Journal of Elementology ISSN 1644-2296

Breś W., Kupska A., Kleiber T., Bosiacki M., Mieloszyk E. 2017. *Influence of sodium chloride on selected growth parameters and macronutrient content in pelargonium leaves*. J. Elem., 22(1): 209-218. DOI: 10.5601/jelem.2016.21.3.1142

ORIGINAL PAPER

INFLUENCE OF SODIUM CHLORIDE ON SELECTED GROWTH PARAMETERS AND MACRONUTRIENT CONTENT IN PELARGONIUM LEAVES

Włodzimierz Breś, Agnieszka Kupska, Tomasz Kleiber, Maciej Bosiacki, Elżbieta Mieloszyk

Chair of Plant Nutrition
Poznań University of Life Sciences

Abstract

The aim of this study was to assess the potential of cultivation of *Pelargonium* × *hortorum* cv. Survivor Dark Red in a substrate contaminated with sodium chloride. After applying 0.45, 0.96, 1.47, 1.98, 2.49, 2,99 g NaCl dm^{-3}, the substrate contained 200, 400, 600, 800, 1000, 1200 mg Na^+ and 287, 595, 903, 1211, 1519, 1827 mg Cl^- dm^3. Growing medium with natural sodium (22 mg Na^+) and chloride (13 mg Cl^-) content comprised the control. Electrical conductivity (EC) of the substrates was as follows: 0.11, 0.62, 1.28, 1.75, 2.42, 2.82, 3.72 mS cm^{-1}. Water purified by reverse osmosis was used for watering the pelargonium plants. The effect of sodium chloride on the chemical composition of leaves was evaluated based on the analysis of leaf blades collected at the flowering stage. Sodium chloride negatively influenced all measured plant growth parameters. Increasing salinity also decreased the chlorophyll index values. Significant reduction in the number of inflorescences was recorded in plants grown at ≥ 800 mg Na^+ and ≥ 1211 mg Cl^- in 1 dm^3 of peat substrate. However, the pelargonium plants grown in a substrate containing up to 600 mg Na and 903 mg Cl still retain high decorative value. The increasing sodium chloride content in peat substrate increased the concentrations of phosphorus and calcium in the leaves. Simultaneously, the concentrations of potassium and magnesium decreased, while the concentration of nitrogen was found to be stable. Despite increasing doses of sodium chloride, the content of N, P, K, Ca and Mg in pelargonium leaves fell within or slightly exceeded the established range of guideline values.

Keywords: geranium, nutritional status, salinity.

prof. dr hab. Włodzimierz Breś, Department of Plants Nutrition, Poznan University of Life Sciences, Zgorzelecka 4, 60-198 Poznan, Poland, e-mail: wbnaw@up.poznan.pl

INTRODUCTION

The quality of plants and products of plant origin largely depends on growing conditions. In many regions, salinity is the major factor limiting plant cultivation. Besides climatic, hydrologic, geologic and rock weathering conditions, de-icing of roads with sodium chloride is mostly reported to be the cause of salinity (Bach, Pawłowska 2007, Lundmark, Jansson 2008, Wilkaniec et al. 2013). Sodium chloride may also be found in composts produced from municipal sewage sludge (Cai, Gao 2011). Sodium content in sewage sludge varies greatly, ranging from 0.12 (Reddy et al. 2012) to 6.42% Na, by weight (Liu, Sun 2013). The scanty published data concerning chlorine content in municipal sewage sludge is suggestive of it being as high as 1.9 g kg $^{-1}$ d.w. (Czyżyk, Kozdraś 2004). The sources are NaCl used in food processing, chemicals applied in detergents and used in paper production. Organic materials added to compost not only change the C:N ratio, but also affect the content of other elements. The authors mentioned above recorded an increase in Cl^- to 43.3g kg $^{-1}$ (d.w.) after sewage sludge composting with rye straw. Mineral elements differed in their ability to be removed from the composts. Sodium and chlorides are leached readily. For instance, 24-148 mg dm^{-3} of Cl^- was found in the leachate from sewage sludge originating from a rural, mechanical and biological wastewater treatment plant (Czyżyk, Rajmund 2009). Sewage sludge storage has been forbidden since 1 January 2016 (Niesler, Nadziakiewicz 2014).

Another interesting example of waste is spent mushroom substrate (SMS). Studies suggest that SMS may be used as a soilless medium owing to its high organic matter content, water and nutrient holding capacity (Clark, Cavigelli 2005). However, fresh SMS has potentially high salt content, which may restrict the use of fresh SMS as a growing medium for salt sensitive plants (Fidanza et al. 2010, Zhang et al. 2012). Total salinity is not always the most important parameter. Excessive Na^+ and Cl^- content detected in some batches of this waste material may be a threat to plants (Majchrowska-Safaryan, Tkaczuk 2013). Medina et al. (2009) found 1175 mg Na^+ and 3566 mg Cl^- per 1 dm^3 of medium (water soluble forms) in spent mushroom substrate after *Agaricus bisporus* cultivation. There is a limited body of research on the use of SMS as a soilless growing medium in horticulture production. In this context, search for rational, environmentally friendly waste disposal is an important direction in research, also undertaken in Poland (Zawadzińska, Salachna 2014). Uncontrolled application of SMS leads to soil contamination. After 3 years of its use as mulch in an avocado orchard, the content of Cl^- in the arable layer increased to 178 mg and Na was raised to 141 mg in 1 dm^3 (Danai et al. 2012).

Crops differ significantly in their resistance to high salinity. The symptoms of sodium chloride excess in the root environment include plant growth retardation, discoloration, development of leaf necrosis, and finally plant death. This is caused by the disturbance of water uptake, reduced photosynthesis, changes of the pigment content and mineral nutrition disorders (Moradi, Ismail 2007, Tabatabaei et al. 2008, Dkhil, Denden 2012). Studies on plant resistance to salinity focus mainly on agricultural crops. There is clearly less information concerning ornamental plants. Sadly, the opinions are sometimes ambiguous. For example, *Pelargonium* × *hortorum* is implicated to be a plant of low (Huang, Cox 1988) or moderate tolerance (Villarino, Mattson 2011) to salinity.

The aim of this study was to assess the potential for pelargonium cultivation in a substrate contaminated with sodium chloride. The choice was not accidental, since pelargonium is one of the most popular ornamental plants. The research results focusing especially on the physiological and biochemical responses of plants have already been published (Breś at al. 2016). In the paper presented below, we discuss the effect of sodium chloride on the selected growth parameters and the content of macroelements in leaves of pelargonium. These data will help to verify opinions on the sensitivity of this plant. Then, it will be possible to make a decision whether it is possible to cultivate pelargonium in soils contaminated with sodium chloride and what proportions of the aforementioned waste materials as components of substrates can be recommended.

MATERIAL AND METHODS

The study was conducted on *Pelargonium x hortorum* cv. Survivor Dark Red. The experiments were established on 27 April 2012 and 26 April 2013 (planting of rooted seedlings) and they were completed on 14 July 2012 and 18 July 2013 (stage of plant flowering). Prior to planting, the substrate (highmoor peat) was limed to pH 6.0. After liming it was found that the content of Ca (1245 mg dm^{-3}) and Mg (160 mg dm^{-3}) was sufficient and therefore these components were not supplemented. The other macro- and microcomponents in the substrate were supplemented, providing the following final levels (mg dm^{-3}): N 200, P 250, K 300, Fe 75, Mn 35, Zn 30, Cu 10, B 2 and Mo 1 mg dm^{-3} of substrate, respectively. Application of increasing doses of NaCl (0.45, 0.96, 1.47, 1.98, 2.49, 2,99 g dm^{-3} of substrate) led to an increase in the content of Na^+ to 200, 400, 600, 800, 1000 and 1200 mg Na, while for Cl^- the concentrations were 287, 595, 903, 1211, 1519, 1827 mg dm^{-3}, respectively. Substrate with natural sodium (22 mg Na^+) and chloride (13 mg Cl^-) content comprised the control. After mixing all components, the electrical conductivity of the substrates was the following: 0.11, 0.62, 1.28, 1.75, 2.42, 2.82, 3.72 mS cm^{-1}. To maintain the optimum conditions for pelargonium, additional N 150, P 80, K 100 mg dm^{-3} of substrate were applied in the middle of June. Pelargonium plants were planted in containers filled with 7 dm^3 growing medium. 3 plants were grown in each container, and one treatment was composed of 10 containers. Water purified by reverse osmosis was used for plant watering. The chemical composition of water was as follows (in mg dm^{-3}): N-NH_4, N-NO_3 and P-PO_4 <1, K 0.1, Ca 3.6, Mg 0.2, S-SO_4 0.3, Na 0.5, Cl 0.3, Fe 0.036, Mn 0.005, Zn 0.075, B 0.005, Cu and Mo - trace amounts, HCO_3^- 28.2, pH 6.87, EC 0.05 mS cm^{-1}. For the measurements, 20 plants randomly chosen from each treatment were used. At the stage of flowering, the fresh weight of aerial plant parts and the plant height to the apex were determined. Moreover, the number of lateral shoots, leaves and inflorescences were counted. The total length of lateral shoots was also measured. Using a SPAD 502 Plus Chlorophyll Meter, light absorption by the leaf blade was measured (first leaf located above the second inflorescence). The results were expressed in non-standardized units, i.e. SPAD (The Signaling Pathway Database). SPAD readings correlate well with chlorophyll concentrations (Rodriguez, Miller 2000). Moreover, the general ornamental value of pelargonium in the flowering stage was evaluated. The focus was on the overall conformation, morphology and flowers. The rating from 1 (the lowest) to 5 (the highest – the reference found in plant catalogues) was applied.

The effect of sodium chloride on the chemical composition of fully mature leaves was evaluated based on the analysis of leaf blades collected at the flowering stage. In order to assay total forms of nitrogen, phosphorus, potassium, magnesium and calcium, dry plant material was mineralized in concentrated sulfuric acid. After mineralization, the following determinations were performed: N – using the Kjeldahl procedure, and K, Mg and Ca – atomic absorption spectroscopy (AAS). Spectrophotometric methods were applied in the analysis of P. The results of the research were given as means for two years. The data were subjected to the analysis of variance using the Newman-Keuls test at the significance level $\alpha = 0.05$. The results presented in tables are the means from two years.

RESULTS AND DISCUSSION

The experiments showed that salinity caused by sodium chloride negatively influenced all measured pelargonium plant parameters (Figures 1-2). The dose of 0.96 g NaCl dm^{-3} (treatment 400 mg Na^+ and 595 mg Cl^-) of peat substrate significantly decreased the fresh weight of a plant (19.6%), its height (11%) and the number of leaves (10%). Cultivation of pelargonium in a substrate supplemented with 1.47 g NaCl dm^{-3} (600 mg Na^+ and 903 mg Cl^- dm^{-3}) resulted in a reduced number of lateral shoots and a lower chlorophyll index of leaf blades (SPAD), the difference being 21% and 6%, respectively. However, even the highest dose of NaCl did not cause chlorosis and leaf necrosis was found. The reduction of the assimilating area of plants may be considered as an avoidance mechanism, minimizing water losses when the stomata are closed, which happens to many species under osmotic stress (Ruiz-Sánchez et al. 2000, Jamil et al. 2007, Breś at al. 2016).

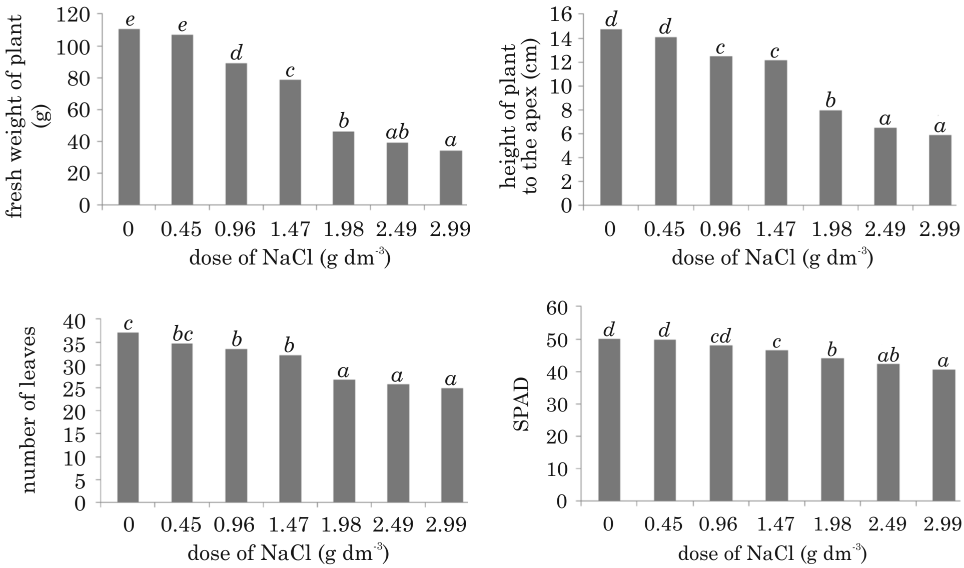

Fig. 1. Effect of sodium chloride dose on fresh weight of plant, height of plant to the apex, number of leaves and *leaf* chlorophyll index

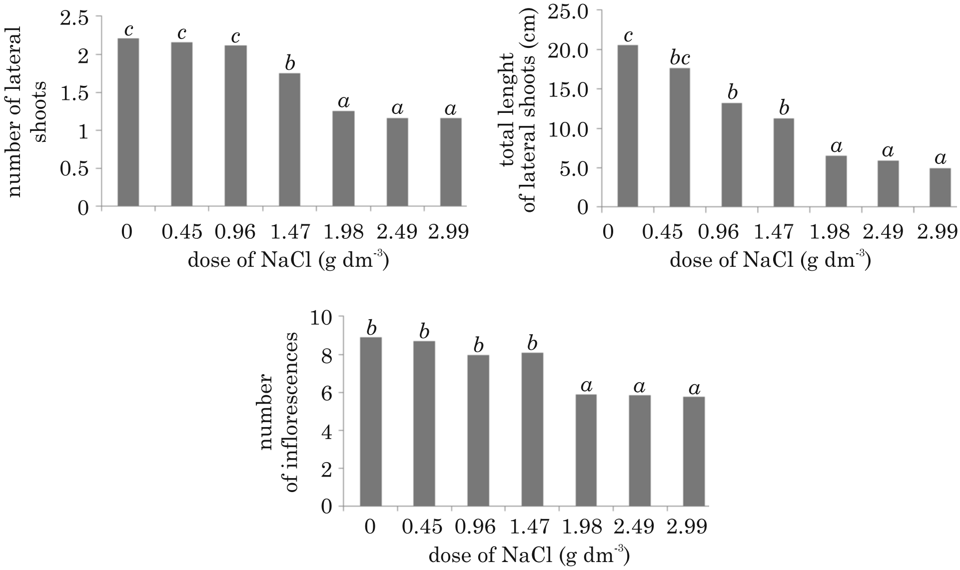

Fig. 2. Effect of sodium chloride dose on number of lateral shoots, total length of lateral shoots and number of inflorescences

The ornamental value of plants depend largely on their flowering. In the case of the pelargonium cultivar Survivor Dark Red tested, significantly fewer inflorescences were counted on plants grown in a substrate supplemented with three highest NaCl doses (1.98 - 2.99 g NaCl dm^{-3}). When evaluating the effect of sodium chloride on pelargonium, the visual evaluation of ornamental value conducted at the stage of flowering proved to be highly useful (Table 1). In our opinion, plants grown in a substrate containing up to

Table 1

Quality appraisal of the ornamental value in pelargonium conducted on the last day of the experiment

Dose of NaCl (g dm^{-3})	Evaluation
0	5.0
0.45	5.0
0.96	4.5
1.47	4.5
1.98	3.5
2.49	3.0
2.99	2.0

600 mg Na^+ and 903 mg Cl^- dm^{-3} (1.47 g NaCl dm^{-3}) still retain high ornamental value. Higher contents were harmful to plants and the quality of pelargonium plants was not satisfactory. It is very difficult to refer our results to the literature due to discrepancies in methodologies used. According to Weinhold and Scharpf (1997), 225 mg Na^+ and 1000 mg Cl^- are admissible contents in substrates for *Pelargonium zonale* cv. Pulsar Red. Moreover, critical contents of Na^+ were reported for Rieger begonia (*Begonia elatior* 'Netja') – 550 mg, petunia (*Petunia* × *hybryda* 'Blue Flash') – 540 mg, and primrose (*Primula obconica* 'Juno Deeprose') –- 140 mg dm^{-3} of substrate.

Addition of sodium salt to substrate disturbs the ionic balance in the root medium, resulting in the appearance of antagonisms between ions. This typically pertains to Na^+ - K^+, Na^+ - Ca^{++}, N - NO_3^- - Cl^-. Consequently, ion uptake by plants is affected and ion distribution to individual organs is distorted. The results of our chemical analyses of pelargonium leaf blades showed varied effects on the leaf blade chemical composition (Table 2). The increase of salt doses caused significant increases in the phosphorus and calcium concentrations. Simultaneously, concentrations of potassium and magnesium decreased, while the concentration of nitrogen was found to be stable. The greatest deviations from the control were shown in the case of phosphorus (+ 47%), magnesium (-30%) and potassium (-23%). Breś et al. (2016) reported that in pelargonium grown in the described conditions, the concentration of sodium increased about 16-fold (from 0.08 up to 1.34% d.w.) and chlorine was raised by about 6-fold (from 0.32 do 1.85% d.w.). Similar albeit not identical changes were reported in many plants, including pepper hybrids and mandarin (Chartzoulakis, Klapaki 2000, Garcia-Sanchez et al. 2002). Discrepancies are found particularly among calcium concentrations. For example, the sodium content increased while that of calcium decreased

Table 2

Concentrations of sodium, chloride and macroelements in leave blades of pelargonium (g kg^{-1} d.m.)

Element	Dose of NaCl (g dm^{-3})							Reference sufficiency ranges
	0	0.45	0.96	1.47	1.98	2.49	2.99	
N	36.5*a*	35.5*a*	35.5*a*	36.0*a*	35.0*a*	36.0*a*	35.0*a*	33.0-48.0**
P	5.5*a*	6.2*a*	7.5*b*	7.2*b*	7.7*b*	8.0*bc*	8.1*c*	4.0-6.7**
K*	46.0*cd*	45.0*cd*	45.0*cd*	44.0*c*	37.0*b*	36.3*b*	33.5*a*	25.0-43.0**
Ca	31.0*a*	30.5*a*	32.0*b*	34.1*c*	34.7*c*	36.0*d*	35.5*d*	12.8-19.7***
Mg	4.0*d*	4.0*d*	4.0*d*	3.7*c*	3.5*b*	3.5*b*	2.8*a*	2.0-5.2**

* Breś at al. (2016), ** Kofranek and Lunt (1969), *** Krug et al.(2010);
Means followed by the some letters did not differ significantly at $p \leq 0.05$.

in leaves of *Celosia argentea* (L.) irrigated with saline wastewater (Carter et al. 2005). It was observed that at slight salinity the content of Ca in plants typically increases, although when a certain salinity threshold is exceeded (different for various species and cultivars) the Ca content in plants decreases (Wilson et al. 2000). A high Cl^- content reduces the photosynthetic capacity and yield volume due to chlorophyll degradation. However, some authors believe that the causative role of Cl^- toxicity in growth and yield under salinity stress may have been underestimated (Tavakkoli et al. 2010). This opinion was confirmed in experiments on *Medicago media*. The researchers found a less negative effect on plant growth in Cl^- treatments and a relatively greater effect in comparison with equimolar treatments of NaCl and Na^+ (Al-Rawahy, Farooq 2012). In our experiments with *Pelargonium* × *hortorum*, the decrease of SPAD can be attributed not only to the chlorophyll degradation caused by Cl ions, but also to the decrease of the magnesium content in leaves, especially in the treatment with the highest dose of NaCl (Table 2).

Plant tissues contain on average 0.03 - 0.7% Cl (Robinson, Downton 1984, Zhou, Zhang 1992) and 0.09 - 1.6% Na (Loupassaki et al. 2002, Borkowska, Lipiński 2007, Breś et al. 2014). In leaves of pelargoniums grown in a substrate with higher doses of sodium chloride, the sodium concentration exceeded 1%, while the chloride level almost reached 2%. Thus, it may be stated that *Pelargonium* × *hortorum* cv. Survivor Dark Red is able to bioaccumulate these elements in excess of the average levels. Plants accumulating considerable amounts of sodium and chlorine are used in phytoremediation of Na^+ and Cl^- ions from salt polluted urban areas (Wrochna et al. 2006, Qadir et al. 2007, Manousaki, Kalogerakis 2011).

This study shows that salinity caused by sodium chloride modifies the chemical composition of leaves. In the diagnostics of the nutritional status of plants, it is important to identify the scale of changes. Particularly, results of chemical leaf analyses should be compared with recommendations (guideline values) established by Kofranek and Lunt (1969) and Krug et al. (2010). The data are listed in Table 2. Comparison of our results of the chemical analyses of leaves with guideline values indicates that despite salt stress the content of N, P, K, Ca and Mg fell within or exceeded slightly the established range.

CONCLUSION

According to SHANNON and GRIEVE (1999) salt concentration at which a 50% reduction of fresh matter has been observed can be considered a threshold salinity level for a particular plant. In the experiments presented herein, such high decrease of fresh mass was caused by the dose of 1.98 g NaCl dm^{-3} of substrate. Moreover, the ornamental value of pelargonium growing in this substrate was not satisfactory. Plants grown in the substrate containing up to 600 mg Na^{+} and 903 mg Cl^{-} (1.47 g NaCl dm^{-3}) still retain a high ornamental value. Furthermore, the nutritional status of these plants is very close to the optimum. Thus, these values should be considered as permissible in an assessment of the potential for pelargonium cultivation in urban soils and in growing mediums contaminated with sodium chloride. The results of our experiments support the opinion of HUANG and COX (1988) that *Pelargonium × hortorum* is a plant of low tolerance to salinity caused by sodium chloride.

REFERENCES

AL-RAWAHY S.H., FAROOQ S.A. 2012. *Influence of intracellular Na+ , K+ and Cl^{-} on the salt tolerance in suspension cell cultures of Medicago media.* Afr. J. Biotech., 11(20): 4499-4512. DOI: 10.5897/AJB11.1800

BACH A., PAWŁOWSKA B. 2007. *The impact of environmental pollution on the condition of tree plants in Kraków.* Czasop. Techn. 10, Architektura, 5A: 114-116. (in Polish) https://suw.biblos.pk.edu.pl/resources/i4/i0/i3/r403/BachA_WplywZanieczyszczenia.pdf

BORKOWSKA H., LIPIŃSKI W. 2007. *Content of selected elements in the biomass of several species of energy plants.* Acta Agroph., 10(2): 287-292. (in Polish) http://www.old.acta-agrophysica.org/artykuly/acta_agrophysica/ActaAgr_152_2007_10_2_287.pdf

BREŚ W., KUPSKA A., TRELKA T. 2014. *Response of scarlet sage and common sunflower plants to salinity caused by sodium salts.* Fol. Univ. Agric. Stetin. Agric., Aliment., Pisc., Zootech., 315(32): 5-14. http://www.wydawnictwo. zut.edu.pl/files/magazines/1/48/609.pdf

BREŚ W., KUPSKA A., BANDURSKA H., NIEDZIELA J., FRĄSZCZAK B. 2016. *Responses of pelargonium (Pelargonium × hortorum* L.H. Bailey*) to long-term salinity stress induced by treatment with different NaCl doses.* Acta Physiol Plant., 38: 26-36. DOI: 10.1007/s11738-015-2048-8

CAI H., GAO D. 2011. *Phytotoxicity of salts in composted sewage sludge and correlation with sodium chloride, calcium nitrate and magnesium nitrate.* J. Plant Nutr., 34(12): 1788-1796. DOI: 10.1080/01904167.2011.600406

CARTER C.T., GRIEVE C.M., POSS J.A., SUAREZ D.L. 2005. *Production and ion uptake of Celosia argentea irrigated with saline wastewaters.* Sci. Hort., 106(3): 381-394. DOI: 10.1016/j.scienta.2005.04.007

CHARTZOULAKIS K., KLAPAKI G. 2000. *Response of two greenhouse pepper hybrids to NaCl salinity during different growth stages.* Sci. Hort., 86: 247-260. DOI: 0.1016/S0304-4238(00)00151-5

Clark S., Cavigelli M. 2005. *Suitability of composts as potting media for production of organic vegetable transplants.* Compost Sci. Util., 13: 150-155. http://naldc.nal.usda.gov/download/37185/PDF

Czyżyk F., Kozdraś M. 2004. *Chemical properties and composting of sludge from rural wastewater treatment plant.* Woda Środ. Obsz. Wiej., 4/2a (11): 559-569. (in Polish) http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-BATC-0011 -0089

Czyżyk F., Rajmund A. 2009. *Nitrogen loss during composting sewage sludge in a prism with plant remains.* Woda Środ. Obsz. Wiej., 9/3 (27): 29-37. (in Polish) http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-BATC-0002-0031

Danai O., Cohen H., Ezov N., Yehieli N., Levanon D. 2012. *Recycling of spent mushroom substrate (SMS) in avocado orchards.* J. Agric. Sci. Tech., B. 2: 1165-1170. http://www.davidpublishing.com/davidpublishing/upfile/12/13/2012/2012121370647121.pdf

Dkhil B.B., Denden M. 2012. *Effect of salt stress on growth, anthocyanins, membrane permeability and chlorophyll fluorescence of okra (Abelmoschus esculentus* L.*) seedlings.* Am. J. Plant Physiol., 7(4): 174-183. DOI: 10.3923/ajpp.2012. 174.183.

Fidanza M.A., Sanford D.L., Beyer D.M., Aurentz D.J. 2010. *Analysis of fresh mushroom compost.* Hort. Technol., 20(2): 449-453. http://horttech.Ashspublications.org/content/20/2/449.full.pdf+html

Garcia-Sanchez F., Jifon J.L., Carvajal M., Syvertsen J. 2002. *Gas exchange, chlorophyll and nutrient contents in relation to Na^+ and Cl^- accumulation in 'Sunburst' mandarin grafted on different rootstocks.* Plant Sci., 162(5): 705-712. DOI: 10.1016/S0168-9452(02)00010-9

Huang Z.T., Cox D.A. 1988. *Salinity effects on annual bedding plants in a peat-perlite medium and solution culture.* J. Plant Nutr., 11(2): 145-159. DOI: 10.1080/019041 68809363792

Jamil M., Rehman S., Lee K.J., Kim J.M, Kim H.S., Rhae S. 2007. *Salinity reduced growth PS2 photochemistry and chlorophyll content in radish.* Sci. Agric., 64: 111-118. DOI: 10.1590/S0103-90162007000200002

Kofranek A. M., Lunt O.R. 1969. *A study of critical nutrient levels in Pelagonium hortorum, cultivar 'Irene'.* J. Am. Soc. Hortic. Sci., 94: 204-207.

Krug B.A., Whipker B.E., McCall I., Cleveland B. 2010. *Geranium leaf tissue nutrient sufficiency ranges by chronological age.* J. Plant Nutr., 33: 39-350. DOI: 10.1080/01904160903470398

Liu J., Sun S. 2013. *Total concentrations and different fractions of heavy metals in sewage sludge from Guangzhou, China.* Trans. Nonferrous Met. Soc. China, 23: 2397-2407. http://www.tnmsc.cn/down/2013/08_en/29-p2397.pdf

Loupassaki M.H., Chartzoulakis K.S., Digalaki N.B., Androulakis I.I. 2002. *Effects of salt stress on concentration of nitrogen, phosphorus, potassium, calcium, magnesium, and sodium in leaves, shoots, and roots of six olive cultivars.* J. Plant Nutr., 25(11): 2457-2482. DOI: 10.1081/PLN-120014707

Lundmark A., Jansson P. 2008. *Estimating the fate of de-icing salt in a roadside environment by combining modelling and field observations.* Water Air Soil Pol., 195: 215-232. DOI: 10.1007/s11270-008-9741-9

Majchrowska-Safaryan A., Tkaczuk C. 2013. *Possibility to use the spent mushroom substrate in soil fertilization as one of its disposal methods.* J. Res. Appl. Agric. Eng., 58(4): 57-62. (in Polish) http://www.pimr.poznan.pl/biul/2013_4_12MT.pdf

Manousaki E., Kalogerakis N. 2011. *Halophytes – an emerging trend in phytoremediation.* Int. J. Phytoremediat., 13(10): 959-969. DOI: 10.1080/15226514.2010.532241

Medina E., Paredes C., Pérez-Murcia M.D., Bustamante M.A., Moral R. 2009. *Spent mushroom substrates as component of growing media for germination and growth of horticultural plants.* Bioresource Technol., 100(18): 4227-4232. DOI: 10.1016/j.biortech. 2009.03.055

Moradi F., Ismail A.B. 2007. *Responses of photosynthesis, chlorophyll fluorescence and*

ROS-scavenging systems to salt stress during seedling and reproductive stages in rice. Ann. Bot., 99(6): 1161-1173. DOI: 10.1093/aob/mcm052

Niesler J., Nadziakiewicz J. 2014. *The energy potential of sewage sludge in Silesian Voivodeship.* Arch. Waste Manage. Environ. Prot., 16(1): 49-58. (in Polish) http://awmep.org/?journal=ago&page=article&op=view&path%5B%5D=349

Reddy S.A., Kale A., Kale R.D. 2012. *Management of secondary sewage sludge by vermicomposting for use as soil amendment.* Global J. Biotech. Biochem., 7(1): 13-18. DOI: 10.5829/idosi.gjbb.2012.7.1.61248

Robinson S.P., Downton W.J.S. 1984. *K, Na and Cl content of isolated intact chloroplasts in relation to ionic compartmentation in leaves.* Arch. Biochem. Biophys., 228(1): 197-206. DOI: 10.1016/0003-9861(84)90061-4

Rodriguez I.R., Miller G.L. 2000. *Using a chlorophyll meter to determine the chlorophyll concentration, nitrogen concentration, and visual quality of St. Augustinegrass.* HortScience., 35(4): 751-754. http://hortsci.ashspublications.org/content/35/4/751.full.pdf+html

Ruiz-Sánchez M.C., Domingo R., Torrecillas A., Pérez-Pastor A. 2000. *Water stress preconditioning to improve drought resistance in young apricot plants.* Plant Sci., 156: 245-251. DOI: 10.1016/S0168-9452(00)00262-4

Shannon M.C., Grieve C.M. 1999. *Tolerance of vegetable crops to salinity.* Sci. Hortic. Amsterdam, 78: 5-38. DOI: 10.1016/S0304-4238(98)00189-7

Tabatabaei SJ, Yusefi M, Hajiloo J. 2008. *Effects of shading and NO_3:NH_4 ratio on the yield, quality and N metabolism in strawberry.* Sci Hortic. Amstedram, 116(3): 264-272. DOI: 10.1016/j.scienta.2007.12.008

Tavakkoli E., Rengasamy P., McDonald G.K. 2010. *High concentrations of Na^+ and Cl^- ions in soil solution have simultaneous detrimental effects on growth of faba bean under salinity stress.* J. Exp. Bot., 61(15): 4449-4459. DOI: 10.1093/jxb/erq251

Qadir M., Oster J.D., Schubert S., Noble A.D., Sahrawat K.L. 2007. *Phytoremediation of sodic and saline-sodic soils.* Adv. Agron., 96: 197-247. DOI: 10.1016/S0065-2113(07)96006-X

Villarino G.H, Mattson N.S. 2011. *Assessing tolerance to sodium chloride salinity in fourteen floriculture species.* HortTechnol., 21: 539-545. http://horttech. ashspublications.org/content/21/5/539.full.pdf+html

Weinhold F., Scharpf H.C. 1997. *Tolerance of ornamental plants to salt, sodium and chloride in potting substrates containing compost of separately collected organic residues.* Acta Hortic., 450: 221-228. DOI: 10.17660/ActaHortic.1997.450.26

Wilkaniec B., Borowiak-Sobkowiak *B.,* Wilkaniec A., Breś W., Frużyńska-Jóźwiak D. 2013. *The evaluation of factors determining the health condition of Acer platanoides and Tilia cordata in selected sites of urban greenery of Poznań, Poland.* J. Plant Protec. Res., 53(1) 60-64. DOI: 10.2478/jppr-2013-0009

Wilson C., Scott M. Lesch S.M., Grieve C.M. 2000. *Growth stage modulates salinity tolerance of New Zealand spinach (Tetragonia tetragonioides* Pall.*) and red orach (Atriplex hortensis* L.*).* Ann. Bot., 85: 501-509. DOI: 10.1006/anbo.1999.108

Wrochna M., Gawrońska H., Gawroński S. W. 2006. *Effect of salt stress on fresh and dry matter production and accumulation of Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^- ions in selected species of ornamental plants.* Acta Agroph., 7(3): 775-785. (in Polish) http://www.old.actaagrophysica.org/artykuly/acta_agrophysica/ActaAgr_134_2006_7_3_775.pdf

Zawadzińska A., Salachna P. 2014. *The effect of substrates containing municipal sewage sludge compost on the accumulation of macrocomponents in Impatiens walleriana* Hook. J. Elem., 19(1): 253-263. DOI: 10.5601/jelem.2014.19.1.545

Zhang R.H., Duan Z.Q., Li Z.G. 2012. *Use of spent mushroom substrate as growing media for tomato and cucumber seedlings.* Pedosphere, 22(3): 333-342. DOI: 10.1016/ S1002-0160(12)60020-4

Zhou B.K., Zhang X.Y. 1992. *Effects of chloride on growth and development of sugarbeet.* Soil Fert., 3: 41-43. (in Chinese)