Original scientific paper
Journal of Central European Agriculture, 2021, 22(2), p.390-396
DOI: /10.5513/JCEA01/22.2.3063

Beetroot response to sodium chloride as a component of fertilizers

Leonid UBUGUNOV, Maria MERKUSHEVA, Oxana VISHNYAKOVA (✉)

Institute of General and Experimental Biology, Siberian Branch of the Russian Academy of Sciences, Ulan-Ude, Russia

✉ Corresponding author: ok_vish@mail.ru

Received: October 8, 2020; accepted: March 23, 2021

ABSTRACT

Sodium use combined with NPK fertilizers can potentially increase beetroot (*Beta vulgaris* L.) yield and quality. This hypothesis was studied in three field experiments with beetroot in Western Transbaikalia throughout the seasons 2012-2014. The effects of a combination of fertilizers and different Na amounts (10, 20, and 40 kg Na/ha) combined with the chloride on beetroot yield, storage root quality, and sugar accumulation were estimated. As a result, Na application increased beetroot yield by 13-22%, as compared to the mineral fertilizers along, and the highest Na dose contributed to the maximum beetroot yield. The rising of the root mean weight was detected. Also, crude protein and vitamin C were increased in beetroots, while crude fibre and nitrates were decreased. Along with increased sodium concentration, potassium amount in dry matter of roots and tops were declined. Both roots and tops were found to have more efficient P and N uptake.

Keywords: *Beta vulgaris* L., sodium application, root yield, root quality

INTRODUCTION

Modern society must focus on increasing crop yield and nutritional value while also maintaining soil fertility to ensure the food security of the world's rising population. Mineral fertilizers combined with a set of basic plant nutrition elements are primarily capable of solving these tasks. Still, it is necessary to consider the biological features of crops to get a reasonable balance between food quality and the economic efficiency of agriculture. The halophytic sea beet (*Beta vulgaris* subsp. *Maritima* (L.) Arcang.) is the wild ancestor of the cultivated forms of beetroot (*Beta vulgaris* L.). Beetroot growth was reinforced in saline soils, according to research (Yamada et al., 2002). Watering plants with saline solution had a positive influence on beetroot yield and quality. The root crop contained more dry matter (DM), nitrogen (N), and sodium (Na) than plants watered with freshwater (Rumasz et al., 2002). Using water-soluble sodium phosphate as part of NPK fertilizer for beetroot cultivars ensured a positive yield response with the increase of DM and nitrate reduction (Mashkin, 2004). The chemical properties of sodium (Na) are very similar to potassium (K). Na accumulates in vacuoles and compensates for K more efficiently than other alkaline elements (Flowers, 2004; Zang et al., 2010). Sodium can even replace 95% of the K in some cultivars without decreasing the yield (Subbarao et al., 1999). However, cultivating this crop in moderately alkaline soils or applying Na as a fertilizer requires control over the potassium level in plants. Its low level facilitates Na absorption, increases the water content in leaves and osmotic potential, but decreases the amount of chlorophyll (Subbarao et al., 2000; Subbarao et al., 2003; Kronzucker et al., 2013). Beetroot comprises about 10% of all vegetable plantings and around 9% of the total yield of field vegetables produced in the Republic of Buryatia (Siberia, Russia). This crop is usually grown in the soils of river valleys. The study aimed to see how applying sodium chloride (NaCl) combined with mineral fertilizers affected the yield and quality of beetroot cultivated on irrigated fluvisols.

MATERIALS AND METHODS

Experimental site and season

The study was carried out in 2012-2014 in the Zaigrayevski district of the Republic of Buryatia (Western Transbaikalia, Russian Federation; 51°56'N, 108°08'E). In terms of atmospheric moisture and its dynamics, the study area is unfavorable for plant cultivation. The long-term average cumulative annual precipitation is 231 mm, with 201 mm for the months of May to September. Throughout the research, precipitation for this period totaled 152 mm (in 2012), 142 mm (in 2013), and 176 mm (in 2014). The mean annual temperature ranged from -1.0 °C to 0.5 °C.

Experimental design

Univariate field experiments with four replicates were performed in a randomized block design. The mid-early beetroot (*Beta vulgaris* L.) cv `Bordo 237` was tested for its response to increasing doses of sodium chloride in combination with NPK complex fertilizers. Mineral fertilizers with the amounts: N (120 kg N/ha), P (60 kg P/ha), K (150 kg K/ha) were added in spring before sowing in the form of ammonium nitrate (34% N), triple superphosphate (17.4% P), potassium chloride (52.7% K), and sodium – in the chloride form in the doses of 10, 20 and 40 kg Na/ha.

The crop production method was traditional for beetroot cultivation. Untreated beetroot seeds were sown directly into the soil with a 45 cm × 10 cm plant spacing and a 12 m^2 main plot area. The seeding time was May 20th. The harvest time was September 10th. Since the arid climate of the region predetermines vegetable cultivation with the additional wetting, irrigation was applied to all variants, including the control one. The field moisture capacity of the soil during dry periods declined to 12-13%. The experimental plots were irrigated 8-10 times per season with a 200 m^3/ha water volume to keep soil moisture within 65-70% of the field capacity. The experimental design is shown in Table 1.

Table 1. Experimental design

Treatment	Mineral fertilizers dose, NPK (kg/ha)	Na (kg/ha)
A	-	-
B	N120 P60 K150	-
C	N120 P60 K150	10
D	N120 P60 K150	20
E	N120 P60 K150	40

Quality analyses

After harvesting, roots were cleaned, air dried, and a root weight was measured. Dry matter, crude protein (CP), crude fibre (CF), crude ash (CA), and total sugar (TS) contents were determined by standard laboratory methods and procedures (EC No 152/2009) for beetroot quality estimation. The iodate method (Samotus et.al., 1982) was used for vitamin C (ascorbic acid) assessment, and the spectrophotometric method (PN-92/A-75112) for nitrates content. Macronutrients accumulated in roots and shoots were estimated after samples mineralization: P – with the photometric method, K and Na – with the flame emission spectrophotometry, N - with the Kjeldahl method.

Soil characteristic

The soils used in the experiment were classified as fluvisols according to the IUSS Working Group WRB (2015). The upper soil layers have a sandy loam texture, while the underlying strata have a sand texture. pH of the topsoil was slightly alkaline; organic carbon and total N content were low. Available forms of nutrients, such as nitrate (2-3 mg/kg), phosphorus (7-20 mg/kg), and potassium (20-25 mg/kg) – were deficient (Table 2, 3). Extent and forms of Na accumulation in the soil were previously shown; water-extractable Na amount was low and did not exceed 0.01-0.02% (Merkusheva et al., 2011).

The light texture of the soil and periodic irrigation makes it possible to use sodium chloride as fertilizer. The chloride ion does not accumulate in the soil and is gradually washed, so it does not cause salinity.

Table 2. Soil physical and chemical properties before setting of the experiments, mean values and standard deviation for three years

Horizon	Soil depth (cm)	Soil particles[1], mm (%)			pHw[2]	Organic carbon[3] (%)
		1-0.1	0-0.02	<0.002		
Ah	0-25	79 ± 7	18 ± 5	3 ± 1.0	7.1 ± 0.1	0.76 ± 0.10
AC	25-60	74 ± 6	21 ± 5	5 ± 2.0	7.5 ± 0.4	0.48 ± 0.05
C	60-90	88 ± 7	10 ± 3	2 ± 0.8	7.4 ± 0.3	0.06± 0.03

[1] Laser diffraction analyzer Analysette 22 Wet Dispersion Unit
[2] (1:2.5 m/v ratio)
[3] Skalar auto-analyser, Primacs SNC-100

Table 3. Some indicators of soil fertility before setting of the experiments, mean values and standard deviation for three years

Horizon	Soil depth (cm)	N[1]	Na[2]	P[3]	K[3]	NO_3^{-4}
		(%)		(mg/kg)		
Ah	0-25	0.11 ± 0.02	3.00 ± 0.4	20 ± 4	25 ± 9	3 ± 1.4
AC	25-60	0.08 ± 0.01	2.40 ± 0.3	13 ± 4	20 ± 6	3 ± 1.6
C	60-90	0.02 ± 0.01	2.80 ± 0.4	7 ± 3	13 ± 5	2 ± 0.9

[1] Kjeldahl method
[2] Flame photometry
[3] Double lactate method, pH 3.6 (1:50 m/v ratio)
[4] Nitrate electrode method (0.04M $(NH_4)_2SO_4$ extraction)

Statistical analysis

The influence of research factors (year and treatment) was evaluated using the two-way ANOVA (F-test). When significant differences were detected, the means were separated with Fisher's LSD (least significant difference) test (P<0.05). Microsoft Excel and Statistica 12 software were used for statistical data processing (StatSoft Inc., 2013).

RESULTS AND DISCUSSIONS

Beetroot yield

In 2012, 2013 and 2014, the average beetroot yield (BY) was low at 14.0, 12.6 and 19.2 t/ha, respectively (Table 4). Our study confirmed the dominant effect of the seasonal factor on the BY ($F(2,60) = 159.2$, $p = 0.05$). In 2014, more favorable natural moisture conditions were noted, which led to a significant increase in BY with all the experiment variants compared to the previous years. The treatments had a less significant impact ($F(19,60) = 23.9$, $p = 0.05$).

Mineral fertilizers had a major effect on BY every year throughout the study. The average BY over three years was 38% higher than the control. In 2012 a notable effect of Na addition was recorded in treatment D, in 2013 in treatments D and E, in 2014 for all sets with Na treatment. During the last two years, the highest Na (treatment E) dose contributed to the maximum BY 23.4 and 33.9 t/ha, respectively. In general, as compared to the background, NaCl application increased BY by 13-22%. The low level of available K can explain the high efficiency of Na in studied soils. Such an outcome is in line with data reported by Christenson and Draycott (2006). All treatments, on average, increased BY significantly compared to control: A (15.3) < B (21.1) < C (23.9) < D (24.7) < E (25.8).

The average weight of one root crop was 70-80 g. This value was taken as a control. The average weight reached 90-140 g in the background and 100-170 g in C-E treatments.

Table 4. Beet yield depending on fertilization and Na dose (t/ha)

Treatment	2012	2013	2014	Means	Over control (%)	Over background (%)
			Beet roots			
A	14.0[c]	12.6[c]	19.2[c]	15.3[c]	-	-
B	18.5[b]	17.3[b]	27.4[b]	21.1[b]	38	-
C	19.9[ab]	20.1[ab]	31.5[a]	23.9[ab]	56	13
D	21.5[a]	21.1[a]	31.4[a]	24.7[a]	61	17
E	20.1[ab]	23.4[a]	33.9[a]	25.8[a]	69	22
			Beet tops, dry phytomass			
A	1.47[c]	1.22[c]	1.84[c]	1.51[c]	-	-
B	2.18[b]	2.06[b]	3.43[b]	2.56[b]	69	-
C	2.22[b]	2.14[b]	3.57[b]	2.64[b]	75	3
D	2.10[b]	2.31[ab]	4.09[ab]	2.83[b]	87	10
E	2.87[a]	2.70[a]	4.53[a]	3.37[a]	123	32

Different letters (in columns) indicate statistically significant differences between treatments at $P<0.05$

After harvesting, beet top phytomass (BT) varied according to moisture availability, mineral nutrition, and NaCl doses (Table 4). The annual effect of NPK fertilizers on BT was significant. In comparison to the control, BT enhanced by 1.7 bolds on average over three years. Only with Na 40 (treatment E), NaCl substantially contributed to BT over the years of the experiment. The highest value was recorded in 2014. A weight roots/ tops ratio (in dry matter) was: in the variant A – 1:1.7; B – 1:1.9; in variants C, D, E – 1:1.8; 1:1.9; 1:2.2 respectively. These findings verified the highest efficiency of the maximum Na dose for BT.

Beet quality

The quality of the beetroot is known to depend on several factors, including plant genotype (the cultivar) and growing conditions, such as precipitation and temperature during the vegetative season, and plant mineral nutrition (Akula and Ravishankar, 2011; Szopinska and Gaweda, 2013; Petek et al., 2016). Beetroots can store a lot of sugar, which determines their nutritional value (Tretyakov, 2000; D'Egidio et al., 2019). The content of protein and non-protein nitrogen compounds, vitamins, macro-and micronutrients, and antioxidant activity all affect the quality of edible roots (Petek et al., 2017; Petek et al., 2019).

The optimal Na dose was determined through biochemical characterization of storage roots. Such analysis allows for the production of macronutrient-dense vegetables and optimization of crop productivity and quality while avoiding the use of excessive fertilizers. The beetroot cultivar had a relatively high content of DM, CP, TS, and low nitrate level (maximum permissible concentration of nitrate is 1400 mg/kg (Customs Union..., 2011)) (Table 5). Mineral fertilizers decreased the accumulation of dry matter, sugars, fibre and vitamin C in storage roots. However, they increased protein and, in particular, nitrates by 2.2 bold. Compared to the fertilizers alone, adding sodium to the basic minerals resulted in a considerable reduction in nitrates and a crude fibre with D and E treatments. The changes in DM were positive but not statistically significant. The presence of Na did not affect CP content; it remained in the background. With the minimum sodium dose (10 kg/ha), vitamin C

Table 5. Beetroot quality depending on NPK fertilization and Na dose (3-year average 2012-2014)

Treatment	Dry matter	Total sugar	Crude protein	Crude fibre	Vitamin C	Nitrates
	%				mg/kg	
A	17.1	12.1^{a}	1.9^{b}	1.05^{a}	12.9^{a}	520^{c}
B	15.7	9.9^{b}	2.4^{a}	0.80^{b}	10.1^{b}	1137^{a}
C	16.1	10.7^{ab}	2.1^{ab}	0.86^{b}	13.1^{a}	1006^{a}
D	16.4	11.1^{ab}	2.5^{a}	0.63^{c}	13.6^{a}	840^{b}
E	16.9	12.4^{a}	2.6^{a}	0.60^{c}	13.4^{a}	788^{b}

Different letters (in columns) indicate statistically significant differences between treatments at P < 0.05

levels increased relative to the control level. It is the most sensitive indicator of Na application among all quality indexes used in this work.

In the control plots, root crops accumulated an average of 1.85 t/ha of TS. The use of mineral fertilizers (B) had a negative effect on this indicator (Table 5). With Na 40, TS content in beetroots was restored to the control level. A positive correlation was discovered between the amount of Na applied and the number of carbohydrates present (R^2 = 0.40, P < 0.05, n = 12) (Figure 1). As a result, adding Na to mineral fertilizers is a viable option for improving beetroot quality. According to Wakeel et al. (2011), sodium improved water balance, allowing beet shoots to maintain turgor in dry weather and promoting plant metabolic processes.

The amount of ash in the dry matter of beet leaves and roots differed significantly. The CA ratio of tops to roots ranged from 2.8 in control to 3.6 in treatment C (Table 6). K accumulation in roots was 3 - 4 higher compared to the level in the leaves. Na amount in roots consisted of 3.5% for the control. On average, beetroot plants grown with sodium application had substantially higher Na content in their storage roots than those grown without sodium. When Na 20 and Na 40 were applied, the highest values were recorded. Na content in beet tops was found to be 2.2-2.9 times higher than in roots. K was negatively correlated with Na in the beetroot mineral composition in roots (R^2 = –0.94, P < 0.05, n = 12) and tops (R^2 = –0.92, P < 0.05, n = 12) in all treatments excluding the control one, K to Na ratio is an indicator of plant salt metabolism. The optimal value ranges from 7 to 1, showing the salinity tolerance mechanism (Bgatov, 1999). The root and top ratios for the beets without any treatments were 6.8 and 5.5, respectively. K input with mineral fertilizers shifted the ratio to the higher values - 9.9 and 6.6. On the other hand, sodium had a negative effect on this indicator, reducing it to 6.0 and 4.7 with Na 40 dose in the roots and tops, respectively.

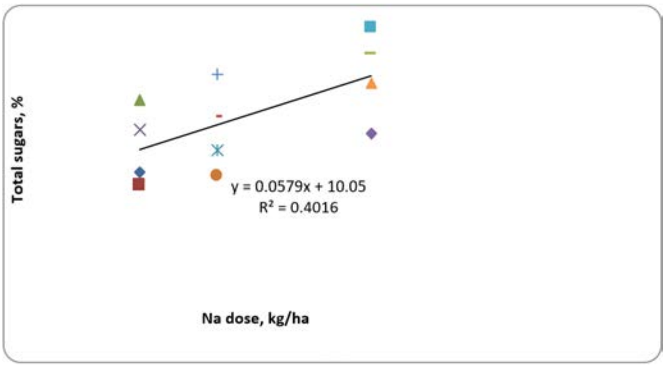

Figure 1. Total sugars content in beetroots as a function of Na dose applied

The amounts of nitrogen, phosphorus, potassium, and sodium that had accumulated were estimated (Table 6). The intake coefficients of mineral fertilizers and Na were determined. Combined treatments significantly raised P and N intake coefficients by both roots and tops, decreased the intake coefficients of K and Na fertilizers by roots and increased by tops.

Table 6. Content and removal of N, P, K, and Na by roots and tops of beetroots, in dry matter (3-year average 2012-2014)

Treatment	Ash	N	P	K	Na	N	P (P_2O_5)	K (K_2O)	Na
	Content (%)					Removal (kg/ha)			
Beet roots									
A	6.79	1.76^{c}	0.27^{b}	1.63^{c}	0.24^{b}	45.9^{c}	7.0^{c} (16.0)	42.5^{b} (51.2)	6.3^{c}
B	7.77	2.42^{a}	0.38^{a}	2.87^{a}	0.29^{a}	80.1^{b}	12.6^{b} (28.9)	95.0^{a} (114.5)	9.6^{b}
C	6.77	2.11^{b}	0.31^{ab}	2.58^{ab}	0.29^{a}	81.0^{b}	11. 9^{b} (27.3)	99.1^{a} (119.4)	11.1^{ab}
D	6.95	2.44^{a}	0.32^{ab}	2.32^{b}	0.31^{a}	97.1^{a}	12.7^{b} (29.1)	92.3^{a} (111.2)	12.3^{a}
E	7.28	2.49^{a}	0.33^{a}	1.92^{b}	0.32^{a}	108.6^{a}	15.7^{a} (36.0)	83.7^{a} (100.9)	13.9^{a}
Beet tops									
A	19.01^{b}	1.62^{b}	0.18^{b}	1.55^{b}	0.28^{c}	24.5^{c}	2.7^{c} (6.2)	23.4^{c} (28.2)	4.2^{c}
B	23.87^{a}	2.18^{a}	0.21^{a}	2.24^{a}	0.34^{b}	55.8^{b}	5.4^{b} (12.4)	57.3^{b} (69.0)	8.7^{b}
C	24.38^{a}	2.17^{a}	0.22^{a}	2.20^{a}	0.36^{b}	57.3^{b}	5.8^{b} (13.3)	58.1^{b} (70.0)	9.5^{b}
D	23.07^{a}	2.28^{a}	0.23^{a}	2.10^{a}	0.36^{b}	64.5^{b}	6.5^{b} (14.9)	59.4^{b} (71.6)	10.2^{b}
E	21.47^{a}	2.40^{a}	0.23^{a}	1.99^{a}	0.42^{a}	80.9^{a}	7.8^{a} (17.9)	67.1^{a} (80.9)	14.1^{a}

Different letters (in columns) indicate statistically significant differences between treatments at $P<0.05$

CONCLUSIONS

According to this study, beetroot cultivation on fluvisols with low fertility levels under irrigation did not result in high root yield without the addition of nutrients. NPK fertilizers increased the average beetroot yield by 1.4. The addition of sodium to essential nutrients increased beetroot yield. It affected the increase of one root mean weight to the standard. NaCl combined with the minerals had a positive effect on beetroot quality: i.e. total sugars, crude protein, and vitamin C were increased with the concurrent reduction of nitrates and fibre. Meanwhile, a relatively high nutrient accumulation was registered. Although the maximal sodium dose had the most significant impact on beetroot yield and root quality, there was no significant difference between treatments D and E. As a result, the dose of Na 20 combined with basic minerals can be recognized as the most effective for achieving our research objectives.

ACKNOWLEDGEMENTS

The study was supported by the Ministry of Science and High Education of Russian Federation, project No. 121030100228-4.

REFERENCES

Akula, R., Ravishankar, G.A. (2011) Influence of abiotic stress signals on secondary metabolites in plants. Plant Signaling and Behavior, 6, 1720-1731. DOI: https://doi.org/10.4161/psb.6.11.17613

Bgatov, A.V. (1999) Biogenic classification of chemical elements. Philosophy of Science, 2 (6), 12-24 (in Russian).

Christenson, D.R., Draycott, A.P. (2006) Nutrition – phosphorus, sulphur, potassium, sodium, calcium, magnesium and micro-nutrients – limiting and nutrient deficiencies. In: Draycott, A.P., ed. Sugar Beet. Oxford, OX: Blackwell Publishing Ltd., pp. 185-220.

Customs Union Commission (2011) Technical regulations of the TR CU 021/2011 "On food safety". Moscow, Russia. Available at: http://www.eurasiancommission.org/ru/act/texnreg/deptexreg/tr/Documents/TR%20TS%20PishevayaProd.pdf. [Accessed March, 10 2021].

D`Egidio, S., Galieni, A., Stagnari, F., Pagnani, G., Pisante, M. (2019) Yield, quality and physiological traits of red beet under different magnesium nutrition and light intensity levels. Agronomy, 9 (7), 379. DOI: https://doi.org/10.3390/agronomy9070379

Flowers, T. J. (2004) Improving crop salt tolerance. Experimental Botany, 209, 9-20.

IUSS Working Group WRB of Food and Agriculture Organization of the United Nations (2014, update 2015) World Reference Base for Soil Resources International Soil Classification System for Naming Soils and Creating Legends for Soil Maps, World Soil Resources Reports 106. Rome, Italy. Available at: http://www.fao.org/3/a-i3794en. [Accessed May, 2 2020].

Kronzucker, H.J., Coskun, D., Schulze, L.M., Wong, J.R., Britto D.T. (2013) Sodium as a nutrient and toxicant. Plant and Soil, 369, 1-23. DOI: https://doi.org/10.1007/s11104-013-1801-2

Mashkin, V.A. (2004) Trisodiumphosphate as an effective phosphate fertilizer. Potato and Vegetables, 5, 10-11 (in Russian).

Merkusheva, M.G., Ubugunov, L.L., Andreeva, I.M., Baldanova A.L. (2011) Sodium in the system soil – plant of floodplain grasslands of the Western Transbaikalia. Vestnik of Buryat State Academy of Agriculture, 4 (25), 37-43 (in Russian).

Petek, M., Toth, N., Pecina, M., Karazija, T., Herak Custic, M. (2016) Macrominerals in Red Beet Root under Organic and Mineral Fertilization. Agricultural Conspectus Scientificus, 81 (3), 173-179.

Petek, M., Toth, N., Pecina, M., Lazarevic, B., Palcic, I., Herak Custic, M. (2017) Status of Fe, Mn and Zn in red beet due to fertilization and environment. Journal of Central European Agriculture, 18 (3), 554-570. DOI: https://doi.org/10.5513/JCEA01/18.3.1930

Petek, M., Toth, N., Pecina, M., Karazija, T., Lazarevic, B., Palcic, I., Veres, S., Custic, M. H. (2019) Beetroot mineral composition affected by mineral and organic fertilization. PLoS One, 14 (9), e0221767. DOI: https://doi.org/10.1371/journal.pone.0221767

Rumasz, E., Koszanski, Z., Biczak, R., Rychter, P. (2002) Influence of saline water irrigation on the yield and some physiological processes of red beet. Folia Universitatis Agriculturae Stetinensis, 90, 207-212.

Samotus, B., Leja, M., Scigalski, A. (1982) A comparison of four methods of determination of ascorbic acid in fruits and vegetables. Acta Agraria et Silvestria, Series Agraria, 21, 105-121.

StatSoft, Inc. (2013) Electronic Statistics Textbook. Tulsa. Available at http://www.statsoft.com/textbook/.

Subbarao, G.V., Wheeler, R.M., Stutte, G.W., Levine, L.H. (1999) How far can sodium substitute for potassium in redbeet? Plant Nutrition, 22 (11), 1745-1761. DOI: https://doi.org/10.1080/01904169909365751

Subbarao, G.V., Wheeler, R.M., Stutte, G.W., & Levine, L.H. (2000) Low potassium enhances sodium uptake in red-beet under moderate saline conditions. Plant Nutrition, 23 (10), 1449-1470. DOI: https://doi.org/10.1080/01904160009382114

Subbarao, G.V., Ito, O., Berry, V.L., Wheeler, R.M. (2003) Sodium – a functional plant nutrient. Critical Reviews in Plant Sciences, 22, 391–416. DOI: https://doi.org/10.1080/07352680390243495

Szopinska, A.A., Gaweda, M. (2013) Comparison of yield and quality of red beet roots cultivated using conventional, integrated and organic method. Journal of Horticultural Research, 21 (1), 107-114. DOI: https://doi.org/10.2478/johr-2013-0015

Tretyakov, N.N., Koshkin, E.I., Makrushin, N.M. (2000) Physiology and biochemistry of agricultural crops. Moscow: Kolos. (in Russian).

Ubugunov, L.L., Andreyeva, I.V., Merkusheva, M.G. (2012) Agrochemical evaluation of sodium chloride as a fertilizer of natural floodplain grasslands of the Western Transbaikalia. Agrochemistry, 3, 32-40 (in Russian).

Wakeel, A., Farooq, M., Qadir, M., Schubert, S. (2011) Potassium substitution by sodium in plants. Critical Reviews in Plant Sciences, 30, 401-413. DOI: https://doi.org/10.1080/07352689.2011.587728

Yamada, M., Uehira, M., Hun, L. S., Asahara, K., Endo, T., Eneji, A.E., Yamamoto, S., Honna, T., Yamamoto, T., Fujiyama, H. (2002) Ameliorative effect of K-type and Ca-type artificial zeolites on the growth of beets in saline and sodic soils. Soil Science and Plant Nutrition, 48, 651-658. DOI: https://doi.org/10.1080/00380768.2002.10409253

Zhang, J.L., Flowers, T.J., Wang, S.M. (2010) Mechanisms of sodium uptake by roots of higher plants. Plant and Soil, 326, 45-60. DOI: https://doi.org/10.1007/s11104-009-0076-0