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Correlation of secondary salinization and soil conditioning in vegetable production under irrigation with saline water

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Abstract: Secondary salinization is a main problem around the world due to climate change and intrusion of salts in the soil by improper irrigation. Our aim was to study the soil salinization process by simulating vegetable production under irrigation with saline water (total soluble salt content 700 mg L^{-1}). We tested 6 different technologies of soil conditioner application and 3 vegetable crops with different sensitivity to salinity in a small plot experiment set up on a meadow chernozem soil. During the irrigation season in 2020, we regularly measured the electric conductivity (EC_a) and the soil moisture content (v/v%) in the topsoil (0.1 m) and analysed these parameters with Pearson's bivariate correlation (PCC) method. As our hypothesis, we expected that there is correlation among EC_a, soil moisture content, soil conditioning, and providing the possibility to quantify the secondary salinization process. We found that all the 4 biosynthetic soil conditioners technologies minimized the harmful effect of saline irrigation. In the case of the not salt tolerant (NT) peas, the PCC correlation was higher to compost application and control expressing more intense salinization. NT beans showed a weaker correlation with lower PCCs, which must be due to its higher root activity leading to intensive leaching resulting in a lower degree of salinization. In the case of chilli with low salt tolerance (LT), micro dosing of soil conditioners was not effective in mitigating the harmful effect of secondary salinization, only full doses decreased the PCC. The salt tolerance of the investigated vegetable crops was also manifested in the yields. We found that PCC is a suitable statistical method to understand and quantify the process of secondary salinization.

Keywords: electric conductivity, soil moisture content, soil conditioners, salt tolerance, secondary salinization

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Introduction

Nowadays, soil salinity constitutes one of the major abiotic constraints in global food production and particularly critical in semi-arid and arid regions (Minhas et al., 2020). In regions with the scarcity of good quality water, it is common to practice irrigation with saline groundwater for agriculture. Salinity has a big effect on plant nutrient availability reducing phosphate availability, competitive uptake, and transport or partitioning within the plant and yield performance (Grattan & Grieve, 1998). However, in Hungary's semi-arid regions like Jász-Nagykun-Szolnok (JNS) County with extreme climatic conditions, irrigation water requirement for horticulture increased due to climate change. The water used for irrigation is usually saline in this region. Particularly in Karcag, the irrigation water coming from subsurface water bodies (aquifers) have been monitored and proved not to be suitable for irrigation (Zsembeli et al., 2013, 2015). In such a case, the salt concentration (net accumulation of salts) of a horticultural system is increasing and is considered to have a risk of salinization to land and water resources (Rhoades et al., 1997).

In general, salt composition of the soil solution influences the composition of cation exchange and affects the soil structure and its hydraulic properties (Bower, 1959). The main effect of salinity is the reduction of the transport of Ca^{2+} and mobility to the growing parts of the plant, not only reducing Ca^{2+} availability, but affecting the quality of both the vegetative and the reproductive organs. Salinity, in general, directly affects nutrient uptake, such as Na^+ reduce K^+ uptake or Cl^- reduce NO^{3-} uptake. Apparently, there is antagonism between Cl^- and NO^{3-} (Martinez et al., 1987; Wang et al., 2003). Also, salinity can cause a combination of complex interactions that affects plant metabolism, susceptibility to injury or internal nutrient requirement (Grattan & Grieve, 1998). Salinity is one of the most injurious abiotic stresses for plants that alters different morphological and physiological traits of plants to an abnormal state. The severity of salinity is a complex process and the response is also mediated by environmental interactions with the plant-soil system such as relative humidity, temperature, radiation, genetic background etc. (Sadras et al., 2020; Shannon et al., 1994).

Controlling or reducing salinity levels in the soil depends on the practices of water application including the amount of water, frequency and method of irrigation, drainage, and soil cultivation (Dudley et al., 2008; Pereira et al., 2014; Reeve & Fireman, 1967). Management of saline water for irrigation is often based on application of excess water designed to maintain minimum root zone salinity (Smedema & Shiati, 2002; Burt & Isbell, 2005; Ben-Gal et al., 2008). Nevertheless, in Karcag, the water quality is a limiting factor for leaching purposes (Juhasz et al., 1997). In the MATE Research Institute of Karcag, several studies are carried out focussing on the problem of secondary salinization involving soil conditioner applications for large- and small-scale production and lysimeter experiments. The main concern is the increase of water use efficiency while maintaining sufficient levels of production (Gadissa & Chemeda, 2009; Zsembeli et al., 2021).

According to our previous soil analyses and soil conditioner experiments carried out in Karcag, we categorized soil conditioners into different groups (Kovács et al., 2013; Monori et al., 2009; Szűcs et al., 2014a, 2014b, 2015; Tuba et al., 2020b, 2020a; Zsembeli, Sinka, et al., 2019; Zsembeli, Rivera-García, et al., 2019). The first group includes the natural organic materials (like composts). The organic amendments have the typical use to increase infiltration, retention of water. They are often negatively viewed as waste products with undesirable features such as odour, excessive nitrogen and phosphorus content, incorporating heavy metals, pathogens, toxins and other contaminants, which are potentially transportable to surface or ground waters by runoff or leaching (Bergström, 1990).

The second group of soil amendments are the biosynthetic soil conditioners, which are made mainly by biotechnology companies. These soil amendments use three main sources: clay minerals, trace elements, microorganisms and algae sulphated polysaccharides (Balusson, 2018). Specific organisms are used like renewable raw materials. RHIZO-VAM is a water-soluble soil inoculum that contains in-vitro produced spores and infective propagules of arbuscular mycorrhizal fungus *Rhizoglomus intraradices* in mixture with other natural products, like mycorrhizal helper bacteria, Ca-modulating products and extract of algae stimulates the exchange between the soil and the plant and promotes the growth of the root system. Other strategies that improve plant tol-

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erance against salt stress are the application of plant growth-promoting rhizobacteria (PGPR), plant fungi associations, and organic and inorganic amendments (Kumar et al., 2021; Mekonnen & Kibret, 2021; Nemenyi et al., 2021). These technologies are focused on different areas like plant care, soil life activation, crop nutrition, plant health optimization and improving of soil fertility (Muhammad et al., 2020).

The aim of this recent study was to simulate vegetable production involving irrigation with saline water characteristic to the region of Karcag and soil reclamation by the application of soil conditioners with the purpose of the mitigation of the harmful effect of secondary salinization. In order to understand the salinization process better, a new approach was introduced to reveal the correlation among the electric conductivity (EC_a) and the moisture content (v/v%) of the soil and the PCC value calculated for these regularly measured parameters.

Materials and Methods

The experiment was set up in the Irrigation Experimental Garden (IEG) of the MATE Research Institute of Karcag (RIK) in 2020. IEG is dedicated to carry out experiments to study the process of secondary salinization by simulating the vegetable production and irrigation being typical in the hobby gardens located at Karcag, but also characteristic to the Middle-Tisza region of Hungary (Rivera Garcia et al., 2020). The experiment was settled on a meadow chernozem soil, which is basically salt effected only in the deeper layers. We applied two biosynthetic and one organic soil amendments in order to study their potential secondary salinization mitigating effect, as the treatments of the experiment. All of the indicator crops were vegetable species with various salt tolerance, all are typically grown in the region. The amendments used as treatments and the relevant indicator crops with their salt tolerance degree are listed in Table 1.

The amendments were applied and distributed on 18 small plots of 3×3 m each in May, 2020, prior to sowing or planting of the indicator crops. The small plots were arranged in 3 blocks, each block represented one indicator crop (beans, peas, chili) and was irrigated as the given indicator crop needed it. The blocks consisted of 6 small plots. Within the blocks, 5 plots were dedicated to each amendment (2 plots for Neosol, 2 plots for Physiomax, 1 plot for Terrasol) and there was one untreated control plot. In the case of the biosynthetic amendments (soil conditioners) on the 2 dedicated plots, standard dose and micro-dose were applied. Standard dose represented the full dose of the soil conditioner recommended by the producer of each product. Micro-dose means the application of a reduced amount of soil conditioners. This new technique was developed on the same principle as micro-irrigation: small doses of soil conditioners are placed only close to the roots, not distributed on the whole soil surface. This way, the physical and chemical properties of the soil of the space directly surrounds the roots are reclaimed with lower doses of soil conditioners (Rivera Garcia et al., 2020). It is important to mention that each crop has particular growth stages and water demand, therefore each treatment-crop combination created a certain situation where secondary salinization interacted with the amendments and could cause a different respond in the variables.

We induced secondary salinization by irrigation of vegetable crops with saline water (total soluble salt content 600 mg/L) to understand the salinity process taking place in the upper (0-30 cm) layer of the soil. In order to test the different soil conditioners in the upper layer, we measured the EC_a (mS cm^{-1}) and the moisture content of the soil (v/v%) once week in three repetitions during the

Table 1. The amendments and indicator crops used in the irrigation experiment (Karcag, 2020)

Amendment type	Amendment name and dose	Components	Crops	Degree of tolerance to salinity (Rasool et al., 2012)
Biosynthetic	Neosol (micro-dose: 120 kg/ha, standard dose: 200 kg/ha)	Algae sulphated polysaccharides and trace elements (CaO, Ca, MgO, Mg). (Balusson, 2018, Szűcs et al. 2014b;2015)	chili peas beans	LT NT NT
	Physiomax (Micro-dose: 180 kg/ha, standard dose: 300 kg/ha)	Mineral CO_3 and sulphates as biostimulants (Zsembeli, Sinka, et al., 2019) (Zsembeli, Rivera-García, et al., 2019)	chili peas beans	LT NT NT
Organic	Terrasol biocompost (10 t/ha)	sheep manure 96% + zeolite 2% + mineral phosphate 2% + bacterial culture EM 1) (Monori et al. 2009; Kovács, 2013; Tuba et al. 2020b)	chili peas beans	LT NT NT

LT: low salt tolerance, NT: no salt tolerance

Figure 1. SMT-100 soil moisture probe (left) and the EC-tester (right) Source: I1, I2

Table 2. Salt inputs in the irrigation experiment (Karcag, 2020)

Crop	Number of irrigation events	Irrigation input [mm = L m^2]	Average salt concentration of the irrigation water [mg L^{-1}]	Salt mass input [g m^{-2}]
Beans	9	85	691	58.8
Peas	8	74	691	50.9
Chili	16	253	691	147.7

growing season (15th May – 25th September 2020). Former field studies and lysimeter experiments with soil conditioners carried out at RIK proved that compost (Terra-

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sol) and biosynthetic soil conditioners (Physiomax, Neosol and Explorer) are suitable to mitigate the harmful impact of secondary salinization (Monori et al., 2009; Rivera Garcia et al., 2020; Szűcs et al., 2014b; Zsembeli, Rivera-García, et al., 2019). Nevertheless, in all these investigations, full doses of the applied amendments were studied. We wanted to complete and extend our former findings with the micro-dose application of the two investigated biosynthetic amendments revealing if it is also suitable for the mitigation of the harmful effect of secondary salinization. During the irrigation period, we regularly measured the soil moisture content (v/v%) with an SMT 100 sensor (Figure 1) by Umwelt-Geräte-Technik GmbH, while the EC_a of the upper 10 cm soil layer with a mobile HI 98331 EC-tester by Hanna Instruments.

In order to control the irrigation inputs, we monitored the precipitation data recorded at the meteorological station of RIK. To complete the irrigation schedule, we used sprinkle irrigation to maintain the crop water demand of all the experiments above wilting point, and we monitored the moisture content and maintained above 16% in order to create a suitable environment for the root zone, adopted from Sinka et al. (2019). The salt content of the water we used for irrigation was regularly measured over the irrigation period and was found to be around 700 mg L^{-1}, which is higher than the upper threshold (500 mg L-$^{-1}$) determined in the regulation as the maximum salt content of waters allowed to use for irrigation in Hungary (Zsembeli, Sinka, et al., 2019). Each crop was irrigated as indicated in Table 2 showing the irrigation and salt inputs during the period from May to September 2020. The different input of irrigation (number of irrigation events) depended on the water demand and the salt tolerance of the indicator crop species.

In order to determine the direct effect of soil conditioning on the investigated crops, their yields were measured and expressed in kg m^{-2}. The yield data were derived from the results of several harvest days according to the continuous ripening of the fruits of the crops.

We also investigated the influences of the tested soil amendments on the variables of soil moisture content and EC_a with a statistical analysis. We calculated the means of the two measured variables and calculated the PCC values with the software of Windows Office Excel 2016. PCC is the covariance, a measure of the joint variability of two variables divided by the product of their standard deviations, a measure of the amount of variation or dispersion of a set of values. This statistical analysis gives information about the magnitude of the correlation, as well as the direction of the relationship (Giacomini Sari et al., 2017). In the case of our study, PCC was calculated for the correlation between EC_a and the actual volumetric soil moisture content (Θ). In other words, irrigation with salty water induces higher salt input and soil moisture content, which represents the interaction of electrolyte solution and salts binding to the clay particles. The PCC value close to 1 represents a positive correlation showing the probability of salt accumulation (higher EC_a), hence the risk of secondary salinization is high. In contrast, PCC value tending to 0 shows no significant increase in EC_a even under irrigation with saline water due to the more intensive leaching down to the deeper soil layers and/or the influence of the plant on the salt content of the soil.

Results and discussion

The yields of the three indicator crops irrigated with saline water under soil conditioning are presented in Figure 2. It is obvious that the yields of the investigated vegetable crops cannot be compared to one another, partly because of the differences of their ge-

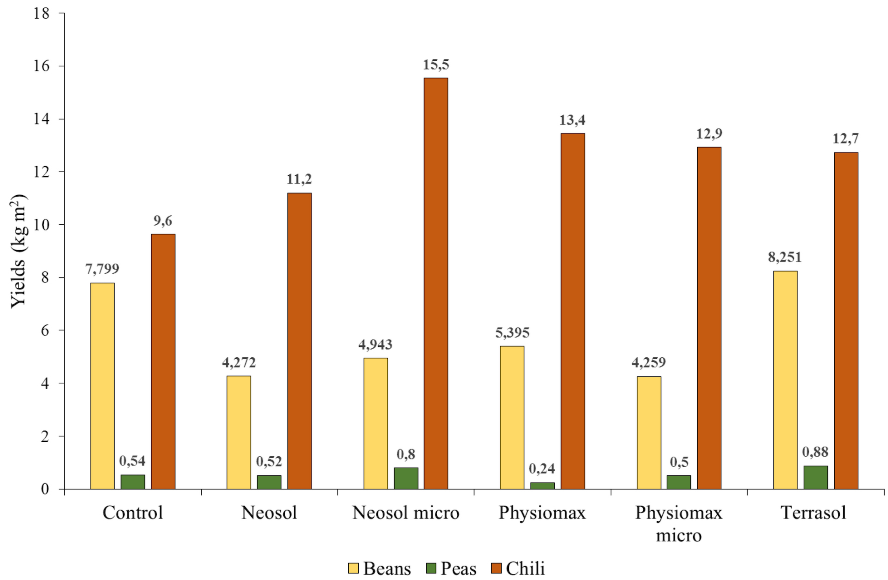

Figure 2. Yields of the indicator crops in terms of the different soil conditioning treatments

netic potential, and partly because of the differences in their vegetation periods. Nevertheless, the longer the vegetation period, the higher the water demand, hence the salt affection due to the irrigation with saline water. This correlation was manifested in the degree of the differences occurred among the treatments. For peas with the shortest vegetation period, the differences in the yields could not lead to the conclusion that they were due to the treatments as the yields were extremely low. For chili, which had the vegetation period until the first frost in autumn, the yield differences were expressive. Beans were in the middle in terms of the length of the vegetation period and the differences in yields as well.

The micro-dose application of Neosol and the Terrasol treatment showed positive effect on the yield of peas. Bean yields were unexpected as the second highest yield was found for the untreated control, while Terrasol was proven to be the best in this case as well. The differences in the yields of beans treated with the two soil conditioners were not significant, though micro-dosing was better for Neosol, while standard dose application of Physiomax was more favourable. In the case of chili with the longest vegetation period, all the treatments showed a yield increasing effect compared to the untreated control. We could reveal a difference between the standard dose and the micro-dose applications of Neosol (with the favour of the latter one), while this was not valid for Physiomax. The compost treatment had also positive effect on the yield of chili, just like in the cases of the other two vegetable crops.

The differences in crops yields are also related to the physiological strategies from each type of plant. Root system architecture and expansion is mostly regulated by water and nutrient uptake efficiency. According to Robin et al. (2016), under salinity stress in particular, both root hair length and density of root hairs per unit surface area decreased 25% to 40%. Liu et al. (2020) suggested that in the development of crops with large root systems could be considered as another tool to cope with soil salinization.

In order to quantify and evaluate the joint effect of soil moisture content and ECa, we differentiated 2 types of salt tolerance of the indicator crops: with no salt tolerance (NT),

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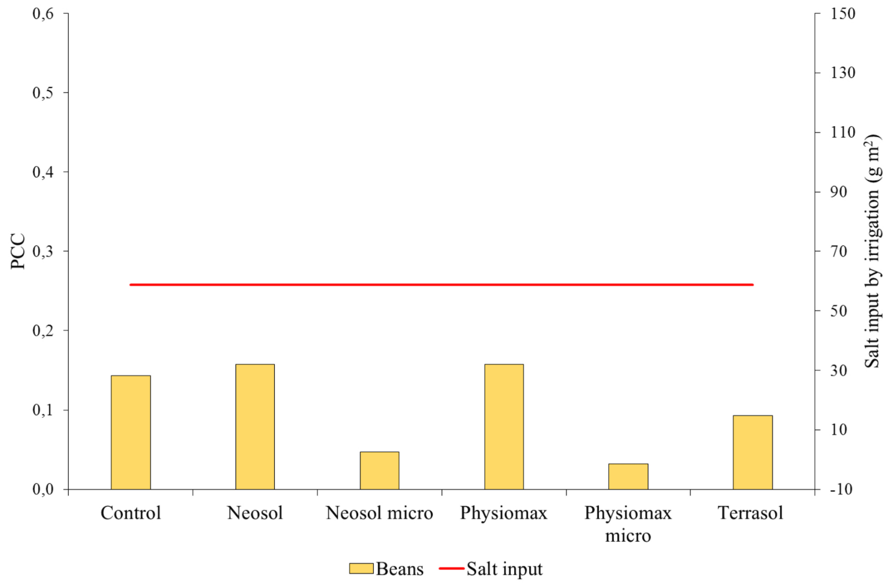

Figure 3. Pearson's correlation coefficients determined by EC_a and moisture content of the 0-0.1 m soil layer in the function of soil conditioning for beans

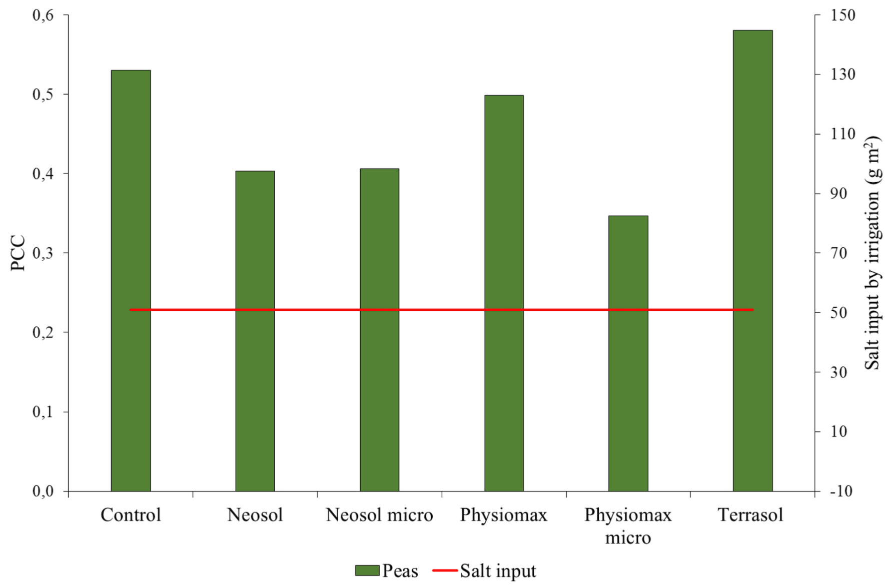

Figure 4. Pearson's correlation coefficients determined by EC_a and moisture content of the 0-0.1 m soil layer in the function of soil conditioning for peas

and low salt tolerance (LT). The PCC values determined by the ECa and moisture content of the 0–0.1 m soil layer in the function of soil conditioning are illustrated in Figures 3-5.

We did not expect a big difference in the correlation between beans and peas as NT crops, but in beans, we observed that salt affected soils increase mineral availability by root exudation and protonation like a strategy under salt stress (Figures 3-4). Beans has a symbiotic association with bacteria, which fix nitrogen, which helps to reduce pH and causing changes in the root zone and it af-

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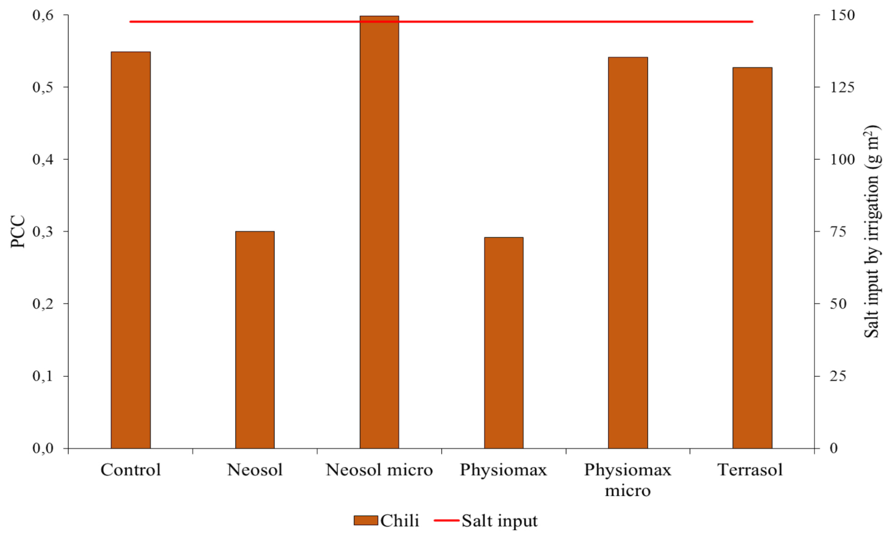

Figure 5. Pearson's correlation coefficients determined by ECa and moisture content of the 0-0.1 m soil layer in the function of soil conditioning for chili

fects the correlation between soil moisture content and ECa in the top layer. Meanwhile peas cannot cope salinity as beans, but the compost addition increased yield by 60% comparing with the control (Figure 2). In addition, Terrasol compost can mitigate the extent of secondary salinization and is commonly used to increase crop productivity, quality, and can improve soil structure, enhance soil fertility, increase soil microbe abundances and activity, and improve the water holding capacity of the soil (Zsembeli et al., 2015). However, in the soil, Physiomax in micro doses had better performance in both crops. In our previous lysimeter experiments with the micro-doses of Physiomax, we found that it improved the effect of leaching in the same meadow chernozem soil and helped the microbiological activity (Rivera Garcia et al., 2020; Zsembeli, Rivera-García, et al., 2019).

Chili is a LT crop and also was tested at different salt inputs and with soil conditioners (Figure 5). Sinka et al. (2019) experienced (in a previous lysimeter experiment on sweet corn) an effective improvement as a result of Neosol application in salts leaching to the deeper soil layers. One particular patent inside Neosol is the Enzyme Catalyser for Organic Substrate (ECO), which is a part of soil enzyme assays emerging as technological tools for various applications in environmental and ecosystem management (Balusson, 2018).

We identified that Terrasol biocompost is beneficial to mitigate the effect of secondary salinization in a certain salinity input range (500–1,000 g L of salt concentration of irrigation water) due to the enormous number of organic compounds in various states of decomposition creates a high content of proteins like lignin. The high content of proteins can be adsorbed by clay minerals and rendered resistant to decomposition creating a higher PCC value. This means that organic colloids supress the harmful effect of salinization under non-tolerant crops under salty water irrigation in clay soils (Foth & Turk, 1972; Kumari et al., 2020).

Biosynthetic soil conditioners interact in different ways in the soil than other amendments. Physiomax is a product that boosts the biological process in the root zone by inoculation of microorganism that can protect the root from the harmful effects of soil solution. In a former study, we found that

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Physiomax effected the PCC value and the yield of chili (Rivera Garcia et al., 2020). In the case of Neosol, algae proteins and clay minerals are able to leach salts and improve plant nutrition (Balusson, 2018), which is in harmony with our recent results. Comparing micro-dose application to full dose application of the investigated soil conditioners, we could establish different effects. Micro-dose application resulted in lower (better) PCC value in the following treatment/crop combinations: Neosol/bean, Physiomax/bean, and Physiomax/pea, while no difference was found for Neosol/pea. Higher PCC values were determined for Neosol/chili and Physiomax/chili.

Conclusion

Based on our results, we could identify that irrigation with saline water creates a positive correlation between soil moisture content and the salts in the upper soil layer (ECa). The correlation depended on the irrigation and the salt content coming from an aquifer (well) water and the amount of clay soil particles in the soil. The proportional positive correlation was increased by adding higher amount of salts getting down to the root zone. We expected a different correlation due to soil conditioners and biotic interactions in the soil (Foth & Turk, 1972). For example, plant growth depends on the climate conditions, irrigation and salt tolerance of the crop. In our case, the investigated meadow chernozem soil contains clayey material that cannot be easily washed. The salt particles dissolved from the irrigation water can easily attach to the soil particles due to the dissociation of anions in the soil solution. Consequently, the soil water and the salts are less available to plants roots (Hewitt & Smith, 1975).

Salinity is an abiotic risk that can cause damage in vegetable crops. In Karcag, water is a limiting factor for normal leaching techniques. Therefore, the need of amendments has been required, but the amount and kind of amendments must best ascertained by soil tests and experimentation. Irrigation with saline water resulted in a positive correlation between ECa and soil moisture content in the investigated meadow chernozem soil. This correlation is useful to monitor the soil health and risk of salt affected conditions. PCC value involves and expresses a favourable condition generated by the higher soil moisture content due to irrigation, and at the same time, it also involves and expresses the unfavourable process of salt affection induced by irrigation with saline water. We found that the harmful effect of salinity in the soil can be managed in the upper layer with plants that can cope salinity with their root architecture supported by soil conditioners or compost. We differentiated the soil conditioners depending on their application doses. We determined that micro-doses of biosynthetic conditioners can be as effective as standard (full) doses with the considerable advantage of much lower application costs. We intend to continue this research by monitoring salt mass balance to understand vertical salt movement.

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