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Wpływ chlorku sodu na zdolność kiełkowania nasion wybranych roślin warzywnych
Effect of sodium chloride salinization on the seed germination of selected vegetable plants

Key words: germination, salt stress, sodium chloride
Słowa kluczowe: kiełkowanie, stres solny, chlorek sodu

Introduction

The issue of soil salinity pertains to 7% of the surface of the Earth (Munns 2003), 30% of agricultural areas and nearly 27% of irrigated arable land (Tester and Davenport 2003). The continuous increase in saline areas is a result of natural processes as well as cause by anthropogenic factors. Sodium, calcium, and magnesium base salts as well as carbonic acid, hydrochloric acid and sulfuric acid salts are mainly responsible for the process of salt accumulation in soil (Siyal et al. 2002). Soil with high concentrations of salt leads to, among others, problems with plant mineral metabolism and osmotic stress. These in turn result in the partial or complete elimination of crop production in a given area (Wróbel et al. 2009). Lower crop yield and quality constitute a characteristic reaction with economic consequences of plant species used in agriculture to the increase in soil salinity (Matuszak et al. 2009). The increased content of Cl^- and Na^+ ions in soil causes undesirable changes in the metabolism of ions, such as: K^+, Ca^{2+}, Mg^{2+}, and NO_3^-, and consequently plays a part in altering the course of metabolic and enzymatic processes (Wrochna et al.

2006). Excessive accumulation of chlorine and sodium ions leads to the death of entire plants or their individual organs.

Providing for the dietary needs of an increasing human population necessitates the conduction of interdisciplinary studies on soil salinity. Taking the above issues into account, studies aimed at determining the seed germination of selected plant species in salt solutions of increased sodium chloride salinization were conducted.

Materials and methods

Based on Domaradzki's and Korpal's (2009) analyses of seed germination conditions, filter paper tests in a laboratory setting were accepted as the most effective and recommended method. Petri dishes lined with filter paper saturated with aquatic solutions containing various amounts of sodium chloride were used in the experiment. The salt concentrations used in the experiment were expressed as conductivity in $mS \cdot cm^{-1}$. The degree of soil salinization was determined in accordance with Richard's (1954) classification of saline soils, based on ranges of characteristic conductivity values and modified to extend the scope of our studies.

Solutions represents various salt concentrations: control with a conductivity of 0 $mS \cdot cm^{-1}$ (redistilled water), non-saline with a conductivity of 2 $mS \cdot cm^{-1}$, of low salinity with a conductivity of 4 $mS \cdot cm^{-1}$, moderately saline with a conductivity of 6 $mS \cdot cm^{-1}$, saline with a conductivity of 8 $mS \cdot cm^{-1}$, highly saline with a conductivity of 10 $mS \cdot cm^{-1}$, and very highly saline with a conductivity of 20 $mS \cdot cm^{-1}$ at a temperature of 25°C.

Six levels of salinity were obtained at a complete saturation of the filter paper with water. Selected species of vegetable plants were applied in the experiment: pepper (*Capsicum annuum* L.) of the Oleńka variety, radish (*Raphanus sativus*) Saxa 2 variety, in-ground tomato (*Lycopersicon lycopersicum*) Huzar variety, greenhouse tomato (*Lycopersicon lycopersicum*) Remiz F1 variety, butterhead lettuce (*Lactuca sativa* var. *capitata*) Syrena variety, carrot (*Daucus carota*) Nantejska variety, and cucumber (*Cucumis sativus* L.) Hermes Skierniewicki F1 variety. A hundred seeds were sown directly onto the filter paper and the Petri dishes were covered in order to keep the solution from evaporating. The study object was then incubated at a temperature of 25°C for five days with a 24-hour light cycle (after this time, the amount of germinated seeds did not change). Three repetitions were carried out for each of the experimental combinations. The effect of the analysis was defined as the number of germinated seeds from the time of sowing to the established reference day, in relation to the number of seeds sown.

Results and discussion

The salt (NaCl) applied in the studies is a substance that is easily dissolved in water. As a result of this property, small doses of this ionic compound lead to changes in the pH of soil solutions. Matuszak et al. (2004) point out that the growth of entire plants is stimulated by suitably low levels of NaCl. Excess salt stress has the opposite effect and can negatively influence the germination ability of plants and its dynamics as well as lead to the serious disruption of plant growth and development (Wrochna et al. 2010).

The proper interpretation of the obtained results requires one to look into the dynamics of seed germination over the course of the whole experiment. A detailed analysis of the sensitivity of individual plant species to soil salinity is presented in Figures 1–7. The negative effect of sodium chloride on the germination ability of pepper (*Capsicum annuum* L.) seeds can be seen in Figure 1, where the analyzed plant variety already revealed a significant sensitivity to salt at the lowest analyzed conductivity of 2 $mS \cdot cm^{-1}$. The number of germinated seeds decreased by 20% when compared to the control group. The solution characterized by a conductivity of 4 $mS \cdot cm^{-1}$ was found to have a clear inhibitory effect on the dynamics and efficiency of seed germination. A saline conductivity of 8 $mS \cdot cm^{-1}$ impaired germination by as much as 93.3%. Higher levels of salinity made plant development impossible. Statistical analysis of the obtained results revealed that differences in the applied concentrations of salt had a significant influence on the number of germinated pepper seeds ($LSD_{0.05}$ = 13.0; SD = 39.7). Looking back at the available literature, pepper is classified as having a medium sensitivity to salinization (Knaflewski 2007). Studies conducted by Kortuby-Amacher et al. (2000) reported a 50% reduction in crop yield at level of salinity equal to a conductivity of 5.1 $mS \cdot cm^{-1}$. The effectiveness of seed germination in the present study coincides with literature data. The analyzed pepper variety is characterized by a moderate tolerance to saline stress.

Radish (*Raphanus sativus*) is considered to be a plant with a high tolerance to sodium chloride (Fig. 2). The lowest analyzed conductivity (2 $mS \cdot cm^{-1}$) during the first days of the experiment had a stimulating effect on the dynamics of seed germination. A clear difference in the speed as well as efficiency of germination is evident when comparing 6 $mS \cdot cm^{-1}$ and 8 $mS \cdot cm^{-1}$ levels of conductivity; the difference in the amount of germinated seeds between these two concentrations amounted to

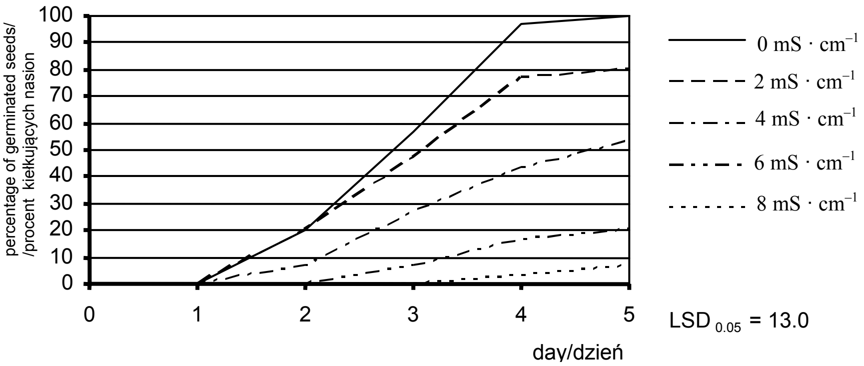

FIGURE 1. Dynamics of pepper seed germination on NaCl containing culture medium
RYSUNEK 1. Dynamika kiełkowania nasion papryki na pożywce z NaCl

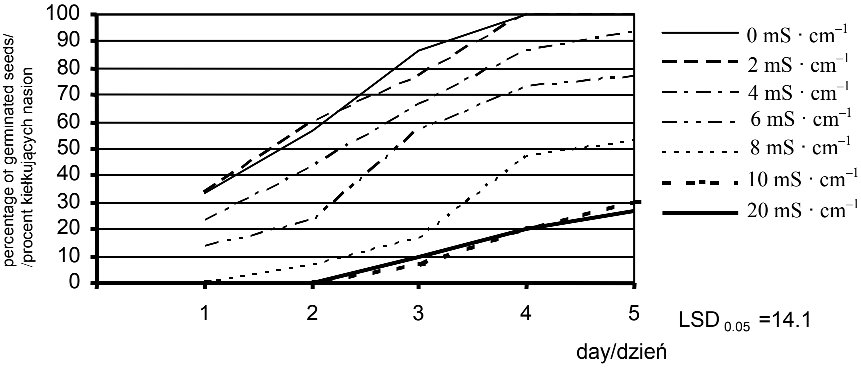

FIGURE 2. Dynamics of radish seed germination on NaCl containing culture medium
RYSUNEK 2. Dynamika kiełkowania nasion rzodkiewki na pożywce z NaCl

23.3%. The highest applied salinity level (20 mS·cm^{-1}), which prevented the germination of most analyzed species, restricted the efficiency of radish seed germination by 73.3%. The disparity in the amount of seeds germinated at high and very high salinity was 3.3%. The differences in the germination efficiency of the Saxa 2 variety at the analyzed levels of NaCl contamination are statistically significant ($LSD_{0,05}$ = 14.1; SD = 29.9). When evaluated in relation to certain kinds of vegetables which react differently to salinity, radish is placed in the category of sensitive plants (Kłosowska 2010). Shannon and Grieve (1999) published studies which indicate that the relative humidity of substrates is of fundamental importance to the saline sensitivity of an analyzed plant. At 70% relative humidity, the sensitivity of radish could be observed when the conductivity of the culture media was as low as 1.3 mS·cm^{-1}. Increasing the level of humidity to 90% resulted in an adequate increase of resistance to salt stress, up to a conductivity of 5.2 mS·cm^{-1}. The influence of salinity on plant germination was conducted at 100% humidification of the substrate. This influenced the higher tolerance range of the analyzed variety of radish.

The effect of sodium chloride on the germination efficiency of the in-ground tomato (*Lycopersicon lycopersicum*) exposed to different levels of soil contamination is illustrated by figure 3. The seeds of the analyzed plant reveal that germination speed and efficiency are significantly restricted (by 57.7%) at a conductivity of 6 mS·cm^{-1} as compared to the control group. The relatively small negative effect of lesser degrees of salinity on plant growth dynamics indicate the resistance of this species to low amounts of salt in the culture media. A solution with a conductivity of 8 mS·cm^{-1} almost completely (in 96.7% of seeds) inhibition germination. The in-ground tomato reveals a low tolerance to soil salinity. Statistical analyses confirmed the differences in germination efficiency under the influence of NaCl to be statistically significant ($NIR_{0.05}$ = 9.21; SD = 46.5).

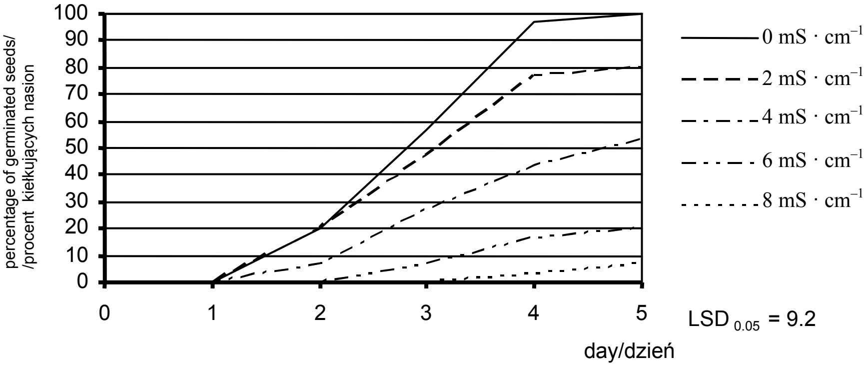

FIGURE 3. Dynamics of in-ground tomato seed germination on NaCl containing culture medium
RYSUNEK 3. Dynamika kiełkowania nasion pomidora gruntowego na pożywce z NaCl

The greenhouse variety of the analyzed plant species was found to have a slightly different tolerance to the amount of salt in the substrate. The range at which salinity affects the seed germination of the above mentioned variety is presented in Figure 4. Depending on its content in the substrate, contamination with sodium chloride effectively influences the seed germination of greenhouse tomatoes (*Lycopersicon lycopersicum*). A low contamination concentration has little negative effect on the dynamics of seed germination, which confirms the resistance of this species to relatively low amounts of salt in the soil. Low soil salinity, similarly to in-ground tomatoes, noticeably delays the germination of seeds. A difference of 30% was observed between the third and fourth day of the experiment in the analyzed plant variety when compared to the control group. In the case of the greenhouse variety, a conductivity of 6 $mS \cdot cm^{-1}$ results in a considerable decrease in the dynamics of seed germination (by 76.7%), whereas the germination efficiency is lowered by 66.7%. A higher level of salinity makes germination of this species completely impossible. This indicates a low toleran-

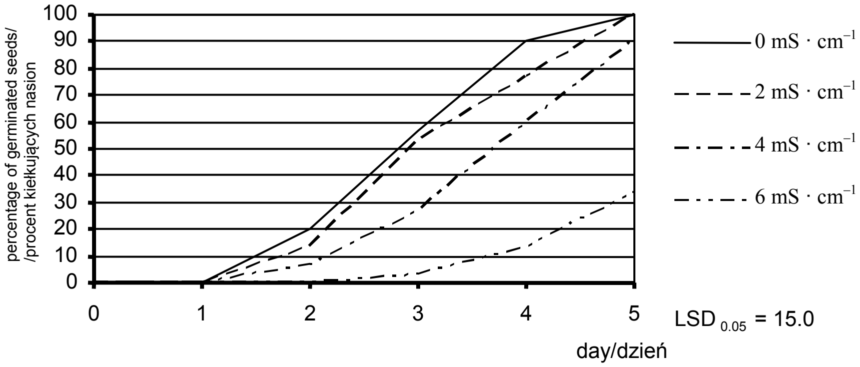

FIGURE 4. Dynamics of greenhouse tomato seed germination on NaCl containing culture medium
RYSUNEK 4. Dynamika kiełkowania nasion pomidora szklarniowego na pożywce z NaCl

ce the greenhouse tomatoe to Na^+ and Cl^- ions in the substrate. Statistical analysis verifies the significant influence of the analyzed factor on the seed germination of the tested plant ($NIR_{0.05}$ = 15.0; SD = 46.1). The conducted studies classify tomato seeds as plants which are sensitive to salinity. It should be noted that the greenhouse variety revealed a higher sensitivity to salt stress. Literary data indicate a moderate sensitivity of the given species. The tolerance of plants to salt ions increases along with age, which influences the classification of species according to Knaflewski (2007). Sacała (2008) brought to attention the observed increase in succulency among different varieties of tomatoes, which increases the species tolerance to salinity. Such a trait is very much desired by gardeners.

When analyzing the influence of NaCl on the dynamics of butterhead lettuce seed germination – *Lactuca sativa* var. *capitata*, it can be concluded that this species of plant is sensitive to salinity (Fig. 5). A low conductivity of the contaminating solution (2 $mS \cdot cm^{-1}$) does not have a significant influence on the germination process. The plant reveals a significant decrease in the dynamics of germination and amount of germinated seeds at a salt concentration equal to that of low substrate salinity. In this case, germination is reduced by as much as 53.3% compared to the control group. The tolerance of butterhead lettuce to salt stress reaches its limit at a conductivity of 8 $mS \cdot cm^{-1}$. Seed germination ability upon applying a solution that is characteristic of saline soils is 90% restricted. Higher concentrations completely prevented the development of the analyzed plant. Statistical assessment indicates the significant influence of various levels of substrate contamination with sodium chloride on butterhead lettuce seed germination ($NIR_{0.05}$ = 10.6; SD = 42.1). Literary data on lettuce is contradictory. Knaflewski (2007) classifies this species as moderately sensitive whereas Kozłowska et al. (2007) believes the plant to be sensitive to salinity. This is probably due to choosing various ranges of tolerance or basing their findings on results obtained when analyzing the salinity resistance of various varieties of plant. The

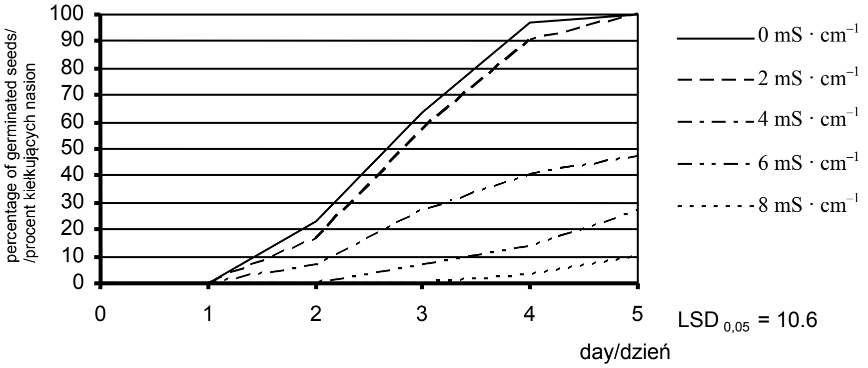

FIGURE 5. Dynamics of butterhead lettuce seed germination on NaCl containing culture medium
RYSUNEK 5. Dynamika kiełkowania nasion sałaty masłowej na pożywce z NaCL

results of the present experiment indicate that in terms of salt stress, the sensitivity of lettuce to Na^+ and Cl^- ions falls into the moderate range. This was also confirmed by studies conducted by Markiewicz and Kleiber (2010) which revealed a salt tolerance of butterhead lettuce of the Brigitta variety to salinity characterized by conductivities in the range of 1.6 to 5.1 $mS \cdot cm^{-1}$.

The changing germination dynamics of carrot seeds (*Daucus carota*) under the influence of salt stress is presented in Figure 6. A low conductivity of the substrate equal to 2 $mS \cdot cm^{-1}$ led to an increase in the germination speed of the given plant when compared to the control group. Carrot of the Natejska variety has a relatively high range of tolerance to salt stress. The gradual increase of sodium chloride content has a negative influence and is distributed proportionately, causing a decrease in the dynamics and sprouting efficiency of the tested plant. Most of the analyzed species display a much more evident decrease in growth rate and restriction of germination ability at a level of NaCl comparable to that of moderately saline soil. A conductivity of 6 $mS \cdot cm^{-1}$ caused a decrease of 40% in the amount of germinated carrot seeds. The highest level of analyzed contamination thwarted germination altogether. Statistical analysis confirmed the significant influence of sodium chloride concentration on germination ($NIR_{0.05}$ = = 14.1; SD = 38.9). In literature, the carrot is classified as a vegetable of moderate sensitivity to salinity (Knaflewski 2007). The present studies indicated a wider salinity tolerance range of seeds of the analyzed species. Shannon and Grieve (1999) revealed that every decrease of carrot root crop yield by 14% is connected with a 1 $mS \cdot cm^{-1}$ increase in salinity above the threshold level. This also pertains to seedling growth and plant germination accounting for the humidity potential of the substrate as well as the remaining environmental factors which may affect it.

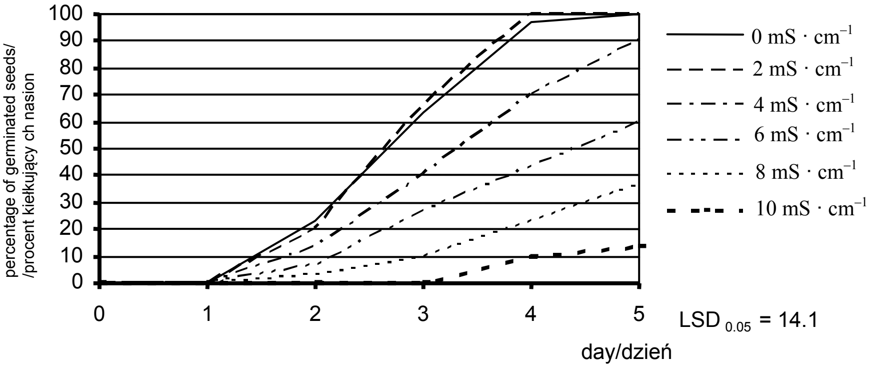

FIGURE 6. Dynamics of carrot seed germination on NaCl containing culture medium
RYSUNEK 6. Dynamika kiełkowania nasion marchwi na pożywce z NaCl

Figure 7 illustrates the varied dynamics of cucumber seed germination (*Cucumis sativus* L.) under the influence

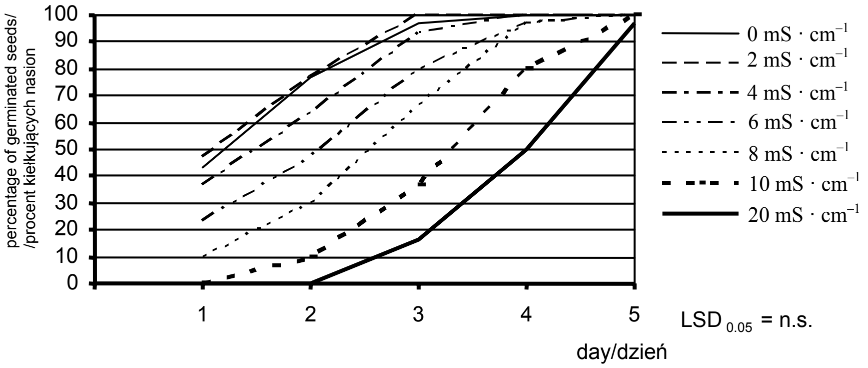

FIGURE 7. Dynamics of cucumber seed germination on NaCl containing culture medium
RYSUNEK 7. Dynamika kiełkowania nasion ogórka na pożywce z NaCl

of substrate contamination with sodium chloride. Our studies showed the lack of the analyzed range of conductivity on the germination efficiency of the tested seeds. The effectiveness of the process stems from the low sensitivity of this plant species to salt stress at the phase of the seed. A decrease in germination speed proportionate to the increase in the conductivity of a given substrate was observed. The tests proved, similarly to carrots, that low contents of sodium chloride have a stimulating effect on the germination process of cucumber seeds. The obtained research results indicate a high tolerance of these seeds to salt stress. Studies conducted by Sacała (2008) did not reveal a significant influence of salinity on the development of cucumber seedlings of the Wisconsin variety at the analyzed levels of contamination (3 and 6 $mS \cdot cm^{-1}$). On the other hand, research conducted by Hawrylak (2007) at the early development stages of the Polan F1 variety cucumber found a phytotoxic influence of salt content with a conductivity of 6 $mS \cdot cm^{-1}$. Each of the experiments was conducted under similar conditions. The contradictory results regarding the assessment of tolerance level on salinity indicate the strong differentiation of this trait in the various varieties of the *Cucumis sativus* plant species.

Conclusion

Increased sodium chloride content negatively influences the germination ability of all analyzed species. A aqueous solution of NaCl with a conductivity of 6 $mS \cdot cm^{-1}$ caused a the dynamics of seed germination to decrease noticeably in the majority of analyzed species, whereas a conductivity of 10 $mS \cdot cm^{-1}$ completely prevented the germination of pepper, lettuce and tomato seeds. The analysis of two tomato varieties indicated a different sensitivity to salt stress within the species. The Remiz F1 greenhouse tomato was shown to be the most sensitive variety in the present study at a conductivity of 8 $mS \cdot cm^{-1}$ (seed germination not noted). The levels of salinity applied in the research did not affect the germination efficiency of cucumber seeds, with an increase in concentration causing a delay in sprouting. A low sodium chloride content (2 mS·cm^{-1}) stimulated the dynamics of radish, carrot and cucumber seed germination when compared to the control group.

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Abstract

Effect of sodium chloride salinization on the seed germination of selected vegetable plants. The article presents studies concerning the influence of sodium chloride salinization on the germination of pepper, radish, in-ground and greenhouse tomato, butterhead lettuce, carrot and cucumber seeds. The studies revealed that an increased sodium chloride content had a negative effect on the germination ability of all tested plant species. An aqueous solution of NaCl characterized by a conductivity of 6 mS·cm^{-1} caused a noticeable decrease in the germination dynamics of most analyzed species, whereas a conductivity of 10 mS·cm^{-1} completely prevented pepper, lettuce and tomato seed germination.

Streszczenie

Wpływ chlorku sodu na zdolność kiełkowania nasion wybranych roślin warzywnych. W artykule przedstawiono badania nad wpływem zasolenia chlorkiem sodu na kiełkowanie papryki, rzodkiewki, pomidora gruntowego i szklarniowego, sałaty masłowej, marchwi oraz ogórka. Konsekwencją nadmiernego skumulowania jonów chlorkowych i sodowych może być obumieranie całych roślin lub pojedynczych organów. Badania wykazały, że podwyższona zawartość chlorku sodu wpływała negatywnie na zdolność kiełkowania roślin wszystkich analizowanych gatunków. Roztwór wodny NaCl o przewodności właściwej 6 mS·cm^{-1} spowodował wyraźne obniżenie dynamiki kiełkowania nasion większości badanych gatunków, natomiast o przewodności 10 mS·cm^{-1} całkowicie zahamowała kiełkowanie nasion papryki, sałaty i pomidorów.

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