Theses of Doctoral (PhD) Dissertation

MITIGATION OF THE EFFECT OF SECONDARY SALINIZATION BY 'MICRO SOIL CONDITIONING'

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1.1. ANTECEDENS AND OBJECTIVES OF THE DOCTORAL DISSERTATION

Secondary salinization is induced by human activities like the development of large-scale irrigation projects. These projects around the world affect the environmental conditions. For example, irrigating with salty water, rising the water table of saline aquifers, clearing the land of native vegetation, leaching and discharge of industrial salts in to the water cycle (LAMBERT et al., 2002). Where there is irrigation for agriculture, no climatic zone in the world is free from salinization. However, the knowledge of farmers how to irrigate their lands properly is low. The lack of knowledge and initiatives to produce high yields is the major soil degradation threat affecting over 10% of the total irrigated land (FAO Soil Portal, 2017; LAMBERT et al., 2002). The effect of salinity by human activities became a land degradation issue with big impacts on environmental health, agricultural production, and economic welfare, eventually evolving into a human health issue (SMITH et al., 2015). During the following years, governments from all around the world will debate about the water utilization for industry, agriculture and human consumption. However, many undeveloped countries use waste water without treating it to irrigate crops for human consumption, because they have not enough fresh water for irrigation. The consequences are soil pollution and population health problems like parasites and intoxication of heavy metals.

Another problem I consider important in horticulture and vegetable production, is the inequality between agricultural land and the environment. In semiarid areas, the production is determined by the arable land and/or resources. The scarcity of water and land creates difficult situation for many small-scale producers or hobby farmers including climate change, increasing demand of production, scarce of economic resources. Small-scale farmers have been developing traditional systems to survive during generations. In other cases, to compensate for the scarcity of land, small producers participate in specialized intensive farming systems, which use synthetic fertilizers and pesticides generating serious imbalance in the environment, such as the depletion of groundwater or eutrophication, and pollution.

My general hypothesis was that we can mitigate the harmful effect of secondary salinization occurs in vegetable production under saline irrigation. The specific hypotheses of my research were as follows:

- Salts getting into the soil by irrigation can be leached with minimizing irrigation and applying soil conditioners.
- The process in the first hypothesis can be quantified by means of lysimeters through the calculation of the salt mass balance.
- The moisture content and the actual electric conductivity (EC_a) of the soil are such variables that are positively correlated and can function as an indicator for secondary salinization.
- The irrigation period is strongly related to the plant cycle (vegetation period) determining the potential to salinization and inversely correlates to the yield.
- CO_2 emission from the soil, hence its microbiological activity, is affected by irrigation with saline water.

The principal aim of my secondary salinization related studies was to understand the dynamics of salt affection in order to adapt mitigation techniques for the long-term sustainability for horticultural production. I intended to propose various methods and analyses to innovate and develop techniques, which are based on the application of microdoses of soil conditioners at sowing or planting time in order to change the physical and chemical properties of soils irrigated with salty water, and at the same time, to create an improved environment for the development of young plants.

The specific aims of my research were as follows:

- To adapt techniques to monitor salinity process to assess salt management.
- To determine the correlation among actual soil EC, soil moisture content, and soil conditioning by developing a new index to quantify the process of secondary salinization.
- To elaborate a new technique of (micro) soil conditioning based on the principle of micro irrigation.
- To study the efficiency of microdose application of soil conditioners comparing them to full dose and compost applications.
- To evaluate the yields of some vegetable crops with different salt tolerance under secondary salinization.
- To reveal and determine the correlation between microbiological activity of the soil and secondary salinization induced by irrigation.

My research work mainly focussed on secondary salinization by irrigation and the application of soil conditioners in order to mitigate its harmful effects. Therefore, I overview the international bibliography according to the following topics relevant to my studies:

- Salt affected soils in the world including primarily and secondarily saline soils
- Saline soils in Hungary
- Secondary salinization including salt content dynamics and salt balance of soils
- Effect and environmental issues of irrigation with saline water
- Soil conditioning including types of soil conditioners
- Effect of soil conditioning on the microbiological activity of the soil

The city of Karcag is in the Great Cumania part of the Middle-Tisza region, which has the most extreme ecological conditions in the Great Hungarian Plain with the highest shortage air- and soil moisture, special pedological, hydrological and geological conditions. For more than 300 years, gardening activities take place in the common's gardens located around Karcag. Is a long tradition for the citizens to grow vegetables and fruits, mainly for their own consumption but also for the local market (ZSEMBELI et al., 2011). Among the pedological factors, the high rate of heavy textured soils containing swelling-shrinking clay minerals. Most of the area is meadow chernozem soil and meadow solonetz. Both soil types can be considered the greatest soils of the region. Due to climate change large amounts of subsurface waters are used for irrigation for vegetables and fruits with high water demand. In previous studies, it was proven that the underground waters in Karcag are not suitable for irrigation (ZSEMBELI et al., 2013). However, both soil types are threatened by secondary salinization (ZSEMBELI et al., 2011). This clandestine irrigation is affecting the environment and can cause secondary salinization. Generally, when the rainfall is below 500 mm. The result of artificial irrigation, is the rise of salt to the surface where salts are deposited in the surface of the soil as a result of evapotranspiration and transpiration (MARTÍNEZ, 2002). In addition is a fact that saline and alkali problems arise even when the drainage facilitates are adequate unless sufficient irrigation water is applied to provide for both crop needs, water consumption and leaching requirements (DONNAN and HOUSTON, 1967).

Soil conditioning is a practice that increases the ability to increase production from crops and horticulture. Any product or material that has specified amount nutrients which is beneficial for soil properties is called soil conditioner. Soil conditioning is defined from GABRIELS et al.

(1981) as a management of the soil to stabilize the soil structure against erosion, salinization, where the root zone has the capability to hold water and nutrients for the plant grow and produce the higher yields. Any soil conditioning has to be related with a physical reclamation. In the salt affected soils, the physical properties of the soil can be remediated with soil loosening. Loosening can be handled by depending on the moisture of the desired depth that is required.

2. MATERIALS AND METHODS

In Karcag, the past 50 years, the temperature average of the air in had been fluctuating. During my research practice, the fluctuation is more extreme, especially summers are hot, when June, July and August are supposed to bring showers during the season (*Fig 1*). In consequence, irrigation is needed to maintain the high production of several crops. Therefore, this research work is dedicated to secondary salinization due to climate change. Nowadays, the rain storms are counted and heavier which damage the crop production due to plant damage, soil erosion and water ponding.

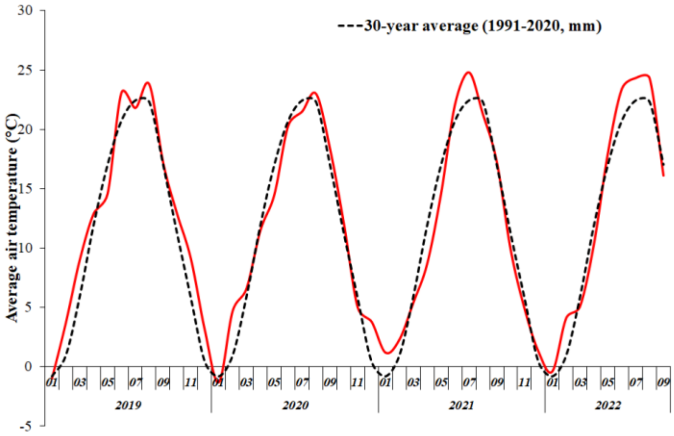

Figure 1. Monthly mean air temperature values during the investigated period compared to the 30-year average data (Karcag, 2019-2022)

In the Research Institute of Karcag, we simulated the circumstances of the vegetable production; therefore, we created the excess of salts in the A-horizon of the soil by means of irrigation with saline well water (coming from the top aquifer). The salt content of the irrigation water we used was around 1,000 mg L^{-1}, which is the double of the upper threshold determined in the regulation as the maximum salt content of waters allowed to use for irrigation in Hungary.

My research included four experiments with irrigation and application of soil conditioners studying their effects on the soil and the indicator crops.

Experiment in simple drainage lysimeters to determine the effects of irrigation with saline water on the salt dynamics of the soil

Lysimeters are effective, versatile tools and very suitable tools for the precise quantification of the processes determining the water- and salt balance of the soil as the elements of the soil water balance and their chemical compositions can be precisely determined. In order to describe the leaching process and determine the salt mass balance of the soil, we investigated 5 simple drainage lysimeters (giving 5 replications *Fig. 2*) irrigated with saline water in the Lysimeter Station of the Research Institute of Karcag in 2019 (ZSEMBELI et al., 2019).

Figure 2. Simple drainage lysimeters dedicated to the study of secondary salinization at the Research Institute of Karcag in June, 2019

In order to understand the salt mass balance, we used Wilcox's (1963) equations were adapted to calculate the relevant amount of the total dissolved salt mass (SM) of the irrigation water (Eq. 1) and the leachate (Eq. 2) from which SB_{TH} was derived (Eq. 3).

$$SM_{IRR} = (V_{IRR} * C_{IRR}) \qquad (1)$$

where SM_{Irr} is the total dissolved salt mass (g), V_{IRR} is the volume (L), and C_{IRR} is the salt concentration (g L^{-1}) in the irrigation water, respectively.

$$SM_{LCH} = (V_{LCH} * C_{LCH}) \qquad (2)$$

where SM_{LCH} is the total dissolved salt mass (g), V_{LCH} is the volume (L), and C_{LCH} is the salt concentration (g L^{-1}) in the leachate, respectively.

$$SB_{TH} = SM_{IRR} – SM_{LCH} \qquad (3)$$

where SB_{TH} is the theoretical salt balance.

If SB_{TH} is equal to zero, neither accumulation nor leaching is taking place in the investigated soil layer.

Preliminary experiment in lysimeters including soil conditioning

The principle of the newly developed technique of micro soil conditioning includes the application of microdoses of soil conditioners. Microdose 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 (*Fig. 3*). 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.

Figure 3. Paper baskets used for the micro soil conditioning experiment in the lysimeters (Karcag, 2019)

Small-plot experiment in the Irrigation Experimental Garden

The experiment is dedicated to carry out monitoring experiments to study the process of secondary salinization by simulating the vegetable production and irrigation being typical in the hobby gardens located in Karcag. As the treatments of the experiment, we applied two biosynthetic and one organic soil amendments in order to study their potential secondary salinization mitigating effect. All of the indicator crops (beans, peas, chilli) 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*.

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

Amendment name and dose	Components	Crops	Degree of tolerance to salinity (Rasool et al. 2012)
Neosol (microdose: 120 kg/ha, standard dose: 200 kg/ha)	Polysaccharides and trace elements (CaO, Ca, MgO, Mg) from algae (Balusson, 2018, Szűcs et al. 2014; 2015)	chilli peas beans	LT NT NT
Physiomax (Microdose: 180 kg/ha, standard dose: 300 kg/ha)	$CaCO_3$ and sulphates as biostimulants (Zsembeli, 2019a,b)	chilli peas beans	LT NT NT
Terrasol biocompost (10 t/ha)	sheep manure 96% + zeolite 2% + mineral phosphate 2% + bacterial culture EM 1) (Monori et al. 2008; Kovács et al., 2013; Tuba et al., 2020)	chilli peas beans	LT NT NT

Legends: LT: low salt tolerance, NT: not salt tolerant

We figured out 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 Pearson's correlation coefficient (PCC) 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. In the case of our study, PCC was calculated for the correlation between EC_a measured with the UMP-1 type mobile probe and the actual volumetric soil moisture content (Θ) measured with SMT-100 soil moisture probe. 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.

In addition, we used a statistic model in order to verify if there is a significance difference in the yields of the three indicator crops grown on the subplots treated with the investigated soil amendments. We used SPSS 27.0.1.0 statistical software to run the one-way analysis of variance (ANOVA) to determine whether there is a statistically significant difference between the yield group means (if the significance value was below 0.05, there was a significant difference). In order to know which of the specific soil conditioning treatment groups differed, I made Multiple Comparison tables containing the results of the LSD post hoc tests.

Pot experiment

This experiment was set in order to evaluate the soil respiration by the CO_2 emission on the soil treated with micro doses of 2 different soil conditioners and 2 irrigation waters with different salt content. I was wondering if the high salt content of the irrigation water has a negative impact on the microbiological activity of the soil, and if yes, it could be mitigated by the application of soil conditioners. Plastic pots (buckets) of 10 L volume were used where each one was filled with 6 kg of soil. 6 treatments and 3 replicates were applied making altogether 18 pots. Two different irrigation waters were used: 1) tap water with 900 mg L^{-1} total soluble salt content, and 2) deionised water as a control of the salt load treatment (*Table 2; Fig. 4*).

Table 2. Treatments of the pot experiment (2022)

Treatment	Soil conditioner	Irrigation water
Physi-1	Physiomax	Tap
Physi-2	Physiomax	Deionised
Neo-1	Neosol	Tap
Neo-2	Neosol	Deionised
Control-1	No	Tap
Control-2	No	Deionised

Figure 4. Measuring with Testo 535 infrared gas analyser

3. NEW CONTRIBUTION TO ACADEMIC KNOWLEDGE

3.1. Salt content dynamics in the topsoil

The dynamics of the EC and the moisture content in the upper soil layer is essential to understand the salinization process. We assumed that the improved soil structure due to soil conditioning results in more intensive leaching of the salts to the deeper layers, hence lower EC_a. The dynamics of EC_a in the upper soil layer (0-10 cm) showed changes during the irrigation period indeed, but differences could be detected at certain points only. The soil EC was found to be dependent on the soil moisture content due to the high salt content of the irrigation water. To corroborate the findings with EC_a, we analysed the salt content of soil treated with the two soil conditioners and the control. We sampled the soil and calculated the actual salt content (m/m%) in the upper layer (*Fig. 5*). Though this measurement did not provide information on the dynamics of soil salt content, we found the differences that were indicated and predicted by the EC_a values more expressed. Based on the results, Explorer could eliminate the accumulation of salts compared with Neosol and the control, hence Explorer is a soil conditioner with the potential to mitigate the harmful effect of secondary salinization under the investigated conditions even in a short term. Long-term effects could not be determined in this experiment, that is why the measurements were extended to the small-plot experiment.

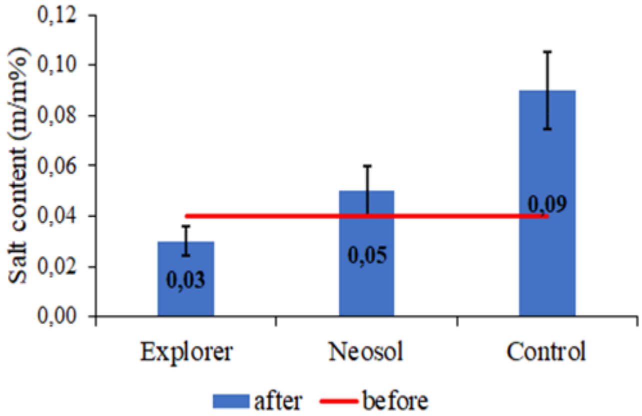

Figure 5. Average actual salt contents of the upper soil layer (0-20 cm) of the lysimeters in the function of soil conditioning before and after the irrigation season (Karcag, 2019)

In fact, secondary salinization was taking place proving that irrigation water was the only source of salt causing higher EC. Therefore, we analysed the data was monitored and analysed. We understand that, 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.

3.2. Assessment of the salt mass balance of the soil

Salt balance and leaching are two basic concepts relating to salinity control that have useful applications to water management in agriculture. The salts move and accumulate in soils largely as a result of movement of water. Measurements of soil water flux and salt movement in soil are difficult to appreciate due to the physical and chemical complexity of most natural soils (BERGSTROM, 1990). The average salt content of the leachate was more concentrated than the irrigation water. Each horizon of the soil columns retained water and salts for a while, and there were slight differences among the lysimeters as replications in the duration of absorbing and retaining the water. We consider the leaching season as the period between the first and last appearance of leachate. The leachate season is very informative in terms of the efficiency of irrigation and the soil moisture profile. The length of the overlap between the irrigation and leachate seasons can indicate if the intensity of irrigation and the hydraulic conductivity of the soil is in harmony or not. The length of the leachate season after the end of the irrigation season is also important showing if there is a chance for the natural precipitation to leach out the harmful salts from the root zone providing good soil status for the next year's crop. The date of the last appearance of leachate (end of the leaching season) is expected to be variable in accordance with the climate change and the increasing frequency of hydrological extremes. The climate conditions have major influence on the rate of processes salt balance.

More detailed information on the process of secondary salinization can be gained by determining the salt profile of the soil column. As theoretical SM and SB calculations do not provide this possibility, the analysis of the soil samples is necessary. In our study, soil samples were taken from three soil layers (0–0.2, 0.2–0.4, 0.4–0.6 m) before and after the irrigation season provided a good opportunity to determine salt profiles. Knowing TSM_{INI} and TSM_{FINAL} of the soil in the three investigated soil layers, we could determine SB_{ACT} for each layer and consequently for the whole 0–0.6 m depth (*Fig. 6*).

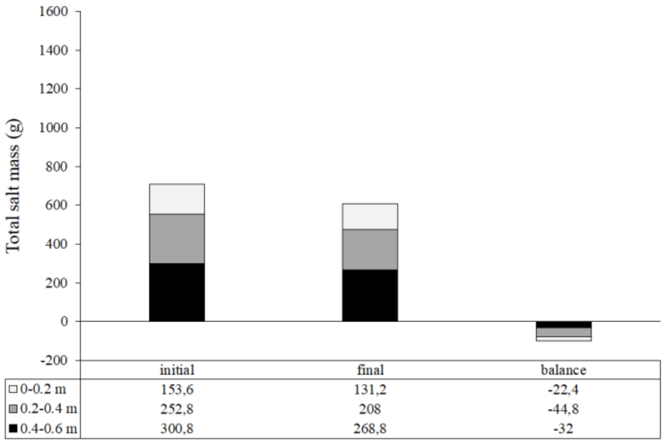

Figure 6. Mean actual salt balance of three soil layers (0–0.6 m depth) of the lysimeters in the irrigation season of 2019

This result reveals that salts can and are supposed to move to the deeper layers within one irrigation period even in the case of such a heavy textured chernozem soil. The nature of this type of soils under semiarid conditions creates swelling-shrinking characteristic, which can change the distribution of pore size. The effect of the wet and dry conditions changes the distribution of moisture and solutes can be rapidly go to deeper layers or stay in upper layers causing salinization (CRESCIMANNO and GAROFALE, 2006).

3.3. Effect of soil conditioning on the salt content of the soil

In the small-plot experiment set on the experiences gained from the lysimeter experiments, three vegetable crops with different salt tolerance and life cycle were rotated between 2020 and 2021. We integrated a complex experiment which involves irrigation with salty water, different doses of soil conditioners and a rotation system. The differences between treatments and soil cultivation techniques had an impact on the soil salt balance, the yields of the indicator crops, and also on the correlation between the soil EC and moisture content of the root zone. I determined the salt profile of the soil of the subplots of the small-plot experiment based on the soil samples taken before (April) and after (October) the irrigation season. Illustrating TSM_{INI} and TSM_{FINAL} of the soil in the three investigated soil layers by means of cumulative column charts shows the salt profiles and we can easily see the differences (changes during the irrigation season) that represent the salt balance for the whole 0.6 m deep soil mass and for each layer in the cases of each subplot with different indicator crops and treatments The salt profiles determined for the subplots covered with beans in 2020 and 2021 are shown in *Fig. 7-9*.

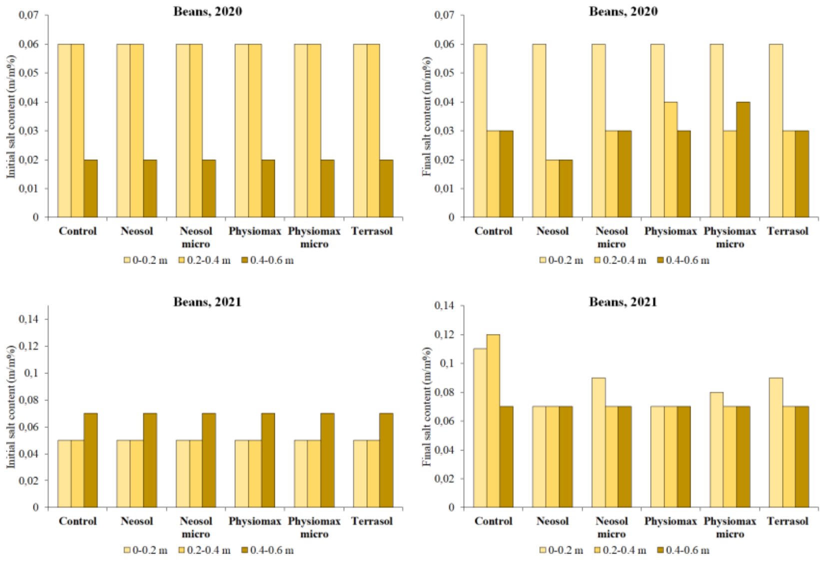

Figure 7. Average actual salt content of three soil layers in the small plots of beans before (left) and after (right) the irrigation seasons of 2020 and 2021

In the first year of the experiment, I did not expect significant effect of soil conditioning in terms of extended leaching in the subplots, but Neosol full application showed promising results in this respect. By the second year of the experiment, we expected more extended effect of soil conditioning in terms of enhanced leaching after the irrigation period. For the whole 0.6 deep soil horizon slightly negative salt balance was characteristic in all the treatments. Neosol full application had the most negative salt balance. In the second year of the experiment, Physiomax and Neosol full applications had the lowest salt balances. For the soil profile deep 0-0.6 m our results described positive balances due to the salt mass movement during the irrigation period (0.01-0.04 m/m%), but Physiomax full application and microdoses showed promising results in this respect. In the second year, there were a positive balance, salt accumulation in the upper layer.

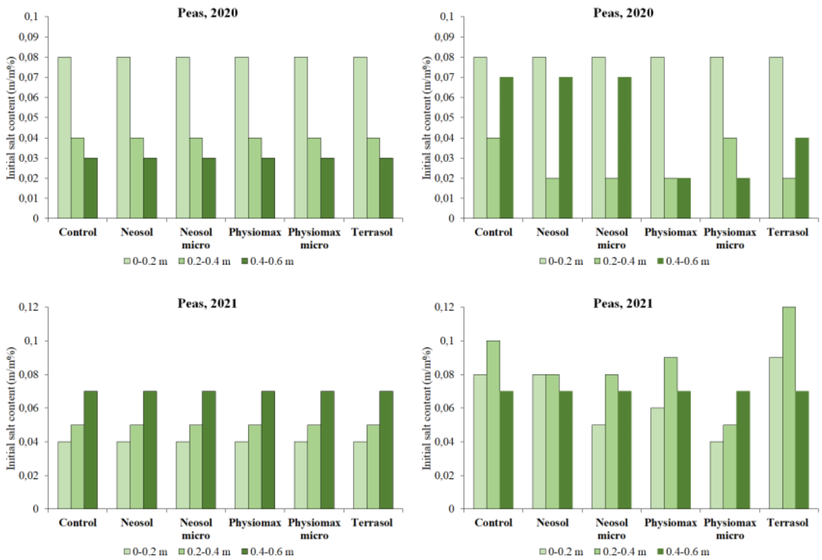

Figure 8. Average actual salt content of three soil layers in the small plots of peas before (left) and after (right) the irrigation seasons of 2020 and 2021

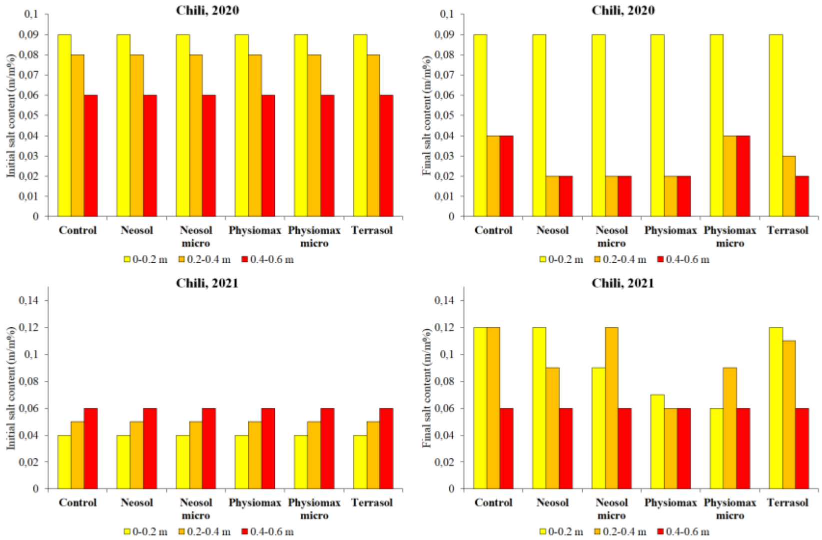

Figure 9. Average actual salt content of three soil layers in the small plots of chili before (left) and after (right) the irrigation seasons of 2020 and 2021

In the first year of the chilli subplots, I recognized in the 0.6 m deep soil layer had negative salt balances for all the treatments. In the second year of the experiment, the upper 0.2 m deep soil layer, described positive balances the salt input by irrigation was even higher than in the first year, while the water inputs were lower. All in all, Physiomax full application had the best salt balance which is a favourable result in this respect.

3.4. Effect of soil conditioning on the yields

In 2019, the yield results were expressive and the differences were in harmony with the soil EC and salt content results in terms of the harmful effect of secondary salinization manifested in yield depressions. *Fig. 10* shows the chili yields in the three lysimeters in the function of soil conditioning. The yields ranged between 741 and 1297 g m^{-2} depending on the treatments, which can be considered normal. The control showed just a slight difference compared with Neosol and bit larger difference with Explorer treatment in the number of chili fruits. Explorer generated the highest yield, while Neosol just a bit higher than the untreated control variant.

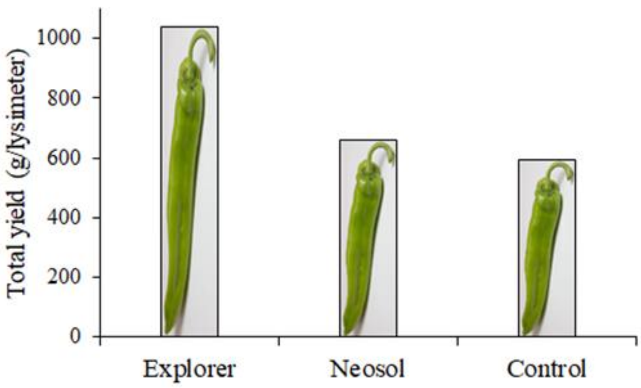

Figure 10. Total yield of chili in one lysimeter in the function of soil conditioning (Karcag, 2019)

In the small plot experiments, it is obvious that the yields of the investigated vegetable crops cannot be compared to one another, partly because of the differences of their genetic 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. I identified an effect in soil salinity and yield production during the rotational crop year showing that salinity accumulation in the root zone can be leached easily in crops with lower irrigation period. In addition, salts were accumulated in the lower layers of the soil profile. In other words, the saline input from the previous crop life cycle can be washed down to lower parts of the root zone by natural leaching. I consider the yield results expressive and the differences are in harmony with the soil EC and salt content results in terms of the harmful effect of secondary salinization manifested in yield depressions.

According to my measurements, the best yield in 2020 was achieved by the micro dose application of Neosol (*Fig. 11*). The other treatments showed no considerable differences, except for Physiomax full dose, which had no positive effect on the yield of peas. Peas have a shallow root depth, probably the micro dose application ensured a closer and faster contact with the conditioner hence a mora favourable environment for the crop resulting in a positive effect on its early development. Soil conditioning was a real competitor of compost application for peas in 2020. The analysis of variance of the yields of 2020 showed strong significant difference between the means of the yield groups (0.00<0.05).

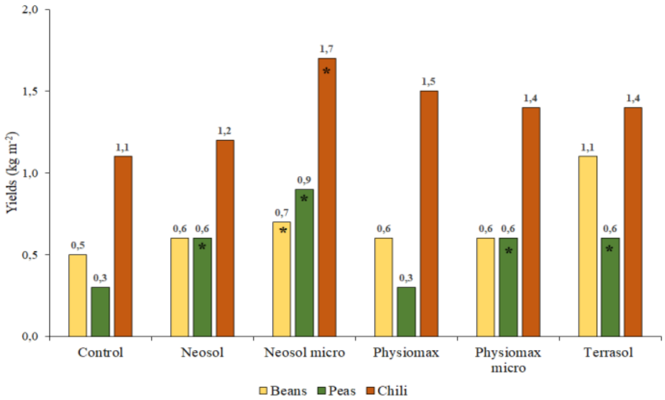

Figure 11. Average yields of the indicator crops in terms of the different soil conditioning treatments in 2020

* *The mean difference compared to the control is significant at 0.05 level*

In the second year (2021), we increased the salt income by irrigation, which projected lower yields due to the effect of extended salt accumulation. Indeed, yields were 50% on average lower (*Fig. 12*). Interestingly and contrary to 2020, the Terrasol treatment resulted in the lowest yield that cannot be explained as a negative effect of compost application. The analysis of variance of the yields showed no significant difference between the means of the yield groups. The post hoc test showed again that if there is no statistically significant difference between the yield groups, only Neosol micro treatment has some positive effect compared to the control. The post hoc test showed statistically significant positive effect of Neosol, Neosol micro, Physiomax micro, and Terrasol treatments compared to the control on the yields in 2020. Neosol micro was significantly better than all the other treatments. Physiomax micro dose application had significantly better effect of the pea yields than its full dose application.

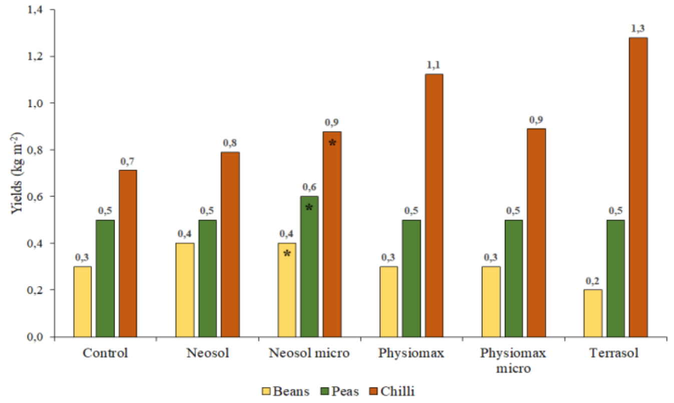

Figure 12. Yields of the indicator crops in terms of the different soil conditioning treatments in 2021

** The mean difference compared to the control is significant at 0.05 level*

The yields of the three indicator crops irrigated with saline water under soil conditioning in 2022 are presented in *Fig. 13*. The third year of the experiment was extremely dry, hence intensive irrigation was essential. The increased amount of irrigation water came together with high salt income, which could project lower yields due to the effect of extended salt accumulation. Nevertheless, bean yields were 0.8-1.8 kg m^{-2} (50% on average) higher than in the previous years. Interestingly and contrary to 2021, the Terrasol treatment resulted in the highest yield which can be explained with the high nutritive effect of compost application when enough water was available for the nutrient uptake. I did not find big differences in the yields in terms of the soil conditioning treatments. Neosol micro dose was not as effective as in the previous years. The analysis of variance of the bean yields of 2022 showed no significant difference between the means of the yield groups (0 >0.05).

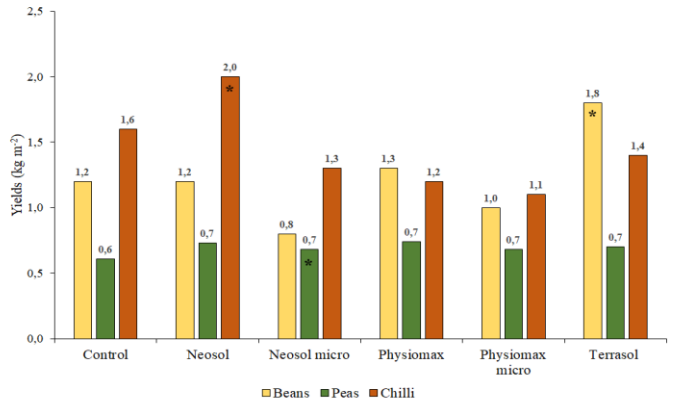

Figure 13. Yields of the indicator crops in terms of the different soil conditioning treatments in 2022

** The mean difference compared to the control is significant at 0.05 level*

3.5. Correlation of moisture content and electric conductivity of the soil with soil conditioning

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 (EC_a). 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 increase adding salts to the root zone. We found a positive correlation between EC_a and soil moisture in the investigated meadow chernozem soil. The PCC values determined by the EC_a and moisture content of the 0-0.1 m soil layer in the function of soil conditioning are illustrated in *Fig. 14-16*. The 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. In order to quantify and evaluate the joint effect of soil moisture content and EC_a, we differentiated 2 types of salt tolerance of the indicator crops: with no salt tolerance (NT), and low salt tolerance (LT).

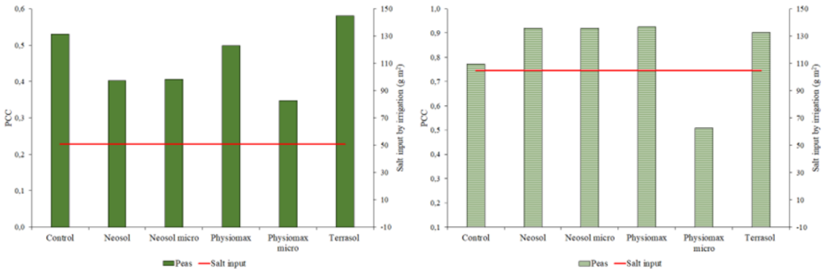

Figure 14. Person's correlation coefficients determined by EC_a and moisture content of the 0-0.1 m soil layer in the function of soil conditioning for peas before (left) and after (right) the irrigation seasons of 2020 and 2021

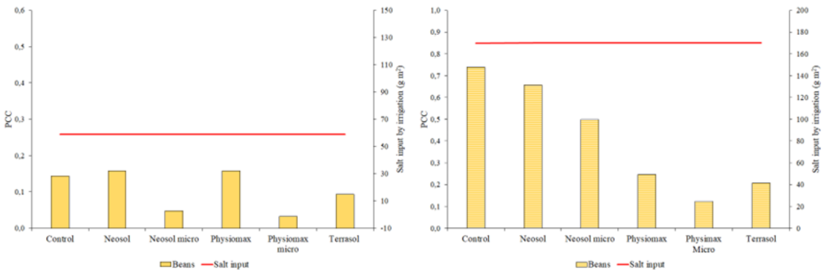

Figure 15. Person's correlation coefficients determined by EC_a and moisture content of the 0-0.1 m soil layer in the function of soil conditioning for beans before (left) and after (right) the irrigation seasons of 2020 and 2021

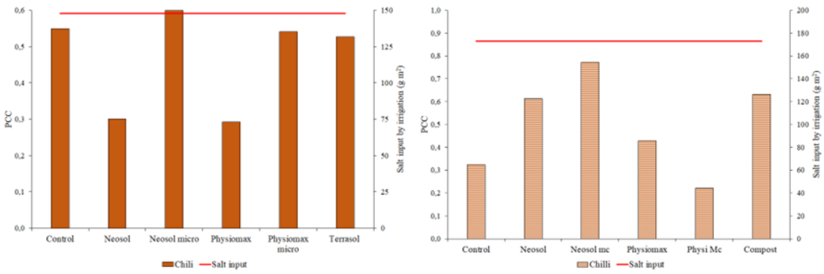

Figure 16. Person's correlation coefficients determined by EC_a and moisture content of the 0-0.1 m soil layer in the function of soil conditioning for chilli before (left) and after (right) the irrigation seasons of 2020 and 2021

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

3.6. Effect of soil conditioning and irrigation with saline water on CO_2 emission from the soil

I found no statistically significant differences among the treatments in both cases (both irrigation waters) indeed (F<F critical). During the phase of the experiment with compost application alone, the results demonstrated that salt concentration of irrigation water and compost ratio had negligible influence on soil respiration. However, following the addition of soil conditioner, a dramatic increase in respiration was recorded with initial spike of chemical reaction and second spike with biological reaction. Just like in that former experiment, the peak in CO_2 emissions were experienced after the treatment with Solactive in both groups of the pots irrigated with tap and deionized water, though the sudden increase was more expressive in the pots with tap water irrigation. Based on this result, it can be supposed that soil bacteria developed in salt affection characteristic to the soils of Karcag find better living conditions if the soil moisture was created by irrigation with saline water than with saltless deionised water. Even though, the research review from RATH and ROUSK (2015) mentioned that the salinity is an important factor for microbial respiration (*Fig 17*). Contrary to our results, the respiration in soils is supposed to negatively correlate with salinity, but microbial respiration is complex and depends on other factors. For example, the C-content or organic material in the soil, because the level of C determinate the size of microbiota. Also common in semiarid ecosystems are calcareous or carbonate-rich soils, and carbonate weathering can be a significant source of CO_2 efflux.

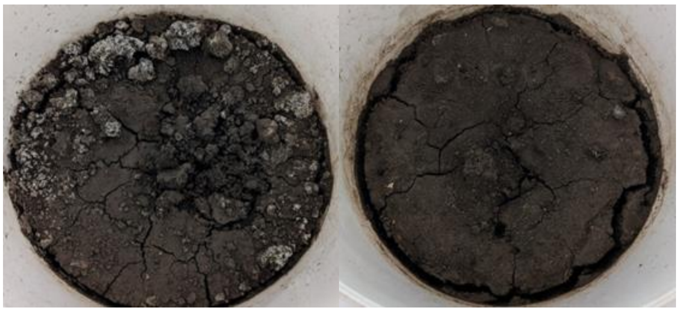

Figure 17. The soil surfaces irrigated with tap water (left) and deionized water (right) in the pot experiment (Karcag, 2022)

It can be concluded that the two investigated soil conditioners had no considerable positive effect on the CO_2 emission from the soil hence its microbiological activity under the given conditions, contrary to Solactive, which was tested at the end of the pot experiment. Nevertheless, higher CO_2 emission values characterized the soil irrigated with saline (tap) water compared to the irrigation with deionized water, but these differences were not statistically significant.

4. CONCLUSIONS

It is known that a high presence of salt-affected soils and the increase of salinity/sodicity with negative outcomes like reduced agricultural yields; salinization of groundwater; biodiversity loss; soil erosion and soil structure degradation due to the removal of vegetation cover can be expected in the coming years. We are conscious about the potential damage of the soil structure, decrease of soil permeability and increase of soil compaction; concentrations of specific ion toxicity; reduced defensive ability of the soil to filter contaminants by surface crusting; increase of osmotic stress and desertification that reduces land value. All these drove the goals of my doctoral project to measure, analyse, compare, design, and innovate the potential mitigation overhead of vegetable production demand under climate change focused on the effect of secondary salinization. Preliminary, based on my research scope, one general hypothesis and five concrete principal hypotheses were determined and tested by means of experiments, measurements and calculations.

The general hypothesis was accepted as we could mitigate the harmful effect of secondary salinization occurring in vegetable production under saline irrigation. We discovered that the salts getting into the soil by irrigation can be leached with minimizing irrigation and applying soil conditioners. The second principal hypothesis that the process of salinization can be quantified by means of lysimeters through the calculation of the salt mass balance could also be accepted, due to the results gained from the monitoring of salt input during one year and the adaptation of calculation to asses salt mass balance in the soil profile. The third principal hypothesis considering that the moisture content and the actual electric conductivity (EC_a) of the soil are such variables that are positively correlated and can function as an indicator for secondary salinization was tested in a small-plot experiment. I used the innovative approach of PCC index for statistical analysis. I concluded that positive PCC values close to 1 indicate a potential salinization, while a negative correlation close to -1 indicates a lack of salts in the investigated soil layer.

My fourth principal hypothesis was that irrigation period is strongly related to the plant cycle (vegetation period) determining the potential to salinization and inversely correlates to the yield. In this case, we used different crops with different salt tolerance levels. Based on the results, I concluded that salty irrigation is an input factor which has a negative correlation with the crop yield hence this hypothesis was accepted. In addition, I proved that soil conditioners can mitigate the harmful effect of salty irrigation depending on the range (amounts) of the added salts. In other words, each soil conditioner has an efficiency depending on the salt input range.

Finally, the fifth principal hypothesis was that soil microbiological activity is negatively affected by irrigation with saline water and it can be quantified by determining the CO_2 emission from the soil, we concluded that CO_2 emission declines in time during the experiment and found no difference among the effect of the soil conditioners.

5. PRACTICAL UTILISATION OF THE RESULTS

The experiences I gained by conducting the experiments dedicated to secondary salinization by irrigation with saline water and the application of soil conditioners for four years of studies are suitable to provide concrete expert advice for hobby gardeners in terms of the recommended doses of micro-dose application of the two investigated soil conditioners that can be directly utilized in the practice. The sowing or planting methods of each vegetable crop were considered during the calculations, namely if the seeds are sown in a row or a nest (e.g., opened with a hoe), or if transplants are planted separately in holes. In the latter case, so called condibags are suggested to be used. A condibag is like a teabag but contains the solid form of the required dose of the given soil conditioner. Condibags can be easily created by using one layer of a piece of paper tissue (*Fig. 16*).

The recommended doses of micro-dose application of the soil conditioners are summarized in *Table 3*. The recommended doses expressed in g m^{-2} were calculated based on the number of plants produced in 1 m^{-2} taking row and plant spacing into account.

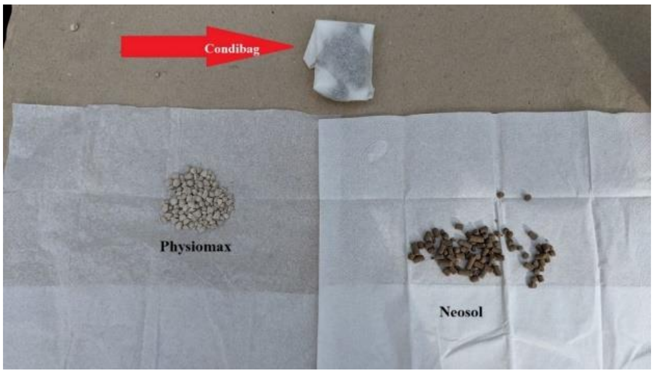

Figure 16. Preparing a condibag for micro soil conditioning

I do not consider my first approach including organic (recycled paper) baskets filled with soil practical enough for the application in the hobby gardens. Nevertheless, the second approach including the distribution of micro doses of soil conditioners in the rows, nests parallel with sowing or the use of condibags at planting time are easy to implement by anyone. Micro soil conditioning based on the principle of micro-irrigation was proven to be useful to reclaim the physical and chemical properties of the soil directly surrounding the roots and has positive effect on the yields as well. Furthermore, this method is economically feasible as its conditioner demand is ~5-10 times lower compared to full dose application.

Table 3. Recommendation for micro-dose application of soil conditioners based on my research

Vegetable crop	Salt tolerance	Full dose recommended by the producers (g m^{-2})		Recommended microdose (g m^{-2})		Type of microdose application
		Neosol	Physiomax	Neosol	Physiomax	
Chilli	Low	20	33	12	20	Condibag
Peas	Non	20	33	12	20	Row
Beans	Non	20	33	12	20	Nest
Tomato*	Moderate	22	33	13	20	Condibag
Carrot*	Low	20	30	12	18	Row
Parsley*	Low	20	30	12	18	Nest
Celery*	Moderate	11	22	7	13	Row
Sweet corn*	Low	33	44	20	26	Row

*based on other experiments carried out in the Irrigation Experimental Garden

Micro soil conditioning is recommended in order to improve the status of salt affected or potentially salt affected soils susceptible for secondary salinization with unfavourable water regime that are characteristic in the hobby gardens near Karcag. I do believe that the harmful effects of irrigation with saline water can be mitigated in a longer term by the application of micro soil conditioning as it has a positive effect on the water and salt regime of the soil, partly by creating a more favourable vertical distribution of the soil water, and partly preserving more moisture in the soil. The main beneficiaries of this method are the gardeners who produce vegetable crops under unfavourable agroecological conditions with irrigation.

Naturally, not only the soil conditioners I used are recommended, any other products are suggested to be tried as soil conditioning, combined with the optimization of irrigation (control of quantity, frequency), can be useful.

Parallel to the application of micro soil conditioning, I also recommend to determine the salt content of the soil before and after the vegetation period by a simple EC meter or a laboratory analysis. Furthermore, if it is also possible, I also recommend to regularly monitor the salt content of the soil and the irrigation water, the actual soil moisture content of the root zone during the vegetation period. I think, that can be expected from the farmers of the 21st century.

All these can ensure a sustainable vegetable production in areas with unfavourable agroecological conditions as the safety of crop production and soil health can be maintained or even increased.

6. NEW SCIENTIFIC RESULTS

1. By means of lysimeters through the calculation of the salt mass balance, I established that more salts getting into the soil by irrigation with saline (~1,000 mg L^{-1} total soluble salt content) water can be leached with applying soil conditioners even in the heavy textured soils characteristic to the gardens around Karcag. The application of Explorer resulted in a negative (-0.01 m/m%), while Neosol just a slightly positive (+0.01 m/m%) salt balance in the upper 0.2 m soil layer during one irrigation period, making soil conditioning recommendable compared to the untreated control with negative (-0.05 m/m%) salt balance.
2. I elaborated a new technique of (micro) soil conditioning based on the principle of micro irrigation involving three different methods of its application with 40% lower dosage (12-20 g m^{-2} instead of 20-33 g m^{-2}) accommodating to different vegetable crops.
3. Based on the well-known correlation between the moisture content and the actual electric conductivity (EC_a) of the soil and involving the effect of soil conditioning, I developed a new index (PCC) that can function as an indicator for secondary salinization.
4. I figured out that microdose application of soil conditioners can be as effective as their full dose applications in terms of yields. Full dose application increased bean, pea, and chilli yields with 13%, 24%, and 24%, while microdose application with 7%, 55%, and 15% compared to the untreated controls, respectively.
5. I quantified the relationship between salt input by irrigation and the salt content of the soil with and without soil conditioning. I found no salt accumulation mitigation effect of soil conditioning for the 0–0.2 m and 0.4–0.6 m soil layers. In the 0.2–0.4 m soil layer, full dose application resulted in 50%, while micro doses 30% salt accumulation mitigation for both soil conditioners under study.
6. I established that CO_2 emission from the soil, hence its microbiological activity, was 50% higher (0.087 g m^{-2} h^{-1}) when irrigated with saline water compared to deionized water (0.058 g m^{-2} h^{-1}), but it was not influenced by soil conditioning.

REFERENCES

Balusson, H.: 2018. The power of algae, serving the planet. Disponible online: https://www.olmix.com/sites/default/files/brochure.olmix_group.corporate.en.pdf

Bergstrom, L.: 1990. Use of Lysimeters to Estimate Leaching of Pesticides in Agricultural Soils. *Environmental pollution*. 61: 325-347. *Birkás, M.*: 2008. Environmentally-Sound Adaptable Tillage. Akadémia Kiadó, Budapest. 354p.

Crescimanno, G. – Garofale, P.: 2006. Management of Irrigation with Saline Water in Cracking Clay Soils. *Soil Science of America*. 1774-1787.

Donnan, W.W., – Houston, C. E.: 1967. Drainage related to irrigation management. Amer. *Soc. Agron*. 11: 974-987.

FAO: 2017. Salt affected soils. FAO soil portal. Disponible In: http://www.fao.org/soils-portal/soil-management/management-of-some-problem-soils/salt-affected-soils/more-information-on-salt-affected-soils/en/

Gabriels, D., – Maene, L. – Lenvain, J. – De Boodt, M.: 1981. Possibilities of using soil conditioners for soil erosion control. [In D.J. Greenland and R. Lal (eds.)], Soil Conservation and Management in the Humid Tropics. Wiley, Chichester, pp. 99–108.

Kovács, Gy. – Tuba, G.– Czimbalmos, R. – Csízi, I.: 2013. Effect of different compost doses on some properties of an extensive grassland soil. *Research Journal of Agricultural Science* (45) 2 157-165.

Lambert, K. – Sedema, I. – Karim, S.: 2002. Irrigation and salinity: a perspective review of the salinity hazards of irrigation development in the arid zone. *Irrigation and Drainage Systems*. 16: 161–174.

Martínez, G.M.: 2002. El cultivo de chile guajillo con fertirrigación en el Altiplano de San Luis Potosí. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, Instituto Nacional de Investigaciones, Forestales, Agricolas y Pecuarias. Campo Experimental Palma de la Cruz. San Luis, Potosí, México. 11.

Monori, I. – Blaskó, L. – Zsigrai, Gy. – Biró, B.: 2008. TERRASOL compost from sheep manure. [In: *Koutev, V.* (Ed./Eds.) Potential for simple technology solutions in organic manure management.] 13th RAMIRAN International Conference. 2008. 06. 28–30. Albena. Bulgaria. 421–424.

Rath, M., – Rousk, J.: 2015. Salt effects on the soil microbial decomposer community and their role in organic carbon cycling: A review. *Soil Biology & Biochemistry*. 81. 108-123*Rengasamy, P.*:2006 World salinization with emphasis on Australia. Journal of *Experimental Botany*, 57: 1017–1023.

Smith, P. – Cotrufo, M.F. – Rumpel, C. – Paustian, K. – Kuikman, P.J. – Elliott, J.A. – Mcdowell, R. – Griffiths, R.I. – Asakawa, S. – Bustamante, M. – House, J.I. – Sobocká, J. – Harper, R. –Pan, G. – West, P.C. – Gerber, J.S. – Clark, J.M. – Adhya, T. – Scholes, R.J. – Scholes, M.C.: 2015. Biogeochemical cycles and biodiversity as key drivers of ecosystem services provided by soils. *Soil*. 665-685

Szűcs, L. – Tuba, G. – Juhász, Cs. – Zsembeli, J.: 2014. Effect of Prp-Sol soil conditioner on a heavy textured soil. *Növénytermelés.* 63: 213-216.

Szűcs, L. – Tuba, G. – Zsembeli, J.: 2015. Talajkondicionáló szerek hatásvizsgálata nagy agyagtartalmú talajon. Agrártudományi Közlemények. *Acta Agraria Debreceniensis.* 63: 137-141.

Tuba, G. – Kovács, Gy. – Rivera-García, A. – Zsembeli, J.: 2020. Examination of the effect of two compost products on the penetration resistance of the soil in reduced tillage. [In: *Jobbágy, J.; Koloman, K.* (Ed./Eds.)]. Technoforum.: 2020: New Trends in Machinery and Technologies for Biosystems. Scientific Papers Slovenská Polnohospodárska Univerzita v Nitre, pp. 152-159.

Wilcox, L.V.: 1963. Salt Balance and Leaching Requirement in Irrigated Lands. Technical Bulletin No. 1290.

Zsembeli, J. – Kovács, Gy. – Szűcs, L. – Tóth, J.: 2013. Examination of secondary salinization in simple drainage lysimeters. *Gumpensteiner Lysimetertagung*. 153–156.

Zsembeli, J. – Rivera-García, A. – Zsembeli, Zs. – Kovács, Gy. – Czellér, K. – Tuba, G.: 2019b. Examination of the effect of soil conditioning on the microbiological activity of three different soil types in a pot experiment. [In: *Makádi, M.* (Ed./Eds.)] LOTEX 2019: 2nd Conference on Long-term Field Experiments: book of proceedings Nyíregyháza, Magyarország. University of Debrecen. pp. 39-44.

Zsembeli, J. – Sinka, L. – Rivera-García, A. – Czellér, K. – Tuba, G. – Koloman, K. – Findura, P.: 2019a. Effect of Soil Conditioning on the Moisture Content and the Salt Profile of the Soil Under Irrigation with Saline Water, Agriculture (*Pol'nohospodarstvo*), 65(2), 77–87. doi: https://doi.org/10.2478/agri-2019-000

Zsembeli, J. – Szűcs, L. – Blaskó, L.: 2011. Secondary salinization by irrigation from drilled wells in Karcag area. 10th Alps-Adria Scientific Work.

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List of publications related to the dissertation

Hungarian book chapters (4)

1. Kovács, G., Tuba, G., Sinka, L., Nagy, P., **Rivera, G. A.**, Zsembeli, J.: A klímaváltozás lokális hatásainak értékelése a szélsőséges időjárási helyezetek tükrében.
   In: 75 éves a Karcagi Kutatóintézet 1947-2022. Szerk.: Zsembeli József, Magyar Agrár és Élettudományi Egyetem, Gödöllő, 27-35, 2022. ISBN: 9789636230135
2. Zsembeli, J., Kovács, G., Sinka, L., **Rivera, G. A.**, Nagy, P., Tuba, G.: A liziméteres mérések kiterjesztése a másodlagos szikesedés kutatásában.
   In: 75 éves a Karcagi Kutatóintézet 1947-2022. Szerk.: Zsembeli József, Magyar Agrár és Élettudományi Egyetem, Gödöllő, 59-72, 2022. ISBN: 9789636230135
3. Sinka, L., Nagy, P., Kovács, G., Tuba, G., **Rivera, G. A.**, Zsembeli, J.: A másodlagos szikesedés okozta növényi stressz mérséklési lehetőségei.
   In: 75 éves a Karcagi Kutatóintézet 1947-2022. Szerk.: Zsembeli József, Magyar Agrár és Élettudományi Egyetem, Gödöllő, 37-46, 2022. ISBN: 9789636230135
4. Zsembeli, J., Kovács, G., Sinka, L., **Rivera, G. A.**, Tuba, G.: Talajjavító és talajkondicionáló szerek vizsgálata tenyészedényes kísérletben.
   In: A talajtan és a kapcsolódó tudományok időszerű kérdései : Kátai János professzor 70. születésnapja tiszteletére. Szerk.: Balláné Kovács Andrea, Tállai Magdolna, Kocsisné Demjén Ágnes, Debreceni Egyetem Mezőgazdaság-, Élelmiszertudományi és Környezetgazdálkodási Kar, Debrecen, 306-311, 2021. ISBN: 9789633189368

Foreign language Hungarian book chapters (1)

5. **Rivera, G. A.**, Nagy, P., Tuba, G., Kovács, G., Sinka, L., Zsembeli, J.: Effect of soil conditioning on the yields of three vegetable crops under irrigation with salty water.
   In: 75 éves a Karcagi Kutatóintézet 1947-2022. Szerk.: Zsembeli József, Magyar Agrár és Élettudományi Egyetem, Gödöllő, 47-57, 2022. ISBN: 9789636230135

<u>Hungarian scientific articles in Hungarian journals</u> (1)

6. Kovács, G., Tuba, G., Sinka, L., **Rivera, G. A.**, Zsembeli, J.: Jász-Nagykun Szolnok megye főbb növényeinek termésátlagai az aszály mértékének függvényében.
Növénytermelés. 71 (2), 63-78, 2022. ISSN: 0546-8191.

<u>Foreign language scientific articles in Hungarian journals</u> (4)

7. **Rivera, G. A.**, Tuba, G., Kovács, G., Sinka, L., Zsembeli, J.: Correlation of secondary salinization and soil conditioning in vegetable production under irrigation with saline water.
Columella. 9 (22), 35-46, 2022. ISSN: 2064-7816.
DOI: https://doi.org/10.18380/SZIE.COLUM.2022.9.2.35

8. Nyaboke, C., Tuba, G., Kovács, G., Sinka, L., Nagy, P., **Rivera, G. A.**, Zsembeli, J.: Environmental and economic consciousness of the farmers of Jász-Nagykun-Szolnok county in soil management based on tala method.
Hung. Agric. Res. 31 (3-4), 12-15, 2021. ISSN: 1216-4526.

9. **Rivera, G. A.**, Tuba, G., Kovács, G., Sinka, L., Zsembeli, J.: Methodology adaptation and development to assess salt content dynamics and salt balance of soils under secondary salinization.
Agrártud. Közl. 1, 199-206, 2021. ISSN: 1587-1282.
DOI: http://dx.doi.org/10.34101/actaagrar/1/8326

10. **Rivera, G. A.**, Tuba, G., Czellér, K., Kovács, G., Zsembeli, J.: Mitigation of the effect of secondary salinization by micro soil conditioning.
Agrártud. Közl. 1, 115-119, 2020. ISSN: 1587-1282.
DOI: http://dx.doi.org/10.34101/actaagrar/1/3720

<u>Foreign language scientific articles in international journals</u> (2)

11. Tuba, G., Kovács, G., Sinka, L., Nagy, P., **Rivera, G. A.**, Bajusová, Z., Findura, P., Zsembeli, J.: Effect of Soil Conditioning on Soil Penetration Resistance and Traction Power Demand of Ploughing.
Agriculture. 67 (3), 113-123, 2021. ISSN: 0551-3677.
DOI: http://dx.doi.org/10.2478/agri-2021-0011

12. Zsembeli, J., Sinka, L., **Rivera, G. A.**, Czellér, K., Tuba, G., Krištof, K., Findura, P.: Effect of Soil Conditioning on the Moisture Content and the Salt Profile of the Soil Under Irrigation with Saline Water.
Agriculture (Poľnohospodárstvo). 65 (2), 77-87, 2019. ISSN: 0551-3677.
DOI: http://dx.doi.org/10.2478/agri-2019-0008

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Foreign language conference proceedings (3)

13. Zsembeli, J., **Rivera, G. A.**, Zsembeli, Z., Kovács, G., Czellér, K., Tuba, G.: Examination of the effect of soil conditioning on the microbiological activity of three different soil types in a pot experiment.
    In: 2nd Conference on Long-Term Field Experiments on the 90th anniversary of Westsik's experiment : proceedings book. Ed.: Makádi Marianna, Debreceni Egyetem AKIT Nyíregyházi Kutatóintézet, Nyíregyháza, 39-44, 2019. ISBN: 9789634901488

14. Sinka, L., **Rivera, G. A.**, Tuba, G., Zsembeli, J.: Mitigation of salt stress caused by secondary salinization.
    In: XX. stiavnické dni 2019: Zborník recenzovanych príspevkov. Ed.: Bianka Horváthová, Veronika Siliková, Univesita Komenského v Bratislave, Brastislava, 254-262, 2019. ISBN: 9788022347952

15. Sinka, L., **Rivera, G. A.**, Czellér, K., Tuba, G., Zsembeli, J.: Simulation of the irrigation practice applied in the hobby gardens of Karcag in simple drainage lysimeters.
    In: Lysimeter - a perfect tool for quantifying fluxes of water, nutrients and pollutants. Hrsg.: Brigitte Marold, Höhere Bundeslehr- und Forschungsanstalt für Landwirtschaft, Raumberg-Gumpenstein, 171-174, 2019. ISBN: 9783902849649

List of other publications

Hungarian book chapters (1)

16. Tuba, G., Nagy, P., Kovács, G., Sinka, L., **Rivera, G. A.**, Zsembeli, J.: A redukált talajművelési rendszer alkalmazása a Nagykunság kötött talajain.
    In: 75 éves a Karcagi Kutatóintézet 1947-2022. Szerk.: Zsembeli József, Magyar Agrár és Élettudományi Egyetem, Gödöllő, 17-25, 2022. ISBN: 9789636230135

Hungarian scientific articles in Hungarian journals (1)

17. Tuba, G., Kovács, G., **Rivera, G. A.**, Zsembeli, J.: Különböző komposztkészítmények hatása a talaj penetrációs ellenállására.
    Növénytermelés. 69 (2), 99-115, 2020. ISSN: 0546-8191.

Foreign language scientific articles in Hungarian journals (1)

18. Gebreyesus, M., **Rivera, G. A.**, Tuba, G., Kovács, G., Sinka, L., Zsembeli, J.: Climatic water balance in Hamelmalo, Eritrea.
    Agrártud. közl. 1, 69-76, 2021. ISSN: 1587-1282.
    DOI: http://dx.doi.org/10.34101/actaagrar/1/8307

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19. Tuba, G., Kiss, J., **Rivera, G. A.**, Czellér, K., Kovács, G., Zsembeli, J.: A fák és a köztesnövény vízfelhasználási konkurenciájának vizsgálata egy agrárerdészeti rendszer első évében. In: XXI. századi vízgazdálkodás a tudományok metszéspontjában : II. Víztudományi Nemzetközi Konferencia. Szerk.: Jakab Gusztáv, Csengeri Erzsébet, Szent István Egyetem Agrár- és Gazdaságtudományi Kar, Szarvas, 219-224, 2019. ISBN: 9789632698083

Foreign language conference proceedings (2)

20. Zsembeli, J., Sinka, L., Tuba, G., **Rivera, G. A.**, Kovács, G.: Water use of lawns determined in weighing lysimeters. In: Lysimeter und Bodenwasserhaushalt: Trockenheit - Bewässerung - Ertragssicherheit / Brigitte Marold, Höhere Bundeslehr- und Forschungsanstalt für Landwirtschaft, Raumberg-Gumpenstein, 133-138, 2021. ISBN: 9783902849830

21. Tuba, G., Kovács, G., **Rivera, G. A.**, Zsembeli, J.: Examination of the effect of two compost products on the penetration resistance of the soil in reduced tillage. In: New Trends in Machinery and Technologies for Biosystems. Ed.: Ján Jobbágy, Koloman Kristof, Slovenská polnohospodárska univerzita v Nitre, Nitra, 152-159, 2020. ISBN: 9788055221663

Foreign language abstracts (1)

22. Sinka, L., Takácsné Hájos, M., Kovács, G., Tuba, G., **Rivera, G. A.**, Zsembeli, J.: Assessment of 1-triacontanol treatment of sweetcorn (zea mays l. convar. saccharata) aiming its salt tolerance improvement on the base of a pot experiment. *Acta Biologica Marisiensi. 4* (Suppl.), 19, 2021. ISSN: 2601-6141.

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