. 2014. *The efficiency of foliar boron fertilization of two sugar beet varieties.* Part I. *The yielding and technological quality of roots.* Fragm. Agron., 31(3): 7-18. (in Polish)

Ashraf M., Foolad M.R. 2005. *Pre-sowing treatment – a shotgun approach to improve germination, plant growth, and crop yield under saline and non-saline conditions.* Adv Agron., 88: 223-271. DOI: 10.1016/S0065-2113(05)88006-X

Borowski E., Michałek S. 2011. *The effect of foliar fertilization of French bean with iron salts and urea on some physiological processes in plants relative to iron uptake and translocation in leaves.* Acta Sci. Pol. Hort. Cult., 10(2): 183-193.

Buchholz K., Märländer B., Puke H., Glattkowski H., Thielecke K. 1995. *Neubewertung des technischen Wertes von Zuckerrüben.* Zuckerindustrie, 120: 113-121.

Chen K., Arora R. 2013. *Priming memory invokes seed stress-tolerance.* Environ. Exp. Bot., 94: 33-45. DOI: 10.1016/j.envexpbot.2012.03.005

Ciećko Z., Grzegorzewski K., Żołnowski A., Najmowicz T. 2004. *The influence of mineral fertilization on yielding, sugar content in roots and chlorophyll content in leaves of sugar beet.* Biul. Inst. Hod. Rośl., 234: 137-143. (in Polish)

Conrath U. 2011. *Molecular aspects of defence priming.* Trends Plant Sci., 16(10): 524-531. DOI: 10.1016/j.tplants.2011.06.004

FAO WRB 2014. *World reference base for soil resources.* FAO, SRIC, ISSS. Rome. PTG 2015.

Hoffmann Ch. M. 2010. *Root quality of sugar beet.* Sugar Tech, 12(3-4): 276-287.

Jisha K.C., Vijayakumari K., Puthur J.T. 2013. *Seed priming for abiotic stress tolerance: an overview.* Acta Physiol. Plant., 35: 1381-1396. DOI: 10.1007/s11738-012-1186-5

Kiepul J., Gediga K. 2000.*Utilization of foliar applied manganese and iron by barley and sugar beets.* Zesz. Probl. Post. Nauk Rol., 471: 319-324. (in Polish)

Marinković B., Grujić M., Marinković D., Crnobarac J., Marinković J., Jaćimović G., Mircov D.V. 2008. *Use of biophysical methods to improve yields and quality of agricultural products.* J. Agric. Sci., 53(3): 235-241.

Masri M. I., Hamza M. 2015. *Influence of foliar application with micronutrients on productivity of three sugar beet cultivars under drip irrigation in sandy soils.* World J Agric Res., 11(2): 55-61. DOI: 10.5829/idosi.wjas.2015.11.2.1846

Panella L. 2010. *Sugar beet as an energy crop.* Sugar Tech., 12(3-4): 288-293. DOI: 10.1007/s12355-010-0041-5

Pietruszewski S., Wójcik S. 2000*a*. *Effect of magnetic field on yield of the sugar beet cultivars Kalwia and Polko.* Inż. Rol., 5(16): 207-210. (in Polish)

Pietruszewski S., Wójcik S. 2000*b*. *Effect of magnetic field on yield and chemical composition of sugar beet roots.* Int. Agrophys., 14: 89-92.

Prośba-Białczyk U., Spiak Z., Mydlarski M. 2000*a*. *Effect of fertilization on microelement content in sugar beet.* Part I. *Copper.* Zesz. Probl. Post. Nauk Rol., 471: 441-448. (in Polish)

Prośba-Białczyk U., Spiak Z., Mydlarski M. 2000*b*. *Effect of fertilization on microelement content in sugar beet.* Part II. *Zinc.* Zesz. Probl. Post. Nauk Rol., 471: 449-454. (in Polish)

Prośba-Białczyk U., Spiak Z., Mydlarski M. 2000*c*. *Effect of fertilization on microelement content in sugar beet.* Part III. *Manganese and boron.* Zesz. Probl. Post. Nauk Rol., 471: 455-462. (in Polish)

Prośba-Białczyk U., Szajsner H., Spyrka B., Bąk K. 2012. *The influence of pre-sowing stimulation on seeds on changes in mineral composition and sucrose content in sugar beet.* J Elem., 17(4): 639-648. DOI: 10.5601/jelem.2012.17.4.07

Rochalska M., Orzeszko-Rywka A. 2008. *Influence of alternating magnetic field on respiration of sugar beet seeds.* Int. Agrophys., 22: 255-260.

Sacała E., Demczuk A., Grzyś E., Prosba-Białczyk U., Szajsner H. 2012. *Impact of presowing laser irradiation of seeds on sugar beet properties.* Int. Agrophys., 26(3): 295-300.

Sacała E., Demczuk A., Grzyś E., Prośba-Białczyk U., Szajsner H. 2016. *Effect of laser- and hydropriming of seed on seed on some physiological parameters in sugar beet*. J. Elem., 21(2): 527-538.

Tripathi D.K., Singh S., Singh S., Mishra S., Chauhan D.K., Dubey N.K. 2015. *Micronutrients and their diverse role in agricultural crops: advances and future prospective*. Acta Physiol. Plant., 37:139-153.

USDA-FAS. 2010. *Sugar: World production supply and distribution*. http://www.fas.usda.gov/htp/sugar/2010/sugarMay2010.pdf

Wiszniewska A., Hanus-Fajerska E., Muszyńska E., Ciarkowska K. 2016. *Natural organic amendments for improved phytoremediation of polluted soils: A review of recent progress*. Pedosphere, 26(1): 1-12. DOI: 10.1016/S1002-0160(15)60017-0

Wójcik S. 2006. *Effect of pre-sowing seeds stimulation in magnetic field on the field emergence, yielding and technological quality*. Inż. Rol., 6: 383-388.