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**MITIGATION OF THE EFFECT OF SECONDARY  
SALINIZATION BY ‘MICRO SOIL CONDITIONING’**

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

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# 1. INTRODUCTION

## 1.1. Justification of the study

In the world, more than 100 countries are affected by salinization. Salinization is covering 932.2 million hectares in the globe, but the general sensitivity is focused on arid and semi-arid regions (RENGASAMY, 2006). 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 (RENGASAMY, 2006; 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. It is known that any human activity has an impact on the environment. Intensive agricultural management is one of the causes of soil and water pollution. 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.

Secondary salinization is induced by human activities like the development of large-scale irrigation projects. These projects around the world affect the environmental conditions like 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). These projects involve building of large reservoirs, changing course of rivers, and the irrigation of large landscapes. The effects are large changes in the salt balances of the entire hydro-geological systems (DALIAKOPOULOS et al., 2016).

In almost all agricultural soils, the particles have negative electrical charges at their surface hence they take up (pull in and grip) cations. The most important cations in agricultural soils are sodium, calcium, and magnesium. Magnesium and calcium have a favourable effect in plants and are the principal cations in a normal productive soil.

However, if productive soils are irrigated with salty water coming from groundwaters or waste water rich in sodium, the soil usually adsorbs sodium instead of adsorbing calcium and magnesium. This process is called secondary salinization (BOWER, 1959). In fact, the main cause of secondary salinization is the irrigation practice often connected with pitiable drain conditions (GHASSEMI et al., 1991). However, this type of salinization is restricted to irrigation in the semiarid zone, generally when the rainfall is below 700 mm, and about 110 million ha is located in this zone (GEESON et al., 2003). The impact of irrigation often extends beyond of the immediate irrigated area. Furthermore, the cases of secondary salinization are spread all around the world and each case is different (SMEDEMA, 2000).

For the prevention of secondary salinization, it is a necessity to study on the chemical and physical soil properties. However, with the improvement of the discipline of soil science, the terminology and concept of soil amendments and conditioners were categorized in physical and chemical conditioning. The use of chemical amendments and conditioners has been the part of the agricultural practice. The most of the well-known amendments and conditioners are green manure, peat, crop residues, organic compost and mineral materials such as inorganic phosphate, calcium sulphate, coal dust, rock flour (SOJKA et al., 2007).

There are many ways in which agriculture has an impact on the environment (FAO Soil Portal, 2017). Mostly the mismanagement of fertilization, plant protection and irrigation affect the natural cycles and potentially is a risk for human health. In this study, we focused on salinization of soils, which is one of the most widespread phenomena affecting agricultural activity (RENGASAMY, 2006). Salinity could be considered by primary salinization and secondary salinization. I choose secondary salinization as the topic of my research, because salinity affects the nature in plenty of countries and properties with a variety of extents. Over 10% of the total irrigated land is estimated to be affected by salinity (LAMBERT et al., 2002). Especially, arid and semi-arid regions (like my home country, Mexico as well as Hungary, where I studied and did research) are more sensitive to develop salinity problems. In addition, much of the food we consume and the trend for vegetable-based food in the future can lead to mismanaged irrigation. Watering of crops is one of the major soil degradation causes in the majority of the sub-developed countries, where water is in a polemic and critical situation. In many cities, untreated water coming

from urban areas is used for agricultural irrigation means the only solution. Consequently, public health and soils can be affected by diseases and pollution.

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.

Nowadays, small-scale farmers around the world promote more diversified models in order to reduce the use of chemical inputs. These changes in agricultural systems generally require important investments in knowledge and also material investments (IFAD and UNEP, 2013). Agriculture in the European Union (EU) is protected and subsidized. The food production and research in agriculture is indispensable for the adaptation and the challenges of climate change and globalization. Since the main goal of the United Nations is to minimize hunger, there is an incentive to produce cheap and nutritional food. The idea to remediate hunger and malnutrition around the world from the past years became into the green revolution and the GMO massive production like a technological innovation to solve nowadays problems. Human population has been increasing and also the demand of certain products due to globalization. In consequence, big industries and organizations had developed strategies of food chain and nowadays changed to a vegetarian tendency. Due to this tendency, small-scale farmers and horticultural producers have the potential to increase their enterprise and yields adapting technology to climate change and make a parallel progress in all the food chain with the implementation of local producers and rural development.

Before I came to Hungary, my academic carrier started with studies at biology in order to understand the classification of nature, the big cycles of the earth, and the microscopic world. Later on, during my studies, I focused on the environmental issues of agriculture,

which gave me a perspective of human consumption and the values and concepts that the EU have been made for international interest. Hungary, as a developed and subsidized agricultural country of the EU, has the opportunity and the potential to make high level theoretical and practical research. During my master studies, I had the opportunity to join a research project carried out by the Research Institute of Karcag (RIK), which is a regional research institute dealing mainly with plant breeding, soil cultivation and reclamation, water management including irrigation and lysimeter studies, sheep breeding and grassland management. RIK also shares its innovative technologies and knowledge to farmers and hobby gardeners around the Trans-Tisza region. The research project I was involved aims to mitigate the effect of secondary salinization (which is a considerable issue in Hungary) and develop innovative soil cultivation techniques which can be useful for agriculture including vegetable production in the semiarid regions of Hungary.

During the first phase of my research work, I mainly focussed on the relationship between soil and water, naturally with indicator crops that are grown in Karcag area. In this study, I had understood the soil cultivation techniques, the different types of irrigation and lysimeters, also, I utilized different probes to measure the variants which were involved in the salinization process. I recognized the effect of soil conditioners on various soil properties and the leaching process as the effect of irrigation. By continuing previous studies, we categorized the soil moisture profile, we analysed soil and the leachate samples originating from simple drainage lysimeters. Later, our results gave us the idea to calculate the salt mass balance using the leachate and soil samples data. Based on the achievements gained from the lysimeter studies, the Experimental Irrigation Garden (IEG) was created in RIK. IEG provides a great opportunity to study the effect of salinization on the soil and crops in various small-plot experiments with exact and well-defined circumstances.

In the small-plot experiment dedicated to my research, the approach was to grow vegetables under secondary salinization using different soil reclamation techniques and new generation of soil conditioners. The practical soundness of this research was ensured by simulating the vegetable production, soil management and irrigation habits and conditions characteristic in the gardens popular around Karcag used. In order to analyse the correlation between salinity and soil moisture content in the top soil, I took both

precipitation and irrigation with salty water into consideration. This approach uses their correlation to estimate the potential salinization of each treatment and each crop with various (relevant to the particular crop) soil conditioning techniques. The crops were grown in a crop rotation sown after each other. A new measurement was also introduced by means of a probe determining the electric conductivity (EC) of the soil without disturbing the soil in the root zone.

As the main result of my research project, I present new scientific approaches that innovate and clarify the study of secondary salinization taking place under the studied conditions. The fulfilment of this research programme gave me the opportunity to exploit the interaction of the salinity process and supported my aims and ideas to develop sustainable practices for a healthy environment involving nature protection by the mitigation of soil degradation induced by agricultural practices.

## **1.2. Research hypotheses**

The 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.

### 1.3. Research aims

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. During my studies, I understood the genesis of salt affected soils, I had the task to search for the geological aspects and the land use of Hungary, especially in the Great Hungarian Plain. Also, I focused on irrigation and plant nutrition, crop evapotranspiration, dual crop coefficient under soil water stress conditions. Regarding plant nutrition, I focused on the chemical composition of plants, plant nutrients and their classification, nutrient uptake, visible deficiency symptoms of plant nutrients and nutrient balance. These studies gave me the idea to use micro-conditioning in a lysimeter environment, then in the field using vegetable crops in rotation. I regularly monitored the electric conductivity of waters ( $EC_w$ ), the actual electric conductivity of the soil (and  $EC_a$ ), and the electric conductivity of the saturation extract ( $EC_e$ ) in order to follow the chemical (and indirectly the physical) changes in the root zone. For these experiments, we used new generation of soil amendments and organic material added into the upper soil layer. As a part of this research, the quantification of soil salt content dynamics and salt balance were the goals of this study by adapting and developing methods to the specific agroecological conditions under study.

Another aim of this research was to meet the customization of agriculture facing risks to develop secondary salinization by irrigation with waters that legally are not suitable for irrigation. 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.

## **2. BIBLIOGRAPHY OVERVIEW**

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

### **2.1. Salt affected soils in the world**

Most of salt-affected lands are located in arid and semi-arid zones of the world, the majority of countries affected by salinity being in a broad belt extending from the sub-Saharan Africa through the Middle East and into Central Asia.

Worldwide around 4 million square kilometres of land has been affected by primary (natural) salinization to various degrees and at least half of world's countries have some quantity of land affected by salinity (CORBISHLEY and PEARCE, 2007). In addition to natural salinization, it is estimated that more than 75 million hectares of land is affected by human-induced salinization of which more than 50% occurs in irrigation landscapes. Salinization already affected crop productivity in 20–30% of irrigated lands with an additional 1.5 million hectares affected yearly.

#### **2.1.1. Primary soil salinization**

Primary salinization occurs in arid and semi-arid climatic zones and is an abiotic process, which is related to physical and chemical weathering effects from parent material transported by wind and water and deposited into the ground. In fact, is a natural process,

which accumulate salts and transport it (DALIAKOPOULOS et al., 2016). One of the processes is the seawater intrusion, where the salts diluted in the water can be transported and deposited in large quantities into land (HERNANDEZ-LARA, 2000). Close to the shore, soil salinization also is produced by precipitation and aeolian effect. Wind and rain could transport an amount of 100–200 kg/ha/yr meanwhile in areas far inland it may still be about 10–20 kg/ha/yr (SMEDEMA, 2000). In land salt is accumulated in the landscape by rain, even if it contains low amounts of salt, it is deposit by time. However, weathering of the mother rock carry out salts in water, which are transported and deposited in carbonate minerals and/or feldspar in to the soil. Other geological events or specific water formations can affect groundwater and soil salinity (CHARI et al., 2012; HERNANDEZ-LARA, 2000; GEESON et al., 2003; RENGASAMY, 2006).

Other source of primary salinization, what GHASSEMI et al., (1991) has been called non-groundwater-associated salinity, which materials from surface waters are sources of salt deposit by a poor drainage and the water table is deep. The poor hydraulic properties of shallow layers can lead to the accumulation of salts in the topsoil and subsoil layers affecting agricultural productivity (RENGASAMY, 2006; GEESON et al., 2003). In addition, the relation between water table depth and evaporation rate from bare soil is important in arid and semi-arid areas, as a result, the surface layers continuously accumulate salts (CHARI et al., 2012; GEESON et al., 2003).

The groundwater-associated salinity RENGASAMY (2006) and GHASSEMI et al., (1991) explained that the water table in the landscape is close to the soil surface and allow a maximum rate of water movement through the surface layers. The water from groundwater rise to the soil surface bringing the salts dissolved in it to the root zone. The driving force for upward movement of water and salts is evaporation from the soil plus plant transpiration.

### **2.1.2. Secondary salinization**

Secondary salinization is the introduction of salts by human activities by the development of irrigation projects (LAMBERT et al., 2002). The secondary salinity stress affects 7% of the world's total land area. One of the consequences that involves rivers, reservoirs and large-scale irrigation is the losses in yields, meaning in billion-dollar extra cost

around the globe (SHABALA and CUIN, 2008). The entire hydrogeological cycle systems are affected and changes the natural water and salt balances (DALIAKOPOULOS et al., 2016). In fact, irrigation and poor drainage conditions are the main reason that cause secondary salinization (GHASSEMI et al., 1991). However, this type of salinization is restricted to irrigation in the semiarid zone, generally in areas where the rainfall is below 700 mm. About 110 million ha is located in this semiarid zone (GEESON et al., 2003). The impact of irrigation often extends beyond of the immediate irrigated area. Furthermore, the cases of secondary salinization are spread all around the world and each case is different (SMEDEMA, 2000). Different circumstances can cause secondary salinization like; irrigation with salty water; rising the water table of saline aquifers; clear the land of native vegetation; leaching and discharge of industrial salts or waste water into the river system.

### **2.1.3. Saline soils in Hungary**

Hungary has a farming economy but is overwhelmed by severe difficulties of soil and wetland salinization (MÁDL-SZŐNYI and TÓTH, 2009). The 13% percent of the land is considered to be salt-affected due to the conditions from the Pleistocene Era, primary salinization. These Pleistocene sediments have been influenced the shallow fluctuation, saline-sodic groundwaters, and temporary waterlogging (TÓTH, 2011). In this country naturally exist saline and sodic soils. However, the principal source of soil salinization is the shallow groundwater level below the lowland surface. The second scenario are related to waterlogging, which rise the saline ground water (groundwater-associated salinity). The other common scenario is when saline ground water is pumped from a tube well and used for irrigation (salinization from above) (MÁDL-SZŐNYI and TÓTH, 2009). Nevertheless, the soil classification system “Halomorphic soils” are divided into five saline soil types (*Fig. 1*) that are described below according to SZABOLCS (1966).

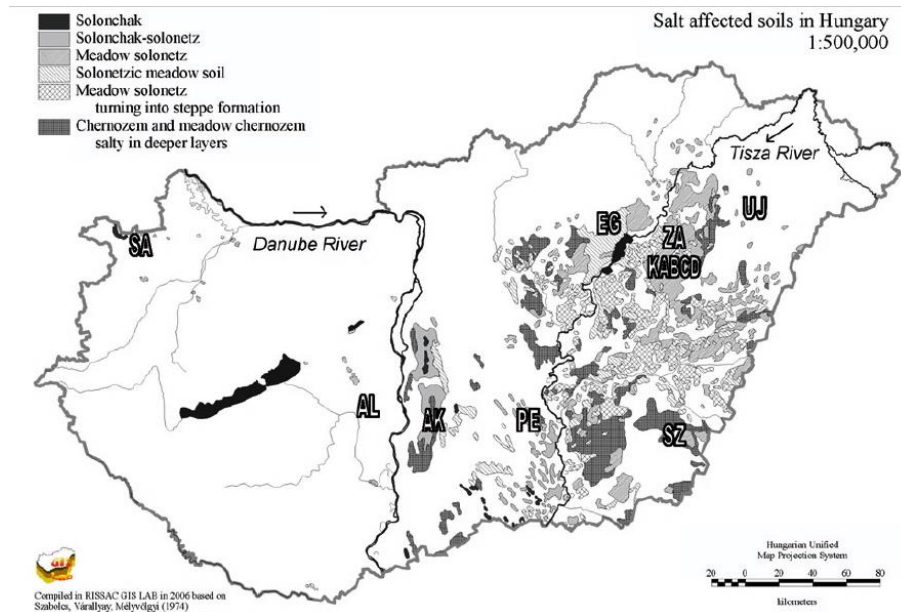


Figure 1. Map of salt affected soils in Hungary (KOVÁCS et al., 2006).

One of the recent studies of monitoring salinization in the Duna-Tisza Interfluvium revealed two different groundwater movement patterns by meteoric gravity. In fact, the fresh water regime over pressured saline water (Danube–Tisza Hydrogeologic Type Section) (MÁDL-SZÓNYI and TÓTH, 2009). The total dissolved solid is 10,000–38,000 mg L<sup>-1</sup> and originated from the basin sediments and partly from the basin basement. The gravitational arrangements' geometry and the flow channel from the rock surface can explain the pattern of soil salinization and the chemistry between the wetlands of Danube Valley and the Ridge Region.

The agricultural academy from the University of Debrecen had been researched out salt-affected soil mainly in mapping and reclamation since the 1920s (ARANY, 1926; 1934). During the 1950s the programs and experiments were held in Hortobágy and consisted in leaching and deep ploughing of sodic soils (SZELÉNYI, 1956; 1957). Years later, in the 1970s experiments consisted in “complex amelioration” which consisted in drainage techniques and application of substances that were used because of the rapid acceptance and expansion (SZÉKYNÉ-FUX and SZEPESI, 1959; FILEP, 1999; FRANZ, 1964). During the 2000s, in order to develop the inclinations of soil degradation processes, monitoring systems have been recognised and studied for 6 years by the Hungarian Soil Information and Monitoring System. KOVÁCS et al. (2006) mentioned that the statistical analysis of salinity data from inherited soil horizons of 69 sample points between 1992 to 2000. They

presented that there is a robust atmospheric regulator over the groundwater table level which result in soil salinity.

### ***Solonchak soils***

These soils are saline, which are mainly located in the region between the Danube and Tisza Rivers in low-lying areas, naturally shorelines of saline/sodic waters. Also, occur in patches east of the Tisza River. The total area is 47 km<sup>2</sup>. The characteristic is that groundwater table profound is 60–80 cm and total soluble salt content of 0.3–0.5% at the surface (sodium-carbonate, bicarbonate, sulphate and chloride). Typically, calcium-carbonate is found in the soil profile and is difficult to differentiate horizons. These soils sustain natural halophyte vegetation which is foraged.

### ***Solonchak-solonetz soils***

Between the Danube and Tisza Rivers saline-sodic soils are located. The total area is 659 km<sup>2</sup>. Naturally, the whole profile contains calcium-carbonate. The soil profile presents a softly settled columnar/prismatic natric (solonetzic). The B horizon can be notable and the ground water table is below 1m. These soils sustain native halophyte vegetation which is grazed.

### ***Meadow solonetz soils***

The “solonetz” are the distinctive sodic soils on the Great Hungarian Plain, generally east of the Tisza River, and west of the Danube River. Total area: 2,749 km<sup>2</sup>. Characterized by large transferrable sodium percent and not high salt content. The soil can be cultivated, if it is not the native vegetation can be foraged. The fertility depends on the thickness of slightly saline “A” horizon and the depth of groundwater table is between 150 and 350 cm. In the B1 horizon typical columnar/prismatic, the value of exchangeable sodium percent (ESP) is at least 20–25%. The determined of salt accumulation can be found in the B2 horizon with perfect prismatic form. The A and B1 horizons are generally absent from Calcium-carbonate.

### ***Deep Mollic Solonetz***

Total zone of 2,122 km<sup>2</sup> where the groundwater table is lower 3–4 m. These sodic soils are leached, therefore the reduces content of soluble salt and calcium-carbonate.

### ***Secondary Salt-Affected Soil (SAS)***

“Halomorphic soils” are SAS types which belong not to secondary saline soils. The other main soil types, such as Solonetzic Meadow soils with total area of 2,419 km<sup>2</sup> and chernozem soils (saline/ sodic subsoil) with overall extent of 4,185 km<sup>2</sup>.

### **2.2. Secondary salinization**

Agriculture is the dominant economic activity for many people and regions around the world. Regarding to small scale farming during the last decades the demographic changes and the improved of the infrastructure has converted the agriculture in to a profitable enterprise (ALI and KAPOOR, 2008). In fact, the scarcity and degradation of land is more endangered in semi-arid areas due to climate change and extreme conditions in the weather. Salinization is one of the problems of arable lands and nowadays in the world exist 30% loss of land, with some estimates as high as 50% by 2050 (WANG et al., 2003).

Nowadays, small scale farming has different problems, where the interactions between agriculture and the environment can be especially unequal, as they are determined by the scarcity of land or resources (FIDA and PNUMA, 2013). These agricultural heritages are covering some 5 million hectares and providing a series of ecological and cultural services to people, such as the preservation of traditional forms of farming knowledge, local crop and animal varieties and socio-cultural organization (ALTIERI and KOOHAFKAN, 2008). Small-scale farmers are considered the most vulnerable group to climate change due to the pressure of consuming goods and services that ecosystem provides; the low capacity to adapt to climate change; dependence on rain season; location of the small holders which are exposed to a variety of climate hazards and the negative impacts on productivity (DONATTI et al., 2019).

Is a long tradition of the citizens to grow vegetables and fruits there, mainly for their own consumption but also for the local market (ZSEMBELI et al., 2011). For more than 300 years, gardening activities take place in the common's gardens located in the city of Karcag. 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). The irrigation from illegal drilled wells is common during the frequently droughty summers.

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 soil salinity cause by human activities is becoming a land degradation issue when soil and environmental conditions allow the concentration in soil layers to rise above a level that impacts on agricultural production, environmental health, and economic welfare, eventually evolving into a sociocultural and human health (LAMBERT et al., 2002; RENGASAMY, 2006; SMITH et al., 2015; GEESON et al., 2003; GHASSEMI et al., 1991). 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).

### **2.2.1. Salt content dynamics and salt balance of soils under secondary salinization**

In semiarid regions, the major soil degradation threats are the mismanaged irrigation affecting over 10% of the total irrigated land (LAMBERT and SHAITI, 2002). The water scarcity and some other problems such as water-logging, salinization, and soil and water quality degradation are a threat to the future of irrigated agriculture. Half of all irrigated soils is affected by soil salinity. New incentives and policies for ensuring the sustainability of agriculture and ecosystem services will be crucial if we are into the commitment to satisfy the demands of yields without compromising environmental integrity or public health (TILMAN et al., 2002).

Irrigation can control the salt balance in the root zone by adjusting the irrigation rate and the salinity of water used for irrigation. However, the leaching the root zone will impact on the salt balance (BOWER, 1959). Management of saline water for irrigation is often based on application of excess water, designed to maintain minimum root zone salinity and thus minimize salinity caused yield water consumption and bring satisfactory yields (BEN-GAL et al., 2008). Another measure to manage salts is soil conditioning in order

to improve the status of salt affected or potentially salt affected soils susceptible for secondary salinization (ZSEMBELI et al., 2019b; RIVERA et al., 2020; KOVÁCS, 2014). The main goal is to stop the effect of soil salinity and prevent stress in the plants like osmotic imbalance, reduced water uptake and transpiration, reduced yields (BURT and BRETT, 2005).

The soil salt balance is the relationship between the mass of salt entering and leaving an area of land. Generally, a favourable salt balance (mass out  $\geq$  mass in) is considered necessary for sustainable irrigated agriculture (THAYALAKUMARAN et al., 2007). Therefore, irrigated agriculture depends on protecting land and water resources from salinity and specially the root-zone against salinity (SHARMA, 1999). A system with increasing salt storage (net accumulation of salts) is considered to have a risk of salinization to land and water resources. The salt balance is applied at the root zone as an indicator of productivity, leaching, drainage, irrigation and salinization (RHOADES et al., 1997). Salt composition of the soil solution influences the composition of cation exchange and affects the soil structure and hydraulic properties. Therefore, the best strategy is to flush and maintain the salt solution below the root zone, but in Karcag, irrigation water is a limiting factor due to its poor quality. In order to prevent salinization, it is necessary to schedule the irrigation by selecting the amount and timing of irrigation to minimize salt accumulation (SINKA et al., 2019).

About the process of soil salinization in the Hortobágy region, one of the most mentioned summaries is from FILEP et al. (1981). They described the importance of the correlation among depth of water table, moisture of soil profile, intensity of evaporation and salt movement depending on the weather conditions in summer and winter. They also discovered that salt movement is equalized considering a long period of time. This means that in natural conditions, the salts are leached during the wet season. They also found that the amelioration for large scale agriculture using deep loosener results in the improvement of the unfavourable soil properties and increases yields.

### **2.2.2. Environmental issues of monitoring irrigation water in salt affected areas**

Agricultural soil is an essential component of the ecosystem and is considered as a huge natural filter. Slight is recognised about the possible growth of pathogenic

microorganisms at different depths in the soil afterward watering the agricultural crops during the whole season (MALAKAWI and MOHAMMAD, 2003). Soil by itself could remove pathogenic microorganisms from applied wastewater, but soil can remove these microorganisms depending on several influences, such as, the type of soil, the nature of the pathogen, temperature and antagonism from the native microflora (GERBA and GOYAL, 1984). Therefore, monitoring of waste water and the prevalence of parasitic infections among agrarian workers and their relatives unprotected to raw wastewater irrigation is necessary. Undesirable environmental and health consequence can occur from long-term wastewater application, due to concentration of calcium, magnesium, bicarbonates, sulphates, nitrates, nitrites hardness, total dissolved solids, conductivity, and alkalinity as well as crops uptake of heavy metal accumulation.

The water concentration and composition of soluble salts in water will determine its quality for various purposes (human and livestock drinking, irrigation of crops, leaching etc.). The quality of water is, thus, an important component with regard to sustainable use of water for irrigated agriculture, especially when salinity development is expected to be a problem in an irrigated agricultural area (ABBOTT and HASNIP, 1997). There are four basic criteria for evaluating water quality for irrigation purposes according to ZAMAN et al. (2018):

1. Total content of soluble salts (salinity hazard).
2. Relative proportion of sodium ( $\text{Na}^+$ ) to calcium ( $\text{Ca}^{2+}$ ) and magnesium ( $\text{Mg}^{2+}$ ) ions – sodium adsorption ratio (sodium hazard).
3. Residual sodium carbonates (RSC) – bicarbonate ( $\text{HCO}_3^-$ ) and carbonate ( $\text{CO}_3^{2-}$ ) anions concentration, as it relates to  $\text{Ca}^{2+}$  plus  $\text{Mg}^{2+}$  ions.
4. Excessive concentrations of elements that cause an ionic imbalance in plants or plant toxicity. The main pollutants in marginal quality waters that pose a threat to irrigated agriculture are salts and toxic ions.

For international standards (e.g., *Table 1*), the order to achieve the first three important criteria, the following characteristics need to be determined in the irrigation waters: electric conductivity (EC), soluble anions ( $\text{CO}_3^{2-}$ ,  $\text{HCO}_3^-$ ,  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$ ) where  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  are optional and soluble cations ( $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ) where K is optional. Finally, boron level must also be measured. The pH of the irrigation water is not an acceptable

criterion of water quality because the water pH tends to be buffered by the soil, and most crops can tolerate a wide pH range.

For the Hungarian standard, all known limit values for salt content serve the purpose of ensuring that irrigation water does not cause harmful salt accumulation in the soil. Therefore, it is not possible to establish a general rule for the permissible salt content of irrigation water, because it is influenced by the water permeability of the soil, drainage conditions, the amount of precipitation, the method of irrigation, the salt tolerance of the plant, etc. (HORINKA, 1997). It is generally accepted that if the salinity of the irrigation water is less than 500 mg/L ( $EC < 0.78$  mS/cm), then the salt pool of the irrigated soil does not usually increase significantly.

*Table 1. Water quality for irrigation (adaptation from AYERS and WESTCOT, 1985)*

Potential irrigation problem	$EC_w$ dSm <sup>-1</sup>	None	Moderate	Severe
Salinity	<0.7-3.0>	<0.7	0.7–3.0	>3.0
			Crop effect	
			Soil effect	
Infiltration	>0.7- <0.3	>0.7	0.7–3.0	<3.0
Sodium	SAR	<3.0	3.0–9.0	>9.0
Chloride	meq/l	<4.0	4.0–10.0	>10.0
Boron	meq/l	6.5-8.4		

*Source: Ayers and Westcott, 1985. Guidelines for interpretation of water quality for irrigation*

FILEP (1999) created a classification for the irrigation water, which can be used in any case. It is included in group I, with a salt concentration of less than 500 mg/L ( $EC < 0.78$  mS/cm) and  $SAR < 2$ . He separated 2 subgroups within the group, high-quality waters are characterized by  $SAR < 1$ . According to measurements, the water of major domestic rivers is of this quality during most of the irrigation season. The II group includes waters that can only be used on certain soils with a good waterproof structure or that are suitable after chemical repair or dilution. The chemical quality of irrigation water depends on the source, chemical water treatment, reduction or adjustment of salinity is not possible, except in exceptional cases, or at least not advisable. However, it must be taken into account that irrigation water with a high salt content changes the chemical properties of the soil in the long term, and it is difficult to restore the original state.

The existence of contaminants in water and microorganisms in particular can have serious consequences. SHUVAL et al. (1986) ranked pathogenic agents in order of risk to humans

and animals as follow: Helminths (high risk), enteric bacteria (medium risk), enteric viruses (low risk). Bacteriophages have been shown to be present in untreated wastewaters, are insistent in the environment, and have the capacity to reach confined aquifers (CHÁVEZ et al., 2011). Recommendations from WHO, (1989), are that for crops eaten raw, the wastewater used for irrigation should not contain helminth egg and 1000 fecal coliforms (MPN/100mL).

Healthiness dangers related with wastewater reuse are amongst the most important concerns. For example, the Mexican Standards (NOM-001-ECOU96) are of < 1 HE/L and 1000MPN/100 mL for all crop types and < 5 HE/L and 1000 NMP/100 mL for crops which are not eaten raw (Jimenez, 1999). But the waste water coming from Mexico City does not have treatment and for this reason contained a high concentration of *Ascaris lumbricoides* eggs 130-135 per litre, faecal contamination ( $6 \times 10^8$  faecal coliforms/100 ml) and somatic bacteriophages (103 PFU/100 mL). The concentration of *Giardia* spp. is 70 and 5567 cysts/L (CHAVEZ et al., 2011). Contempt the increasing use of wastewater in agricultural production, the number of epidemiological studies assessing the public health risks is limited. Other problem from the waste water is the pharmaceuticals which are cast-off in large amounts for humans and livestock in agrarian countries, the residues of which have been frequently found in manure treatment plants and superficial waters (LINDBERG et al., 2005).

Unfortunately, no monitoring systems are available in any water source and all these problems require well designed studies. Groundwater pollution by dissolved organic matter and cleaners is also known, but the main problem is the chlorination of drinking water. The presence of dissolved organic matter may result in trihalomethane formation, in humans, bladder and colon cancers are linked to this pollution. Other pollutants that have to be considered in the monitoring system for irrigation water and salinization process is the heavy metals accumulation mostly in the 0-30 cm of the soils. Afterwards 80 years of effluent irrigation; Cu, Zn, and Pb concentrations rise 3-4 times, whereas Cd concentration displayed a 7-9-fold rise. The outcomes of using wastewater for irrigation show that higher concentrations of Cd, Pb and Mn in blood and also in urine. Isotope revisions done by PAYNE, (1975) confirmed that aquifers can be polluted easily of wastewater infiltrations with an important nitrate concentration in drinking water which means that risks to public well-being.

### **2.2.3. Effect of salinity in agriculture**

Around the world just 20% of the world's croplands are watered, but they harvest 40% of the global produce. In emerging countries irrigation rallies economic returns and enhance production by 400%. Conversely, irrigation can reduce productivity and can have unwelcome ecological costs like water logging and salinity. Subsequently salt concentration alters soil properties and the consequence the crop yields remain at minimal possible levels. Soil salinity is normally measured and expressed on the basis of the electrical conductivity of the saturation extract of the soil ( $EC_e$ ). The yield is decreasing linearly in percentage to the accumulation of salts in the soil and soil solution ( $EC_e$  and  $EC_a$ ) (SHAHBAZ et al., 2005).

One of the consequences of development of industries nowadays is the increasing competition of water scarcity from domestic and industrial uses. By 2025 17 million hectares (Mha) of the irrigated area may experience “physical water scarcity” and 22 Mha “economic water scarcity”. The water accessibility for agriculture over this period is expected to fall from 72 to 62% globally and from 87 to 73% in emerging countries. The claim for freshwater for industrial and domestic city needs is rising quickly throughout semiarid areas. In Asia, for example, 50% of the total fresh water resources are dedicated to increasing rice production. Sustainable agriculture can be threatened by the water insufficiency and hence food security and the livelihoods of producers and consumers (KHAN et al., 2006).

For example, Australian government have to recognised policies to control the allocation of water to all users and to meet necessary ecological requirements, in this country irrigation processes is full mechanized. The rice business in Australia has a price of around \$350 million (AUD) and total value (exportation wages, value-added) of over \$800 million benefiting regional societies and the Australian economy. In contrast, the environmental costs are surreal due to the amount of chemicals and other pollutants in drainage waters, the increasing mosquitos' population and bird control, soil salinization due to rising water tables in the rice-growing areas. This and other major concern for rice-based farming systems in the region lead to the growing demand and challenging water practices. That is why as a mitigation of the environment Australian farming have been

rotating the rice with leguminous, pastures and dryland crops, which recover soil fertility and limit the necessity for insecticides.

As I mentioned before, salinity is one of the biggest risks of misusing irrigation. However, I explain the consequences of salts in the soil-water solution for plants; reduction of evapotranspiration, reduce availability of water to the root, reduces the potential nutrients of the soil solution, crops need extra effort for the uptake of nutrients, cause toxicity to crops, reduces plant metabolism and nutrient deficiency. In addition, under saline conditions, many plants are able to partially recompense for low osmotic potential of the soil water by building up higher internal solute contents. This is done by absorbing ions from the soil solution and by synthesizing organic osmolytes. Both of these reactions reduce the impact of osmotic potential on water availability (CEMEK et al., 2017).

However, the method of irrigation can cause different crop deficiencies or damage. For example, the sprinkler irrigation, result in toxic conditions for all crop due to the adsorption of sodium chloride through the leaf. In fact, reduces plant growth by reducing the rate of leaf elongation, the expansion, and the division of cells. In direct toxic conditions generally occur in surface or trickle irrigation, where high levels of sodium can induce calcium deficiencies. Saline irrigation ( $4-8 \text{ dS m}^{-1}$ ) reduces evapotranspiration by 50%. The plant reduced water loss by closing partially the stomata, leading to limited  $\text{CO}_2$  assimilation rates, as well as reduced plant development, sugar accumulation, and fruit growth. However, synthesis of organic osmolytes does require outflow of metabolic energy. The production of vegetables and fruits is possible by providing adequate drainage and salt export facilities by monitoring different climatic and irrigation properties (SPERLING et al., 2014).

One of the successful monitory programs for sustainable agriculture is the SIMDualKc model. This programme monitors salinity stress and can be used to support irrigation scheduling in saline conditions. This monitoring program simulates soil water content in the soil salinity status given by the electrical conductivity of the soil saturation extract ( $\text{EC}_e$ ) at the beginning and at the end of each growing season, crop tolerance to soil salinity ( $\text{EC}_e$  threshold), and soil water availability under saline condition. SIMDualKc was able to compute evaporation and transpiration under salinity stress using an approach based on the soil water content status (ROSA et al., 2016). Other technologies which help

to accurate estimation for crops stress is the remote sensing which is able to identify of the crop coefficient ( $K_c$ ).

The  $K_c$  is a critical calculation to explain the effect of transpiration from plants and planning appropriate irrigation management for efficient crop yield. The crop coefficients of various crops were tabulated in 1998 by ALLEN et al., assuming that respectively crop is a standard crop under unrestricted irrigation conditions. However, these tabulated coefficients mandatory adjustments beforehand application at local study sites. The local environmental conditions, such as soil fertility, salinity, climatic conditions (i.e., precipitation, wind speed, and relative humidity), and managerial factors needed to be taken into consideration to develop an adjusted  $K_c$  curve. In addition, is problematic to apply the crop coefficient approaches under water-stressed, salinity conditions or in the presence of high rates of soil evaporation.

The remote sensing facilitates planning of adequate irrigation schedules for successful water and agricultural management. In addition, the spatial distribution of the  $K_c$  could be estimated and applied to the input datasets to predict crop productivity with various models and to develop a new drought index that considers the crop water demand at different growth stages. The remote sensing approach has been employed as an alternative for the calculation of irrigation due to several advantages, including reflection of the actual environmental conditions and ability to obtain the real time  $K_c$ . This calculation is coming from different values obtained from satellite images like: Various vegetation indices (VI) derived from satellite data including Leaf Area Index (LAI), Normalized Vegetation Index (NDVI), and Soil Adjusted Vegetation Index (SAVI). By combining the effects of the soil moisture and the two vegetation indices (NDVI and LAI) detected by the remote sensing, the satellite-based  $K_c$  corresponded well with the observed  $K_c$  (PARK et al., 2017).

Sustainable irrigation is a challenge for the different semiarid regions, is an essential to measure water quality movements, clarify environmental impacts and evaluate the trade-off between yield reduction and groundwater uses to irrigate (ISIDORO and GRATTAN, 2011). However, intensive agriculture depends on the environment and plants have a plasticity to the environment conditions, salinity and pollution. Therefore, is not significant how efficient we can succeed the inputs or monitoring systems on the location.

If is not satisfactory living cycle of the plants, there will be no production or even incomes from the cultivation. The most cost-effective choice may be to increase water use efficiency and decrease undesirable impacts on the environment thereby reducing the related costs of keeping our natural capital. There is a need to fundamentally rethink sustainability of food production, rational pricing and sharing of water and commodities to justify investment that will maintain and enhance ecosystem function.

### **2.3. Soil conditioning**

The use of soil stabilizing conditioners or materials has been practiced in agriculture for millennia. Most of the common conditioners are green manure, peat, crop residues organic compost and mineral ingredients such as coal dust, rock phosphates, rock flour, gypsum (SOJKA et al., 2007). The need of amendments and the volume and kind of amendment is best discovered by soil test. Soil conditioners have been investigated since the requirement for biochemical and physical conservation or enrichment of the soil and for the dumping or management of waste materials (BOWER, 1959). Soil improvement materials and soil conditioners are terms often used interchangeably. Materials which improve soil properties and suitability for plant growth are considered soil conditioners. Soil amendments are products that improve the performance of the soil. They enhance soil formation by binding soil particles into large particles, improving air exchange, water retention and flow, root growth, and the performance of fertilizers. However, they focus on a specific aspect of improving the quality of soil, which is that of its structure. Meanwhile, soil improvement material as an alternative considered when the natural soil does not meet the engineering requirements for a project. In Hungary, according to the directive of the former Ministry of Agriculture No. 36/2006. these two groups of yield increasing materials are distinguished as follows: soil improvement materials are yield increasing materials of industrial origin that can positively change the unfavourable-, and maintain the favourable soil properties, while soil conditioners are yield increasing materials of industrial origin that can positively affect the physical, chemical, and biological properties of the soil.

In almost all agricultural soils the particles have negative electrical charges at their surface they absorb (attract and hold) positively charged salt constituents called cations. The common cations are calcium, magnesium, and sodium. Calcium and magnesium are the

principal cations found in normal, productive soils, and they have a favourable effect upon the physical condition of the soil. If soils have come in contact with high sodium irrigation or ground waters, they usually contain adsorbed sodium as well adsorbed calcium and magnesium and adsorbed sodium has an effect to the soil, this is called secondary salinization (BOWER, 1959).

### **2.3.1. Organic soil conditioners**

Three major classes of soil conditioners are existing. The first group is the natural organic materials. These organic amendments have the typical use to increase infiltration, retention of water also, provide substrate for the micro and meso-biological activity improving the aeration, resisting compaction and surface sealing. Organic amendments occur in many forms from compost (fresh, aged, composted) to pulp, biosolids, paper mill sludges, and food processing wastes (LARNEY and PAN, 2006). Indeed, organic amendments are often undesirably features, such as, smell, extreme nitrogen and phosphorus, heavy metals, pathogens, poisons and other toxins, which are possibly portable to shallow or ground waters by runoff or leaching (LARNEY et al., 2011). In the review of organic amendments (LARNEY and ANGERS, 2012) it is expressed that the organic material have different behaviour in the soil reclamation especially in sodic soils. In fact, in the rhizosphere have been seen how the bacterial activity change the chemical and physical structure in the soil more efficiently and fast than the inorganic mineral. The plant rubbishes are covered by mineral particles and developed the centre of water stable aggregates and are threatened from quick decomposition.

CLARK et al. (2009) used gypsum amendment, and found out that was not capable of forming aggregates, which may be attributed to the incapacity of gypsum to stimulate soil. In contrast, the formation of sating resistant macro aggregates (2 mm) was most quick with green plant material, wheat and alfalfa. However, the organic amendments can modify the chemical composition in the soil depending on their source and composition. For example, organic amendments can have variable effects on soil pH. The paper mill slushes can rise pH of degraded acidic soils due to the compounds added during the industrial processing (FIERRO et al., 1999; CAMBERATO et al., 2006).

Indeed, organic amendments are perfect for fast accelerating soil revival progressions and henceforward land recovery. Organic amendments increase in water holding capacity than that of most mineral conditioners for semiarid soils (CAMBERATO et al., 2006; FIERRO et al., 1999). It is known that water holding capacity and its duration depends on other soil properties, the amount of amendment applied and the decomposition status of the organic amendments. More decomposable organic amendments have more intense but shorter-term effects, while recalcitrant materials may be less intense but longer lasting.

Another aspect, is the availability of water at root zone is possibly a more related factor affecting plant development than water-holding capacity at any given water tension. Also, mixtures of amendments might improve than each applied alone. The potential mixture may be most fully realized when inorganic conditioners are useful in combination with organic amendments such as mulch from biomass, biosolids or pulp and paper sludge. However, in order to have a successful treatment, research should be carried out to test several amendments (LARNEY and ANGERS, 2012).

### **2.3.2. Mineral conditioners**

The second group is the mineral conditioners which can modify soil processes, chemical and physical and are used mostly in arid and tropical regions. In sodic salty soils gypsum and sulphur are the chemical amendments most frequently used. Other amendments less frequently used are calcium chloride, sulphuric acid, iron and aluminium sulphates, limestone and lime-sulphur. These amendments, have one characteristic in common-they supply soluble calcium, when used under the correct soil conditions (BOWER, 1959). For sodic soil reclamation, the most commonly amendment is gypsum, due of its low cost and also can affect permeability by means of EC and cation-exchange (LOVEDAY, 1976).

Gypsum is a widely distributed mineral found worldwide in sedimentary evaporite deposits (HURLBUT and KLEIN, 1971). In evaporating seawaters, gypsum is one of the first minerals to precipitate, and is naturally found below rock salt deposits in marine salt domes (MURRAY, 1991; HURLBUT and KLEIN, 1971). SHAINBERG et al. (1989) in

their review of gypsum in soils mention that the sources of gypsum are not only from geologic mines, instead a lot of industrial processes are producing  $\text{CaSO}_4$  by-products.

In the industrial sub products for soil amendments significant is the phosphoric acid from rock phosphate. This rock apertite it is used to manufacture high-analysis P fertilizers, while the by-product gypsum is composed as a waste product. The result is a fine-grained and high-purity material, called phosphogypsum. Phosphogypsum is mostly composed of gypsum but also contains a high level of impurities such as phosphates, fluorides and sulphates, naturally occurring radionuclides, heavy metals, and other trace elements (TAYIBI et al., 2009). The production worldwide is to be around 100-280 Mt per year. Most of this by-product is disposed deprived of any treatment, habitually dump in large stockpiles where they occupy large land areas and cause serious environmental damage. These are generally located in coastal areas close to phosphoric acid plants.

This by-product is produced in big amounts in USA and Europe. Other example is the commonly by-product gypsum in industries that produce sulphuric acids like a waste which neutralized this acid with hydrated lime. Various plating industries produce appreciable quantities of gypsum by this process that are often of high purity (SHAINBERG et al., 1989).

The second mineral more used is the sulphur which is part of each living cell and is part of 2 of the 21 amino acids that form the proteins. Sulphur fertilization is an expanding practice in various countries around the world. Sulphur constitutes 0.1% of the earth's crust but differs a lot in terms of the percentage in each source. Soil organic material is the core source of S approx. 90%. Sulphur can be obtained from mining deposits such as pyrite, or can be obtained chemically by treating natural gases and petroleum refineries. Rains also deposit sulphur as sulphur-dioxide and the quantity depends on the amount of proximity of the industrial zones. The majority of the sulphur sources occur in sulphates, the most common are bisulphates, thiosulfates and polysulphates, while the solid materials available in powder or granules are superphosphate, ammonium sulphate, ammonium sulphonitrate, gypsum, potassium sulphate, sulphur urea (RODRIGUEZ et al., 2006).

The  $\text{SO}_4^{2-}$  is the ionic form of sulphur in which plants absorb them and form compounds such as coenzymes, biotin, thymine and glucosides. Within the sulphur functions are the formation of bonds within polypeptide chains that increases the stability of structures. Participates in oxidation reduction reactions that help create enzymes and vitamins. It also helps to prevent fungal infections in crops (RODRIGUEZ et al., 2006). Sulphur can be soluble in water like sulphates or is not soluble in water like elemental sulphur. The elemental sulphur when is applied is gradually oxidized by micro-organisms in the incidence of air and water to sulphuric acid. Sulphuric acid is a harsh liquid, and is usually about 95% pure. The sulphuric acid can release the  $\text{Ca}^{2+}$  from the  $\text{CaCO}_3$  and exchanges the Na from soil and also can be leached from the soil. If lime is current in the soil, it reacts with the sulphuric acid to form gypsum and minor quantities of calcium bicarbonate (BOWER, 1959).

In recent years, the suppliers innovate the conditioners and offer compound fertilizers (e.g., chemical mixtures with N, P and S) that include  $\text{S}^0$  micronized and  $\text{SO}_4^{2-}$ . From the point of view of the fertilizer industry, the main advantages of these products are the greater safety in the use of sulphur during the production stage of the fertilizer. From an agronomic point of view, an interesting advantage of these sources is that of offering a more balanced P/S ratio for the cultivation of soybeans, the most sown in rainfed agriculture in South America (TORRES-GUGGAN et al., 2004). The domestic sulphur resource is about one-fifth of the world total sulphur in gypsum and anhydrite is almost limitless. The resources of elemental sulphur, 5 billion tons, can be found in evaporite and volcanic deposits and sulphur associated with natural gas, metal, tar sands, petroleum, and sulphides. The 600 billion tons of sulphur is contained in organic matter, coal, shale rich in, oil shale, and but low-cost methods have not been developed to recover sulphur from these sources (USGS, 2014).

Limestone is (calcium carbonate) almost insoluble in alkaline soils but it goes into solution gradually in acid soils and is found in all around the world. The rate at which it goes into soluble calcium depend on the degree of fine particles. For example, the lime particles from sugar workshops is a required source of calcium carbonate for application to soils because the particles are fine. However, lime can have different effects depending on the place is applied. It is occasionally applied to lime free soils, along with acid or acid-forming amendments. For example, soils containing lime, instantly reacts to form

gypsum and provides soluble calcium indirectly, but will be no value, if the addition of limestone to sodium soil already containing lime (BOWER, 1959).

In temperate regions, the conservative aim of liming is to increase soil pH often with a target pH of 6.0 to provide optimum conditions for growth of many temperate crops. By contrast, in tropical regions liming is a hazard. Liming has been reported to increase clay dispersion and reduce aggregate stability and infiltration rates significantly (PAYNE, 1975). In both temperate and tropical regions reports regarding the effects of liming on the physical properties of soils are conflicting. However, other observations mention the reduction of surface cracking, aggregate stability, increases water holding capacity, and infiltration (HAYNES and NAIDU, 1998).

These different effects of lime in tropic and temperate regions are explained by HAYNES and NAIDU (1998) in three terms. First of all, exist a short-term property of liming on dispersion of soil colloids, that attracts hydrous oxides  $Al^{3+}$  and  $Fe^{2+}$  and negatively charged clay surfaces and organic matter encourage flocculation. As pH is higher by liming the net negative charge increased on soil and the ratio of negative to positive charges also increases. At the same time  $Al^{3+}$  activity declines as Al precipitates as hydroxy-Al polymers. As a result, repulsive forces between particles dominate and lead to dispersion (TAMA and EL-SWAIFY, 1978). For example, in Hawaiian liming soil from  $pH_{(H_2O)}$  4.5 up to 6.0 caused dispersion of soil aggregates.

The second term is the direct positive effects of liming on soil structure can be ascribed to the flocculating and cementing actions. This happens when limestone is applied in excess, which can clog pores and forms aggregates, the Hydroxy-Al and FE oxides are polymers adsorbed on clay surface, which flocculate the soil colloids (OADES, 1979). Under field conditions the positive effect of lime is likely to be a result of a combination of cementing and flocculating actions (GREENE et al., 1978).

In fact, the mineral conditioners are used in arid and tropical soils where high landscape applications the temperature promote the bio-oxidation as a result soil physical conditions, particularly soil aggregation and aggregate stability, are likely to improve (HAYNES and WILLIAMS, 1992; HAYNES and NAIDU, 1998, *Fig. 2*).

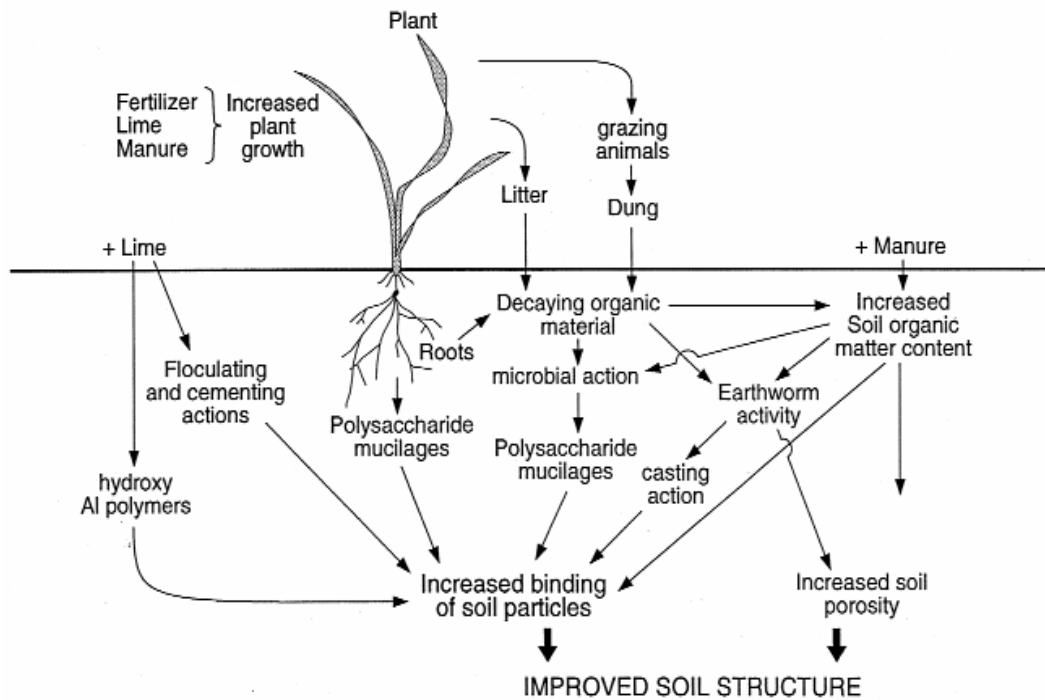


Figure 2. A conceptual model of the major effects that fertilizer, lime and manure have on improving soil aggregation and soil structural condition (HAYNES and NAIDU, 1998).

The organic matter content in the soil and soil biological activity are intimately linked with soil aggregation and soil structural condition. Lime in soils is known to have a brief time to stimulating soil biological activity. In short-term effects liming has been reported to increase microbial biomass content, soil respiration rate, the microbial metabolic solution (microbial respiration per unit biomass), soil enzyme activity (dehydrogenase, sulfatase and protease activity) and net mineralization of soil organic N and S. Also, the microbial population shifts from fungi to actinomycetes to bacteria as pH increases. It is also likely that liming will have long-term effects in increasing soil organic matter content. Liming has also an impact on plants like a large increase in root and top growth and an increase in the returns of C to the soil in the form of dying roots and decaying crop residues (BADALUCCO et al., 1992).

### 2.3.3. Synthetic soil conditioners

Synthetic soil conditioners, like polymeric stabilizers, were created after 1955. These conditioners are used to improve the available water in the soil, physical properties in the soil which facilitate the root penetration, improve infiltration and increase the soil

aeration and microbial activity preventing erosion and water runoff, also improve fertilizer retention in the soil and increase the fertilizer efficiency as well as prevent the contamination of the underwater sources binding heavy metals and mitigate their action on plants, reduce the evapotranspiration rate of the plants inducing a much higher growth rate, reduce compaction tendency, mitigate the effects of salinity. (ZOHURIAAN-MEHR et al., 2010; PAGANYAS et al., 1972).

For example, the hydrolysed polyacrylonitrile and calcium carboxylate polymer had been used like a permeable film resistant to the impact of rain drops erosion, which increase rooting system improving nutrition (WEEKS and COLTER, 1952; SOJKA et al., 2007). Perhaps, the most successful water-soluble soil conditioning polymer “krilium” were sold by Monsanto mainly used for high value crops and specialized uses, but the demand of these product and expenses oriented the synthetic conditioners to other materials (NELSON, 1998). Majority of the materials in synthetic conditioners are polysaccharides, biopolymers surrogates of anionic polyacrylamide (PAM) (SOJKA et al., 2007). The beneficial effects of various polymers with different molecular weights, charge types, and densities applied over a wide range of conditions. This structure of synthetic materials can absorb water 2000 times, which improved the water retention of soils around the seeds or roots in drought occasions. The high-water absorption for capillary action of these materials is attributed to the interconnected super pore structures with diameters of several hundred microns. Also, these are used for dryland and irrigated soils, soils of varying physical and chemical properties, and rainfall with different kinetic energies and other uses are food processing, drinking treatment, (GUILHERME et al., 2015). For the most part, PMA is resistant to microbial attack, and its degradation is mainly through physical breakdown (SEYBOLD, 1994). Also, these polymers are used in agriculture to aid during seedling and germination, immobilizing plant growth regulator or protecting agents for controlled release and seed coatings.

It has been investigated the controlled release of nutrients from the fertilizer- loaded hydrogel into crops (GUILHERME et al., 2015). It is known that a large portion of the fertilizer applied to soil is lost by leaching. However, different polysaccharides, such as chitosan, pectin, carboxymethyl cellulose has been used to prepare hydrogels as a fertilizer release system to nurture the soil (ZOHURIAAN-MEHR et al., 2010; CHEN et al., 2004).

#### **2.3.4. Physical reclamation**

In the salt affected soils, the physical properties of the soil can be remediated with soil loosening. For this method BIRKÁS et al., (2008) explained the steps for assessing soil conditioner. First of all is necessary to identify the spots where the test can be applied, where poor soil condition is probed by the penetration of a stick sound is 10 to 20 cm. Also Spade test can reveal the structure of humidity of the soil and any compacted layer to a depth of 25–28 cm. Also, the penetration resistance measurement with static penetrometer of a 60-degree cone angle are the most commonly used instruments for this purpose today. However, when the soil compaction is between 2.5 MPa and 5.0 MPa loosening is indispensable.

Loosening can be handled by depending on the moisture of the desired depth that is required. For example, BIRKÁS et al. (2008) mentioned that ploughing/disking is the more suitable. In the other hand when the soil is dry the technique is disk subsoiled or cultivator should be used and the surface should be pressed after tillage to minimize further moisture loss. In order to check if the loosening were effective, is necessary to measure the moisture content of the soil and the structure from the desired depth. The loosening is effective if the soil became friable in the entire profile to the planned depth. Also, the effectiveness of loosening can be checked with the aid of instrument using a penetrometer.

#### **2.4. Effect of soil conditioning on the microbiological activity of the soil**

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.

The complex communities of organisms in the soil benefit to global cycles and human sustainability. The consequence of saltiness in the root zone is the alteration in the microorganisms, where constitute less than 0.5% of the soil mass (SMITH et al., 2015).

Soil biodiversity is an important regulator of other soil services including greenhouse gas emissions and water purification (BODELIER, 2011). Although microorganisms contribute in soil properties and processes like: oxidation, nitrification, ammonification, nitrogen fixation, store C and nutrients in their biomass and other processes which lead to decomposition of soil organic matter and transformation of nutrients, also, can promote plant growth and disease control (NAN et al., 2015).

Therefore, these communities have been used to estimating alterations in soil quality, soil biochemical and CO<sub>2</sub> emissions for agricultural production (PHILLIPS and NICKERSON, 2015). The soil CO<sub>2</sub> emission is coming from two different sources. The first one is autotrophic respiration, which is from the activity of organisms that are capable of fixing CO<sub>2</sub> into organic molecules. Autotrophic soil respiration is controlled by photosynthesis, which is regulated by environmental conditions such as solar radiation and atmospheric humidity (EKBLAD and HOGBERG, 2001). The second is called **heterotrophic** soil respiration. This respiration produces CO<sub>2</sub> by all other soil organisms besides roots from processes such as root expansion, mycorrhizal exploration, and microbial decomposition of litter and soil organic matter (DAVIDSON, et al. 2012). In agriculture the physical, chemical and biological status of the soil is determined by nature and soil conditioning (KOVÁCS, 2015).

In our experiments we place N, P and K fertilizers, which can affect the absorption and use of nutrients (including micronutrients), and because could be a negatively affects the beneficial plant rhizobacteria, it reduces crop yield and quality (DINCA et al., 2022). Our aim is to create an experiment to follow the CO<sub>2</sub> concentration in the pot experiment in order to proof if the micro doses of soil conditioners have any effect on the respiration of the microorganism. Even though exist an overlap of all soil physicochemical process like biological processes, cycles and functions.

### **3. MATERIALS AND METHODS**

My research work consisted of four experiments dedicated to secondary salinization by irrigation, the application of soil conditioners and their effects on the soil and the indicator crops:

- an experiment in simple drainage lysimeters to determine the effects of irrigation with saline water on the salt dynamics of the soil,
- a preliminary experiment in lysimeters including soil conditioning,
- a small-plot experiment in the Irrigation Experimental Garden (IEG),
- a pot experiment.

The materials and the applied methods are described according to this division of the experiments.

#### **3.1. Location of the experiments**

My research was carried out at Karcag, Hungary. Karcag, the capital of Great Cumania, is located in the north-east part of Hungary, in the centre of the Great Hungarian Plain. Great Cumania is a 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. The most important chemical factors limiting soil fertility are salinization, alkalinity. The heavy textured soils of the region have very bad physical properties and water regime due to their high clay content with swelling and shrinking characteristic and unfavourable chemical features. Among the hydrological factors, the high rate of areas endangered by excess water (water logging) and high fluctuation of groundwater are characteristic. The unfavourable circumstances due to the changes of too wet and too dry periods can often occur within one year in the same location. Among the meteorological factors, the climatic water shortage of 150-200 mm is dominant. Beyond this the frequency of extreme values of meteorological parameters is higher comparing to the other areas of the country.

The experiments were set partly in the Lysimeter Station, and partly in the Irrigation Experimental Garden of the Research Institute of Karcag (*Fig. 3*).



*Figure 3.* Location of the Lysimeter Station and the Irrigation Experimental Garden at the Research Institute of Karcag

*Source: Google Maps 03.03.2022*

### **3.2. Weather conditions during the investigated years**

The subregion called Great Cumania, where Karcag is located, is one of the driest areas of Hungary with high fluctuation of temperature and the most continental characteristic. Summers are dry, warm with low cover of clouds. The total number of annual sunshine hours is between 1970 and 2020. The annual mean temperature is 10.2–10.4 °C, the mean temperature of the vegetation period is 17.4–17.6 °C. The annual amount of precipitation is between 490 and 510 mm. In order to characterize the weather conditions of the investigated years, the monthly values of the mean air temperature (*Fig. 4*) and the amounts of precipitation (*Fig. 5*) are compared to the 50-year averages based on the data recorded at the meteorological station of RIK (official station belonging to the network of the National Meteorological Service) operating since 2005.

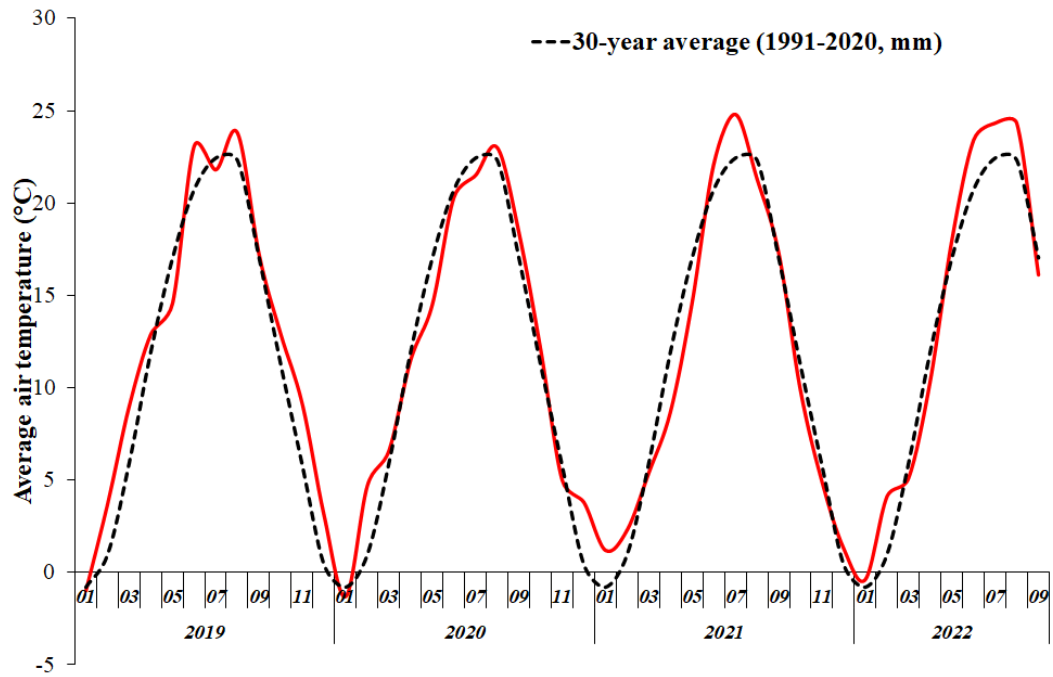


Figure 4. Monthly mean air temperature values during the investigated period compared to the 30-year average data (Karcag, 2019-2022)

The **air temperature** during these 4 years (2019-2022) exceeded the average, which can be due to global warming and climate change. The linear trend shows obvious and gradual increase of the annual mean air temperature in Karcag in last two decades. More importantly than the annual mean air temperature, the annual minimum and maximum values differ in a very wide interval (ZSEMBELI et al., 2019a).

In the past 30 years, the **temperature** average of the air in Karcag had been fluctuating. Nowadays, the fluctuation is more extreme and months like January and February are warmer. Especially summers are hot, when June, July and August are supposed to bring showers during the season. In consequence, irrigation is needed to maintain the high production of several crops. Nowadays, the rain storms are counted and heavier which damage the crop production due to plant damage, soil erosion and water ponding. In Table 2, the number of months with monthly mean temperature higher or lower than the 30-year average are indicated for the three full investigated years. It is interesting to observe that there were no months with mean temperature extremely lower than the 30-year average during 2019-2021. In contrast, extremely warm months are getting more characteristic.

Table 2. Number of months with monthly mean temperature higher or lower than the 30-year average (Karcag, 2019-2021)

Air temperature	Number of months		
	2019	2020	2021
Above average	11	11	9
Below average	1	1	3

The amounts of monthly **precipitation** are also changing nowadays, even more extremes are characteristic than in the case of air temperature. From agricultural point of view the temporal distribution of precipitation is very unfavourable in Karcag. The number of days with precipitation over 20 mm is increasing, even rainfall intensity over 60 mm day<sup>-1</sup> can occur. If we fit a trendline on the data series of the last two decades, a decreasing tendency can be figured out regarding the total amounts of annual precipitations (ZSEMBELI et al., 2019a). In fact, the weather is unpredictable in this respect and the seasonal dynamics detected in the investigated years do not follow the dynamics of the 30-year averages. Comparing the differences in the seasonality in precipitation, we found that higher amounts of precipitation come in the middle of summer and the end of autumn recently.

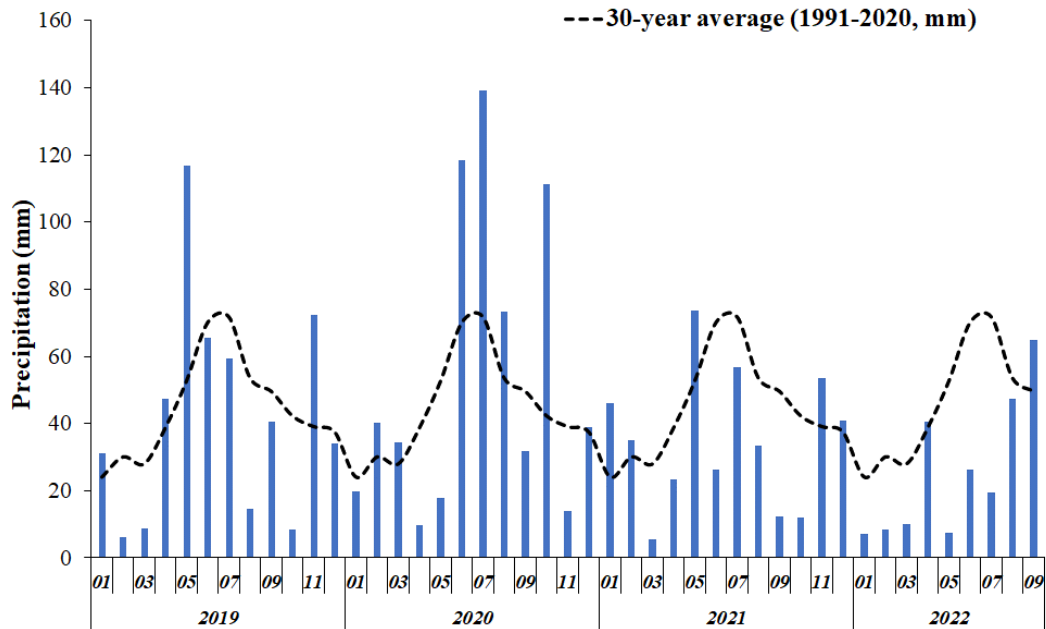


Figure 5. Monthly precipitation values during the investigated period compared to the 30-year average data (Karcag, 2019-2022)

In Table 3, the number of months with the monthly amounts of precipitation higher or lower than the 30-year-average are indicated for the three full investigated years. Weather

extremes like heavy rainfalls or severe droughts have serious effect on the crops and biodiversity. For example, in 2020, the soil got drier due to the lack of precipitation during the autumn and the beginning of winter. Decreasing amounts of precipitation is said to be a consequence of global warming. With the hydrological cycle of the region of Karcag, negative water balance for longer periods is characteristic causing cumulative lack of water. Under such conditions it is almost hopeless to maintain soil productivity and crop production without the risk of desertification and erosion.

*Table 3.* Number of months with monthly amounts of precipitation higher or lower than the 30-year-average (Karcag, 2019-2021)

Precipitation	Number of months		
	2019	2020	2021
Above average	5	5	6
Below average	7	7	6

### 3.3. Lysimeter experiment to study secondary salinization

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 (ZSEMBELI et al., 2013, 2019a) 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) irrigated with saline water in the Lysimeter Station of the Research Institute of Karcag in 2019 (*Fig. 6*).



*Figure 6.* Simple drainage lysimeters dedicated to the study of secondary salinization at the Research Institute of Karcag in June, 2019

The lysimeters contain a heavy textured meadow chernozem soil salty in the deeper layers (Clayicc-Luvic vertic by WRB classification). The main parameters of the meadow chernozem soil filled into the simple drainage lysimeters are listed in *Table 4*. (The laboratory analyses were made according to the Hungarian standards at RIK). This is one of the three typical soil types of the region, and it is especially characteristic in the gardens located in the western part of Karcag, and which are recently used by hobby gardeners to produce vegetables mostly. We simulated the circumstances of the production in these gardens; 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) in each lysimeter.

*Table 4.* Some parameters of the meadow chernozem soil filled into the simple drainage lysimeters

Depth	pH (KCl)	pH (H <sub>2</sub> O)	K <sub>A</sub> *	Salt cont.	CaCO <sub>3</sub>	Hu- mus con- tent	NO <sub>3</sub> - N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
m				m/m %	%	m/m%	mg/kg	mg/kg	mg/kg
0-0.3	5.7	6.7	46	0.04	< 0.05	2.9	9.7	86	338
0.3-0.6	6.9	7.7	52	0.07	1.09	2.3	18.5	40	299
0.6-0.9	7.4	8.2	48	0.05	10.88	1.2	8.5	33	245
Particle size distribution (%)									
Depth	>0.25	0.25-0.05	0.05-	0.02-	0.01-	0.005-	0.002	0.002	
m	mm		0.02	0.01	0.005	0.002	- mm		
0-0.3	0.5	6.4	11.4	15.4	13.6	11.5	41.2		
0.3-0.6	0.2	5.8	7.2	16.3	14.1	10.6	45.9		
0.6-0.9	0.1	3.5	9.0	13.4	16.0	11.0	47.0		

\*K<sub>A</sub> is the plasticity index by Arany

According to the United States Department of Agriculture soil texture triangle (DEREK et al., 2015), all the three investigated soil layers belong to the clay textural class.

The salt content of the irrigation water we used was around 1,000 mg L<sup>-1</sup>, 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 (FILEP, 1999). In our study carried out in 2019, we applied the irrigation protocol and the most suitable frequency according to a preliminary experiment of SINKA et al. (2019). All the lysimeters were irrigated with the same weekly amount of water (16 litres per week). We chose chilli pepper (*Capsicum annuum* L.) as the indicator crop, because due to its shallow root system, it extracts 70–

80% of its water demand from the top 0.3 m soil layer. It is known to be sensitive to salt accumulation ( $1.5 \text{ mS cm}^{-1}$ ) and has high water demand (needs much irrigation water during its vegetation period). Only N-P-K fertilization was applied according to the demand of the indicator crop (BEN-GAL et al., 2008; BARRIOS et al., 2007).

### 3.3.1. Sampling and measurements in the secondary salinization experiment

Before and after the irrigation season, we took soil samples down to 1 m in order to study the leaching of salts to the deeper horizons (*Fig. 7*). We identified 5 soil layers (0-0.2 m, 0.2-0.4 m, 0.4-0.6 m, 0.6-0.8 m, 0.8-1.0 m) and we measured the EC, which refers to the total soluble salt content of the soil ( $\text{TDS (mg L}^{-1} \text{ or ppm) = EC (dS/m) x 640}$  (EC from 0.1 to 5 dS/m) in each layer (FILEP, 1999).



*Figure 7.* Soil sampling from the lysimeters in 2019

We determined how much salt was added through irrigation taking the total amount of irrigation water and its regularly measured salt concentration into account. During the irrigation season (May–October 2019), in situ measurements were carried out two times a week. The electric conductivity (EC) of the soil referring to its salt content was measured with an UMP-1 mobile probe (*Fig. 8*), while soil moisture content with an SMT 100 sensor (*Fig. 9*), both produced by Umwelt-Geräte-Technik GmbH.

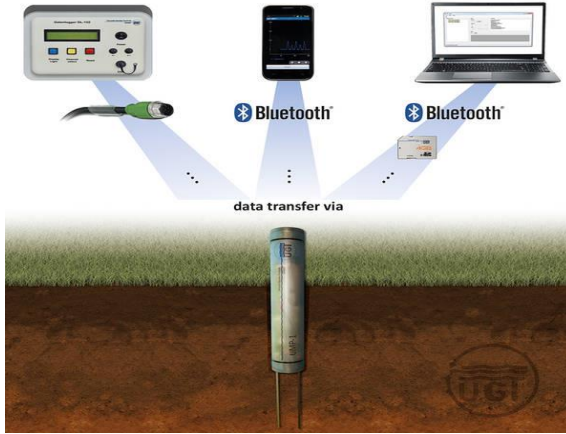


Figure 8. UMP-1 type mobile probe  
(Source: I2)



Figure 9. SMT-100 soil moisture probe  
(Source: I2)

### 3.3.2. Calculation of the theoretical salt balance

The theoretical salt balance ( $SB_{TH}$ ) of the soil columns of the lysimeters was calculated taking the total salt content of the irrigation water (input in a lysimeter system) and of the leachates (output in a lysimeter system) into account. The salt content of natural precipitation (input) was considered zero in this study, and no other salt inputs and outputs were taking place in the salt regime of the lysimeters. Wilcox's equations (WILCOX, 1963) 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).

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

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.

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

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.

$$SB_{TH} = SM_{IRR} - SM_{LCH} \quad (3)$$

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. We used this method, because it is the simplest and the most obvious procedure for a simple drainage lysimeter system as it is based on measured values of inputs and outputs. However, this methodology can also be used to calculate the leaching requirement, which means the fraction of the irrigation water that must be percolated out of the root zone to prevent high salinity exceeding a specified level (HILLEL, 2005).

Before the irrigation season, we took soil samples from the soil layers of 0–0.2, 0.2–0.4, and 0.4–0.6 m, respectively. The samples were analysed in the Central Laboratory of RIK, where the actual electric conductivity of the saturation extract ( $EC_E$ ) was measured by making a saturated paste of soil, adding deionized water to it, extracting the water, and then measuring the EC of the extracted solution with a potentiometer. From  $EC_E$ , the total soluble salt concentration (TSC in w/w%) was determined according to the Hungarian standard MSZ-08 0206/2-78. The sampling and analysis were repeated similarly after the irrigation season.

### 3.3.3. Calculation of the actual salt balance

On the base of the total salt content (TSC) of the soil samples taken before and after the irrigation season, the actual salt balance ( $SB_{ACT}$ ) of the upper three (0–0.2, 0.2–0.4, 0–0.4-0.6 m) soil layers was calculated. First, we calculated the volume ( $V$  in  $m^3$ ) of a specific (0.2 m thick) soil layer of the lysimeters of  $0.8 m^2$  soil surface each getting 0.16  $m^3$  as  $V$ . Then the mass of a 0.2 m thick soil layer ( $m_{soil}$ ) can be calculated from  $V$  and the relevant soil bulk density ( $\rho_b$  in  $Mg m^3$ ) as their product (Eq. 4).

$$m_{soil} = V * \rho_b \quad (4)$$

Knowing  $m_{soil}$  (in g) and TSC (in w/w%) of a soil layer, its total salt mass (TSM in g) can be calculated according to Eq. 5.

$$TSM = m_{soil} * TSC / 100 \quad (5)$$

To quantify  $SB_{ACT}$ , it can be derived from TSM values determined before ( $TSM_{ini}$ ) and after ( $TSM_{final}$ ) the irrigation season (Eq. 6).

$$SB_{ACT} = TSM_{INI} - TSM_{FINAL} \quad (6)$$

### **3.4. Lysimeter experiment to study microdose application of soil conditioners**

In order to demonstrate that the microdoses of soil conditioners can change the physical and chemical properties of the soil water, we established a lysimeter experiment including 8 simple drainage lysimeters in RIK in 2019. The lysimeters were filled with a meadow chernozem soil. We simulated the soil and irrigation conditions characteristic in the gardens around Karcag.

#### **3.4.1. Organic basket method for micro 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. 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. The micro doses were calculated based on the full dose recommended by the producer. The  $\text{kg ha}^{-1}$  amounts were converted into  $\text{g m}^{-2}$  dividing them by 10. The exact amount of soil conditioners for one plant (basket) was calculated by dividing the amount for  $1 \text{ m}^2$  with the number of chili plants on  $1 \text{ m}^2$ .

In order to ensure the micro-dosing of the soil conditioners, as the first approach, we made organic (recycled paper) baskets, which contained 500 g soil, the conditioners and the indicator plant, which was chilli pepper (*Fig. 10*). Indeed, the material of the basket was degraded and did not impede the growth of the roots/plants but kept the amendments close to the roots for a while (the digestion time of the paper baskets was not determined). The material of the baskets, paper has high C: N ratio because of the wood fibre in general (O'BRIEN et al., 2002).



*Figure 10.* Paper baskets used for the micro soil conditioning experiment in the lysimeters (Karcag, 2019)

We placed these sets into the topsoil. The main ingredients of the conditioners are clay minerals, trace minerals and organic nutrients originating from algae (BLOUSSON, 2018). Two soil conditioners were tested and their combination. Involving the untreated control, the experiment was set up with four treatments in two replications. In the control treatment, only N-P-K fertilizers were applied. The treatments of the experiment were as follows: control 3 g of NPK, Physiomax (Physi) 13.5 g, Solactive (Sola) 13.5 g, Neosol plus Physiomax (Sola+Physi) 13.5 g + 13.5 g. Each treatment was equipped with three chili plants in three baskets (*Fig. 11*).



*Figure 11.* Plantation of chili plants in the lysimeters (Karcag, 2019)

The general requirements for the production of this plant make it suitable for being the indicator crop of the experiment, such as life cycle of one year, optimal temperature range

from 20 to 25°C (min. 13°C and max. 40°C); cultivated in tropical, subtropical and tempered regions; soil with good drainage and rich in organic material; soil pH range 5–7; relative humidity of the air range 50–70% (RAMIREZ, 2012).

### **3.4.2. Sampling and measurements in the soil conditioning experiment**

In order to evaluate the effect of the soil conditioners, we took soil samples from the lysimeters to compare the physical and chemical effect of the investigated micro soil conditioners in the topsoil. The samples were taken two times, first we took samples from the upper layer (20 cm) before setting the experiment. The second sampling was in the following spring near the organic baskets (same soil as in the baskets). In the Central Laboratory of RIK, soil plasticity, NPK contents and salt content were measured. The first sampling contributed to determine the necessary fertilizer and soil conditioner doses need to be added to each treatment.

During the harvest days (27<sup>th</sup> September and 11<sup>th</sup> October, 2019) we counted the number of the chili fruits and weighed the total yield separately in order to compare the effects of the soil conditioners on them. Also, we collected leachate water samples from the lysimeters in order to prove that the salts from the topsoil were leached or not. The measured variables were the electric conductivity (EC) of the soil, soil temperature, and soil moisture content, all measured by means of an UMP-1 mobile probe.

### **3.5. Description of the small-plot experiment**

The experiment was set up in the Irrigation Experimental Garden (IEG) of 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 gardens located in 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. According to a recent soil profile description, the humic A horizon goes down to 0.5 m, it is black in wet status. The B horizon is goes down to 0.82 m, compacted with prismatic structure and dark grey colour (HUE 10YR 4/2). Under it, a transitional 0.3 m thick BC horizon can be found with

compacted prismatic structure and brownish grey colour (HUE 10YR 4/4). The C horizon is under 1.1 m, yellow (HUE 10YR 7/8) and contains CaCO<sub>3</sub>.

In 2019, we sampled the upper layers (0–0.2, 0.2–0.4, 0.4–0.6 m). The results of the soil analyses made by the Central Laboratory of RIK according to the Hungarian standards (MSZ) are shown in *Table 5*.

*Table 5.* Soil parameters of the Irrigation Experimental Garden (Karcag, 2019)

Depth (m)	pH <sub>KCl</sub>	K <sub>A</sub> <sup>*</sup>	Salt content (m/m)%	CaCO <sub>3</sub> (m/m)%	Humus content (m/m)%	NO <sub>3</sub> <sup>+</sup> NO <sub>2</sub> (mg kg <sup>-1</sup> )	P <sub>2</sub> O <sub>5</sub> (mg kg <sup>-1</sup> )
0-0.2	6.7	52	0.08	0.42	3.9	49.4	629
0.2-0.4	6.5	53	0.08	0.25	3.4	12.0	348
0.4-0.6	6.4	55	0.07	0.21	2.9	13.9	113

Depth (m)	K <sub>2</sub> O (mg kg <sup>-1</sup> )	Na (mg kg <sup>-1</sup> )	Mg (mg kg <sup>-1</sup> )	SO <sub>4</sub> -S (mg kg <sup>-1</sup> )	Zn (mg kg <sup>-1</sup> )	Cu (mg kg <sup>-1</sup> )	Mn (mg kg <sup>-1</sup> )
0-0.2	626	181	416	26.5	8.6	7.8	462
0.2-0.4	439	46	436	7.2	4.8	5.4	474
0.4-0.6	307	77	434	6.4	1.6	3.9	452

\*K<sub>A</sub> is the plasticity index by Arany

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 (*Fig. 12*).



*Figure 12.* Bean, pea, and chili plants in the Irrigation Experimental Garden (Karcag, 2022)

### 3.5.1. Treatments of the small-plot experiment

Three amendments were applied in the small-plot experiment, their main properties are summarized in *Table 6*. These amendments can be purchased in Hungary and widely known by the farmers. The producers' recommendations can be found in the internet (I1).

*Table 6.* Main components of the soil amendments used in the IEG

Amendment	Type	Main properties
Neosol	soil conditioner	CaO 35%, MgO 8% Moisture content < 0.8% Particle size min. 80% <0.315 mm pH 7.7, Density 1.19 g/cm <sup>3</sup>
Physiomax	soil conditioner	CaCO <sub>3</sub> 76%, MgO 3%
Terrasol	compost	Density max. 0.9 kg/dm <sup>3</sup> Dry matter content max. 60 m/m% Organic material content min. 50 m/m% pH 8.5 ±0.5 Total salt content max. 12.0 m/m% Particle size 100% <25 mm N min. 2.5 m/m%, PO min. 9 m/m% KO min. 5.0 m/m%, Ca min. 1.8 m/m% Mg min. 0.7 m/m%

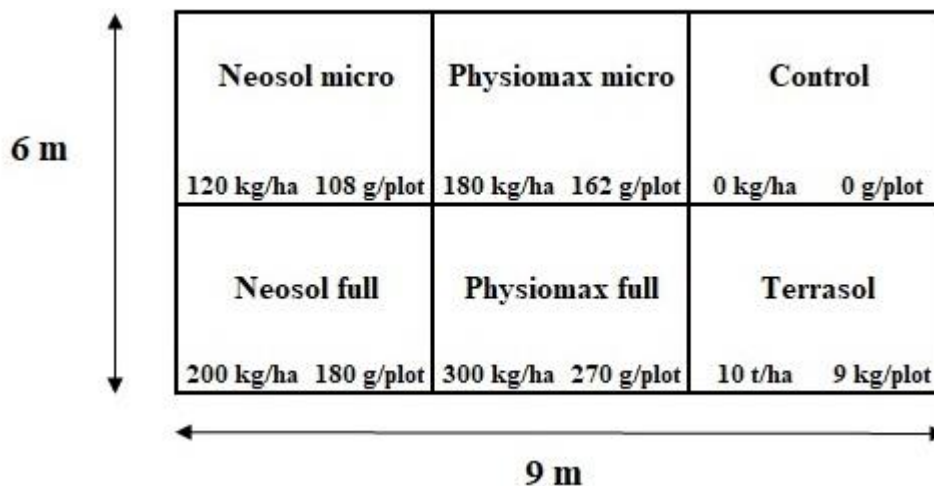
The amendments used as treatments and the relevant indicator crops with their salt tolerance degree are listed in *Table 7*.

*Table 7.* Amendments and indicator crops 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; SZÚCS et al. 2014; 2015)	chilli	LT
		peas	NT
		beans	NT
Physiomax (Microdose: 180 kg/ha, standard dose: 300 kg/ha)	CaCO <sub>3</sub> and sulphates as biostimulants (ZSEMBELI, 2019a,b)	chilli	LT
		peas	NT
		beans	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	LT
		peas	NT
		beans	NT

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

The amendments were applied and distributed on 18 small plots of 3x3 m in May, 2020, 2021, and 2022 prior to sowing or planting of the indicator crops (*Fig. 13*). 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 microdose were applied. Standard dose represented the full dose of the soil conditioner recommended by the producer of each product. 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. 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.



*Figure 13.* Experimental setup of the treatments in the Irrigation Experimental Garden for each indicator crop (Karcag, 2020–2022)

### 3.5.2. Sampling and measurements in the small-plot experiment

We induced secondary salinization by irrigation of vegetable crops with saline water (total soluble salt content  $\sim 700\text{-}900\text{ mg L}^{-1}$ ) to understand the salinity process taking place in the upper (0–0.3 m) layer of the soil. In order to test the different soil conditioners in the upper layer, we periodically monitored and measured the actual electric conductivity ( $\text{EC}_a$ ,  $\text{mS cm}^{-1}$ ) and the moisture content of the soil (v/v%) during the growing seasons (May-September, 2020-2022). Former field studies and lysimeter experiments with soil conditioners carried out at RIK proved that compost (Terrasol) and biosynthetic soil conditioners (Physiomax, Neosol and Explorer) are suitable to mitigate the harmful impact of secondary salinization (MONORI et al. 2008; RIVERA-GARCIA et al. 2020; SZÜCS et al. 2014; ZSEMBELI et al. 2019b). Nevertheless, in all these investigations, full doses of the applied amendments were studied. We wanted to complete and extend our former findings with the microdose 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 by Umwelt-Geräte-Technik GmbH (I3, Fig. 14). In 2020-2021, the  $\text{EC}_a$  of the upper 0.1 m soil layer was measured with a mobile HI 98331 EC-tester by Hanna Instruments.



*Figure 14.* Measurement with the EC-tester by Hanna (I3) in 2022

In 2022, for economy consciousness, instead of the expensive and time costly analysis of so many soil samples, I decided to measure the soil EC as is simple and it needs no

expensive instruments and laboratory analyses, but provides many data with the possibility of repetitions that are necessary for the statistical analyses. Therefore, in 2022, we could purchase another EC-meter, which is suitable to measure the EC of the soil down to 0.6 m (*Fig. 15*). I used this Fieldscout EC-meter by Spectrum Technologies, Inc. to regularly determine the EC of the 0-0.2 and 0.2-0.4 m soil layers, respectively. This way, the dynamics of salt accumulation and movements could also be monitored.



*Figure 15.* Measurement with the EC-tester by Spectrum Technologies, Inc. in 2022

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

### **3.5.3. Irrigation water conditions**

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 maintain 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  $700\text{-}900 \text{ mg L}^{-1}$ , which is higher than the upper threshold ( $500 \text{ mg L}^{-1}$ ) determined in the regulation as the maximum salt content of waters allowed to use for irrigation in Hungary (ZSEMBELI et al., 2011 2019a). Each crop was irrigated as indicated in *Table 8*, showing the irrigation and salt inputs during the three

irrigation periods from May to September in 2020-2022. The different input of irrigation (number of irrigation events) depended on the water demand and the salt tolerance of the indicator crop species.

*Table 8. Salt inputs in the irrigation experiment (Karcag, 2020-2022)*

Year	Crop	Number of irrigation events	Irrigation input [mm = L m <sup>-2</sup> ]	Average salt concentration of the irrigation water [mg L <sup>-1</sup> ]	Salt mass input [g m <sup>-2</sup> ]
2020	Beans	9	85	691	58.7
	Peas	8	74	691	51.1
	Chili	16	253	691	174.8
2021	Beans	15	170	898	152.7
	Peas	9	87	898	78.1
	Chili	19	192	898	172.4
2022	Beans	15	264	796	210.1
	Peas	12	203.5	796	161.9
	Chili	12	190	796	151.2

### 3.6. Description of the pot experiment

The pot experiment was set in RIK in April 2022 on the basis of a similar preliminary experiment carried out in 2018 (ZSEMBELI et al., 2019c). This experiment was set in order to evaluate the soil respiration by the CO<sub>2</sub> 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.

The soil of this experiment was the same type (see 3.5.) as in the small-plot experiment set in the IEG (*Table 9*). 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. The pots were placed indoor ensuring room temperature for the whole investigation period.

*Table 9. Some parameters of the soil used for the pot experiment (2022)*

Soil type	pH (KCl)	K <sub>A</sub>	Salt content (m/m)%	CaCO <sub>3</sub> (m/m)%	Humus content (m/m)%	NO <sub>3</sub> -N mg/kg	P <sub>2</sub> O <sub>5</sub> mg/kg	K <sub>2</sub> O mg/kg
Chernozem	5.5	43	<0.02	< 0.05	3.5	13.6	170	499

*Legends: K<sub>A</sub> – Plasticity according to Arany*

### 3.6.1. Treatments of the pot experiment

We used 2 mineral soil conditioners produced and sold by Timac Agro Ltd. and one control treatment without soil conditioning. The soil conditioner doses in the experiment: 13.5 g of Physiomax (Physi) and 13.5 g of Neosol (Neos). The soil moisture content in the pots was maintained by regular irrigation (in half a litre doses). Two different irrigation waters were used: 1) tap water with 900 mg L<sup>-1</sup> total soluble salt content, and 2) deionised water as a control of the salt load treatment (*Table 10*).

*Table 10.* 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

### 3.6.2. Measurements in the pot experiment

The CO<sub>2</sub> emission of the soils was determined after measuring CO<sub>2</sub> concentrations with a Testo 535 infrared gas analyser. The measurement range of the analyser is 0-10.000 ppm with the resolution of 1 ppm (*Fig. 16*).



*Figure 16.* Measuring with Testo 535 infrared gas analyser

I followed the measurement protocol described by KOVÁCS (2015). The buckets were covered one by one after 1 minute. After the incubation (30 minutes) from the first bucket,

the CO<sub>2</sub> concentration was measured above the soil surface. After one minute, the next bucket was measured, and this process continued till the last bucket. The CO<sub>2</sub> concentration from the soils were measured each week in the investigated period.

Parallel with carbon-dioxide concentration measurements, I regularly determined the soil moisture content (m/m%) by weighing the buckets and calculated the moisture content from change of the soil mass. Furthermore, I measured the EC<sub>a</sub> of the upper 10 cm soil layer with a mobile EC-tester by Hanna Instruments described in Chapter 3.2.2. The calculated CO<sub>2</sub> emission and soil moisture content data, and the measured EC<sub>a</sub> values were arranged in a Microsoft Excel sheet and visualized by indicating their standard deviations.

### **3.7. Statistical evaluation methodology**

#### **3.7.1. Statistical evaluation of the results of the soil conditioning experiment**

During the irrigation season, I measured the EC<sub>a</sub> values in the top soil layer (0–10 cm) in all the treatments and the control plot. I used a statistic model which calculates if the data have a normal distribution and compares groups in order to verify if there was a significant difference among them. I used PSPPire.exe to run the statistical analysis and I choose one-way analysis of variance (ANOVA). This test allowed us to divide the variability of the groups of interest and compare the means between them. However, one way ANOVA showed that at least two groups were different from each other, it did not tell which groups were different. That is why I used an ad hoc test (significant difference test) to tell exactly which groups had a difference in means. (WINKLERS and HAYS, 1975; PORRAS, 2001, BADI et al., 2012).

#### **3.7.2. Statistical evaluation in the IEG complex experiment**

The statistical evaluation of the methodology was carried by continuous numerical variables using independent samples and the sampling process was independent measurements carried out from 2018 to 2022. For the descriptive analysis, I used means, standard deviation and variance, percentiles, correlation and hypothesis testing ( $\alpha > 0.5$ ) for one-tailed test (p-value) used in ANOVA. These statistical points are indispensable to

analyse data and use any statistical software with an accurate driven data conclusion (RUI and ACOSTA, 2019). In addition, I used graphs like bar charts, time charts and box plots to explain the results. Thanks to the easy measurements from the EC and soil moisture content, I could apply different tests and analyses for the different treatments and years.

### **3.7.3. Statistical evaluation of the complex effect of irrigation**

I assessed 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. This statistical analysis gives information about the magnitude of the correlation, as well as the linear direction relationship (GIACOMINI 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 ( $\Theta$ ). 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.

We used a statistic model in order to verify if there is a significant 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.

#### **3.7.4. Statistical evaluation of the results of the pot experiment**

I used the one-way analysis of variance (ANOVA) as a statistic method in order to verify if there was a significant difference in the CO<sub>2</sub> emission and EC<sub>a</sub> values of the soils treated with different soil conditioners and irrigation waters. In order to know which of the specific soil conditioning treatment and irrigation input groups differed, I run LSD post hoc tests with the software of Windows Office Excel.

## 4. RESULTS

### 4.1. Results of the secondary salinization experiment set up in the lysimeters

This secondary salinization experiment was set up based on a preliminary study carried out in 2018 aiming to determine the effect of the application of two soil conditioners on the  $EC_e$  profile of the soil, the  $EC_w$  of the leachate and the yields of chili. The two soil conditioners under study were Solactive (Sola) and Physiomax (Physi) from company Timac Agro. In order to understand the results of the secondary salinization experiment set up in the lysimeters in 2019, some results of the preliminary study are highlighted in this chapter.

We speculated to have different reactions in the upper layer between the control and where soil conditioners were applied. *Table 11* shows the  $EC_a$  values of the top layer of the treatments. The EC value did not change in the control treatment during the time, in the case of the Sola treatment the final EC value was higher than the initial one, while in the Physi and Physi+Sola treatment decreased.

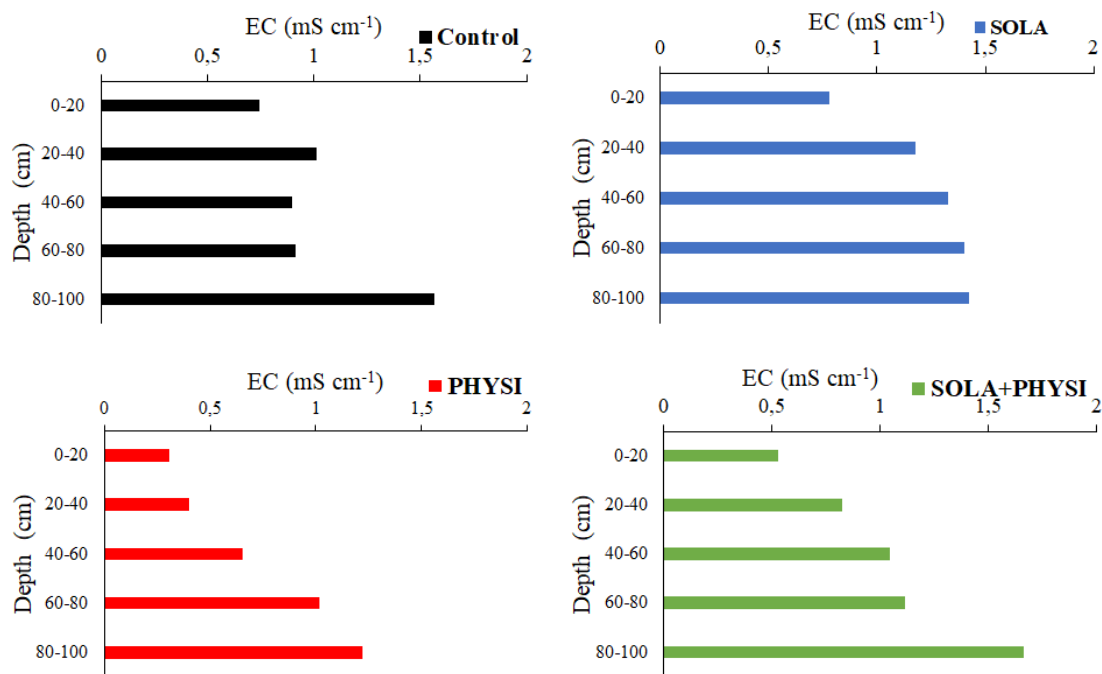
*Table 11.*  $EC_a$  differences measured in the topsoil of the lysimeters (Karcag, 2017-2018)

Treatment	EC (mS cm <sup>-1</sup> ) July 2017	EC (mS cm <sup>-1</sup> ) March 2018	Minimum (mS cm <sup>-1</sup> )	Maximum (mS cm <sup>-1</sup> )	Std. Devi- ation
Sola	0.78	0.81	0.64	3.65	0.92
Physi	0.35	0.15	0.08	2.62	0.74
Sola+Physi	0.53	0.31	0.46	4.304	1.29
Control	0.75	0.75	0.75	3.124	0.78

It is interesting that Sola+Physi combination behaved differently. Possibly Physi reacted with Sola conditioner boosting salt accumulation for a while, but later also enhanced leaching. It is known that irrigation induces changes in the physical, chemical and biological characteristics of the soil, but in this case the salt leaching depends not only on irrigation. The bond between clay and salts is altered by increasing organic matter and moisture. It is known that the addition of amendments causes drastic changes in the characteristics and qualities of soils (MALETIC and HUTCHINGS, 1967), but in this micro-dose the soil slightly modifies the  $EC_a$  values. On the base of the statistical analyses, the standard deviation varied between each data point relative to the mean. For Sola+Physi treatment, the variation was higher than for the other treatments. However, the range among the treatments was 0.97 mS cm<sup>-1</sup>, but the ANOVA test showed no significant

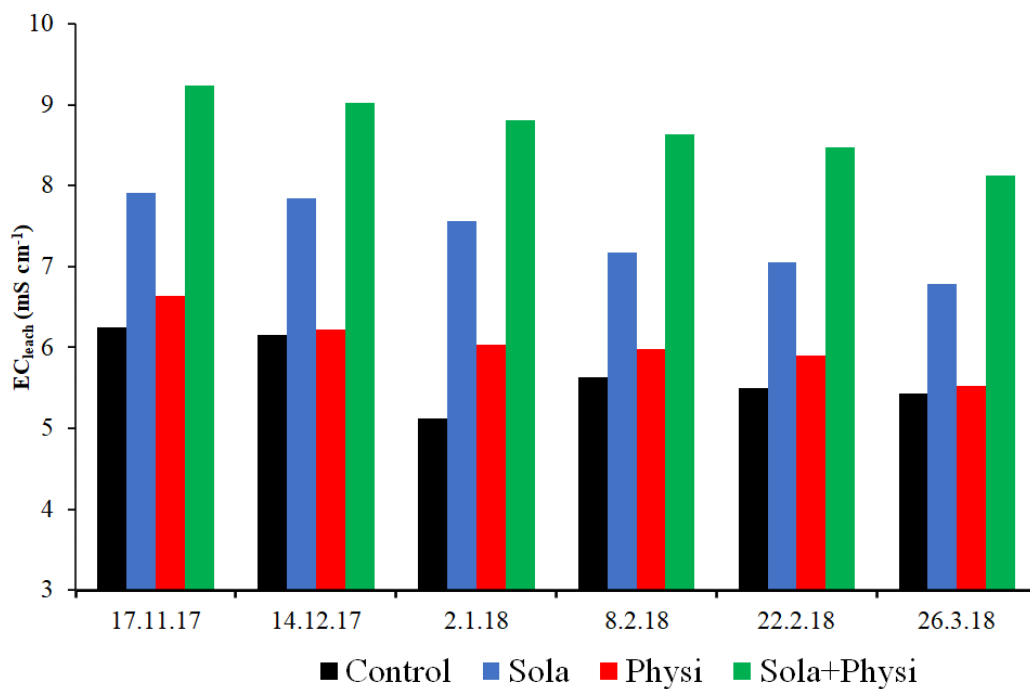
difference between the treatments ( $F = 1.75$  for the  $\alpha 0.1$ ). For instance, the control and the conditioned treatments were not different at all, that means that the  $EC_a$  value was changing during the time and the soil conditioners are not disturbing this natural variation. This is important in the environmental point of view because the native microorganisms are not influenced by rough changes with the application of microdoses of soil conditioners.

The  $EC_e$  profiles determined for the soils of the treatments reflect the distribution of the salts in the different soil layers (*Fig. 17*). In this case, the irrigation water applied contained appreciable quantities of soluble salts and could lead to salinity problems by time. The comparison of the salt profiles of the treatment Sola and the control showed that the salts were not leached down at all from the upper layer. It is possible that the salt content of conditioner Sola was leached into the other layers, meanwhile the salts on the top layer remained like in the control. The soil profile of Physi reflected the action of a salt leaching down to the bottom (80–100 cm). Meanwhile the salt profile of Sola+Physi showed leaching of the salts, but it was less efficient than the other soil conditioner.



*Figure 17.* EC profiles in the function of the treatments in the lysimeter experiment (Karcag, 2018)

We collected the all the waters leached from the lysimeters (drain waters or leachates), we sampled them six times until the end of March of 2018, and their  $EC_{leach}$  was measured in the laboratory. After irrigation with 392.5 mm highly saline water ( $EC_w$  was  $2.8 \text{ mS cm}^{-1}$ ), we expected high salt concentrations due to leaching from the treated soil columns. The first leachate appeared in November 2017, when the whole soil column was saturated over the field capacity and deep percolation occurred through the gravitation pores. The salt content of the leachates was slightly decreasing over the time, but they still had high concentrations ( $>3,000 \text{ mg L}^{-1}$ ). *Fig. 18* shows the salt contents of the leachates at the monitoring dates. Sola+Physi was the treatment in which the water had more salts, because the salts from the conditioners and the salts from the top layer percolated. The Physi treatment and the control could be characterized with similar EC values all over the investigation period. The remaining salts percolated to different levels just like in the case of the control.



*Figure 18.* EC in the leachates in the lysimeter experiment (Karcag, 2017–2018)

The harvest of the chilli peppers was in October 2017. The plant and the fruits were dried and weighed. We compared the dry mass of the plants and the fruits from each treatment. In distinction, Physi treatment had the best improvement in the vegetative growth and yield. However, Sola+Physi treatment had the worst performance on the fruits. The effect of the soil conditioners had better performance in the vegetative part of the plants (*Fig.*

19). In fact, the combination of these two soil conditioners (Sola+Physi) in the dose applied could not be recommended.

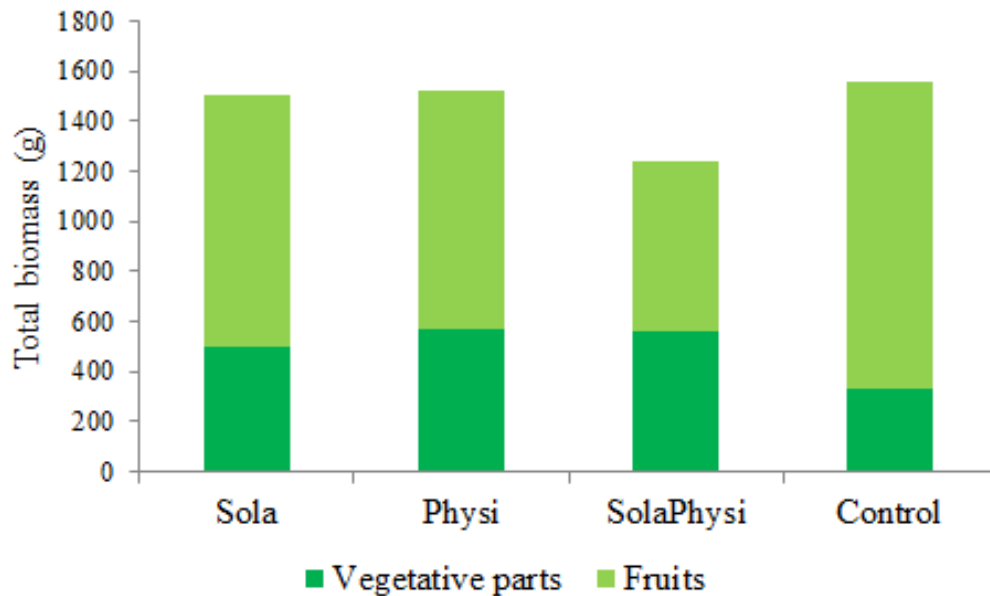


Figure 19. Total biomass results of chili in the lysimeter experiment (Karcag, 2018)

However, all these changes in the soil characteristics and impacts on the yields of chili were too complex to be explained and we needed more information in this respect. Therefore, a modified experiment was continued in the lysimeters in 2019.

#### 4.1.1. 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. The results of the regularly measured soil EC and moisture contents in the 0–0.1 m soil layer are shown in *Fig. 20*. It is obvious that the soil moisture content was between the desired 10 and 20 v/v% most of the time, but sometimes under that range. The soil EC was found to be dependent on the soil moisture content due to the high salt content of the irrigation water. The Pearson correlation test proved the strong association between these two continuous variables ( $r = 0.774$ ). In fact, secondary salinization was taking place proving that irrigation water was the only source of salt causing higher EC. In the irrigation season, the salts from the irrigation water temporarily accumulate on the surface of the soil particles due to the electrical charges. When the soil is dry the adsorbed ions are bounded firmly to the soil particles, but these adsorbed ions

can interchange freely with other soluble cations like  $\text{Na}^+$ . As the proportion of sodium increases, the soil tends to become dispersed and impermeable to water and air, also the ratio in  $\text{K}^+/\text{Na}^+$  change creating a deficient nutrition to the roots (REVEE and FIREMAN, 1967; RANGJIAN et al., 2018).

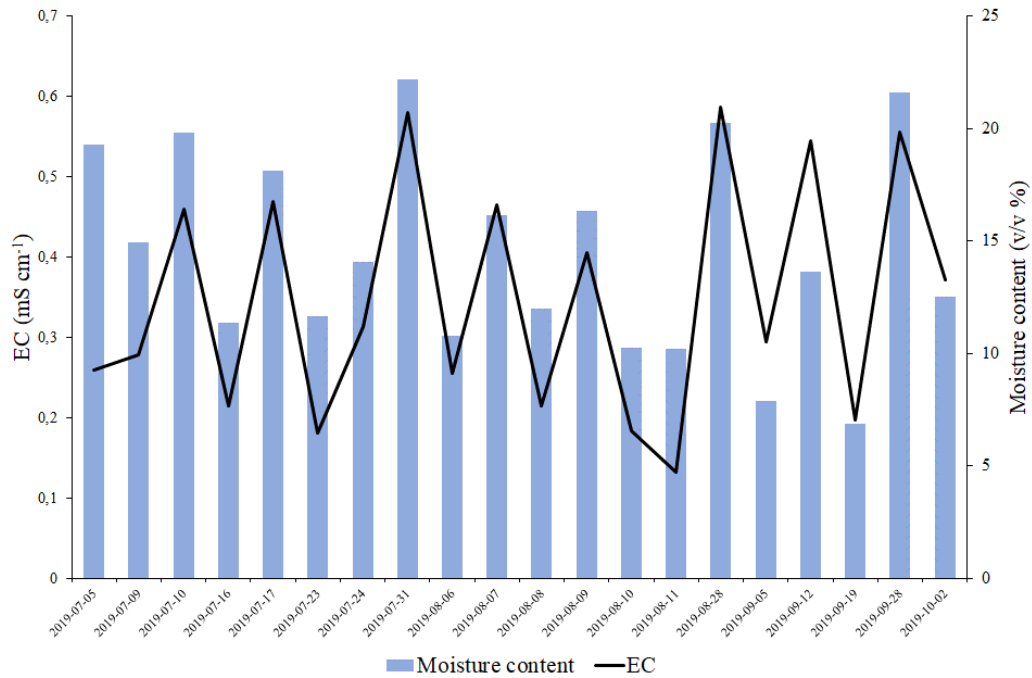


Figure 20. Dynamics of soil EC and moisture content in the 0-0.1 m soil layer (Karcag, 2019)

#### 4.1.2. 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 evaluate due to the physical and chemical complexity of most natural soils (BERGSTROM, 1990). To calculate the  $\text{SB}_{\text{TH}}$  for our lysimeters, we had to know the total salt input from the irrigation water and the total output of the soil of the lysimeters (leachate).  $V_{\text{IRR}}$  was the same for each lysimeter, but we expected some differences in  $V_{\text{LCH}}$  among the lysimeters due to some heterogeneity in the soil structure. We also assumed some changes in  $C_{\text{IRR}}$  and  $C_{\text{LCH}}$  during the investigated period. Therefore, we regularly measured the salinity ( $\text{mg L}^{-1}$ ) of the irrigation water and the leachates to determine the dynamics of these parameters (Fig. 21). 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. For example, during the investigated season of 2019, the first leachate appeared 4 weeks after the irrigation was started, while in some lysimeters a few days later. Likewise, there were some differences in  $V_{LCH}$  and  $C_{LCH}$  among the lysimeters as well,  $C_{LCH}$  varied in the range of 4,000–6,000 mg L<sup>-1</sup>.

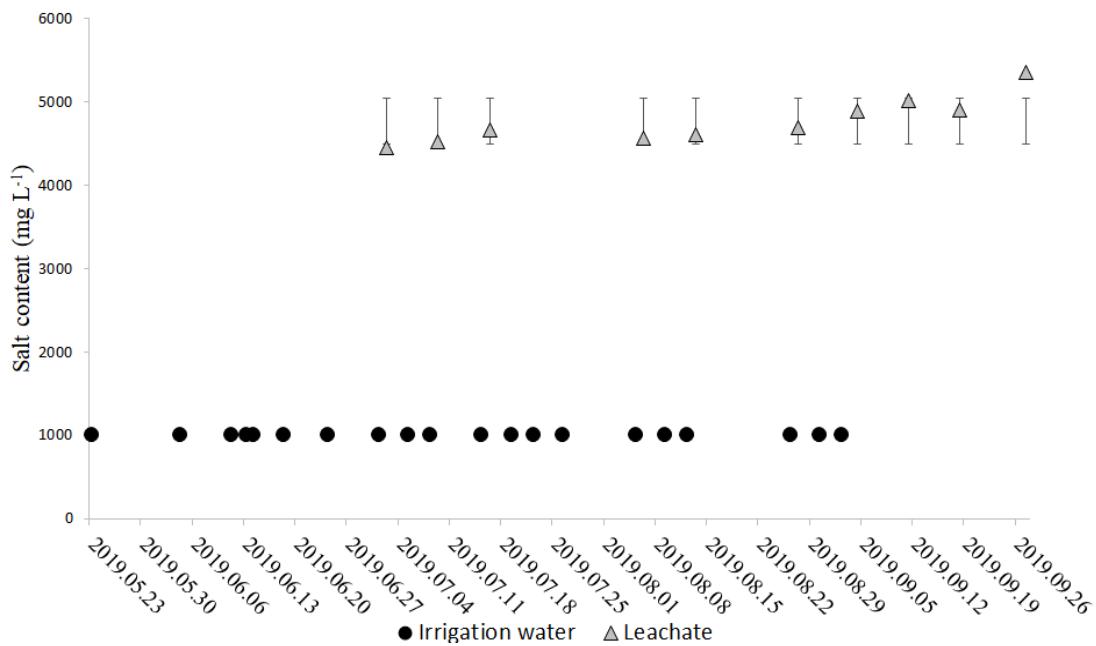


Figure 21. Dynamics of the salt concentration of irrigation (input) and leachate (output) waters in the lysimeter experiment in 2019

We determined the monthly  $SM_{IRR}$  and  $SM_{LCH}$  values for the four months of the irrigation season in 2019, and for the rest of the leaching season (2019–2020), when no salt input just output occurred (Fig. 22). 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. Annual rainfall and weather affect the salinization and desalinisation cycles. For example, rainfall or flooding may leach sufficient salt to achieve a root-zone salt balance under drainage conditions can enhance salt reduction in the root-zone. Furthermore, by means of irrigation, salty water can percolate into the subsoil and the level of groundwater can rise near the surface (MARTÍNEZ, 2002).

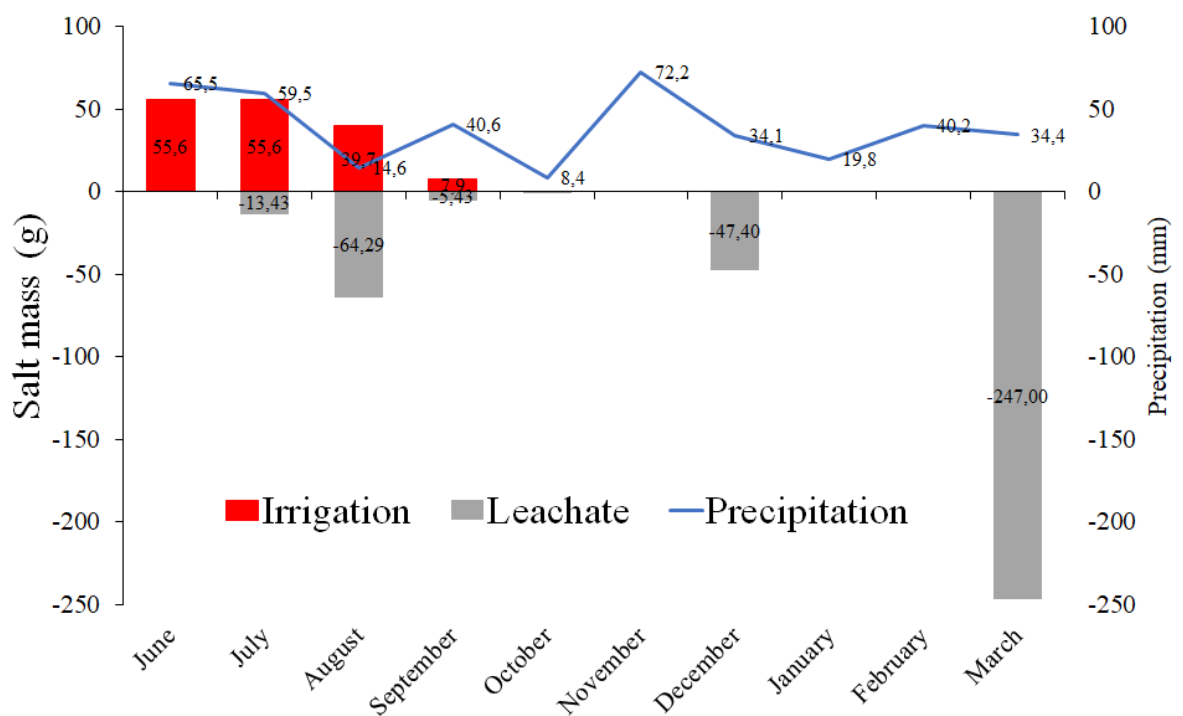


Figure 22. Monthly dynamics of salt mass inputs and outputs of the soil columns of the lysimeters during the irrigation and leaching seasons of 2019–2020

The monthly values of the salt mass inputs and outputs provide information not only on the dynamics, but on the monthly  $SB_{TH}$  of the soil too. During June and July, positive  $SB_{TH}$  was assumed, because there was not significant amount of leachate. In August, the lower amount irrigation and the more considerable amounts of leachate, which removed plenty of salts from the upper layer, resulted in negative  $SB_{TH}$ . After the irrigation season, no salt input but extensive leaching was characteristic due to the natural precipitation in the rest of the year. The dynamics of the salt input and output is dependent on the irrigation water or salt input, but annual weather patterns affect salinization and desalinisation cycles in the root zone (THAYALAKUMARAN et al., 2007). Naturally,

the rain and melted snow intensify salt outlet during the rest of the leaching season resulting in negative  $SB_{TH}$ . In our case, natural precipitation of 389.3 mm contributed to increase the actual soil moisture content of the lysimeters and to the 72.8 mm total average amount of leachate. As an average, 13.3% of the total water input (precipitation + irrigation) was outlet from the lysimeter system by leaching. This ratio also characterises each specific crop year.

#### **4.1.3. Theoretical salt balance of the 0-1.0 m soil layer**

THAYALAKUMARAN et al. (2007) recognised that the method to calculate SB is difficult because of the mismatches of surface and subsurface hydrological boundaries, the subsoil salt store and impacts on downstream or, in this case underground water quality. Therefore, it is practical to consider SB only for the root zone. An improved understanding of the mechanism of leaching and SB can help to adapt to salt stress and to maintain plant growth and ensure successful production (RANGJIAN et al., 2018). By means of lysimeters, accurate data about the volumes of irrigation and drainage (leachate) can be collected precisely, hence the  $SB_{TH}$  valid for the whole soil columns (0–1.0 m) can be calculated. Consequently, lysimeters are suitable to determine  $SB_{TH}$  without taking soil samples. Nevertheless, one of the limitations of  $SB_{TH}$  calculation is that it does not describe the absolute amount of salt or the level of average salinity in the system, just focuses only on the change in the amount of salts. Furthermore, this method cannot give any information on the stratification and translocation of salts. For field conditions,  $SB_{ACT}$  is the suitable method providing more information though not about deep percolation. For the better understanding of the two approaches described above, we introduce both with the data determined for the same lysimeters under study. In the investigated period, slightly negative (-5 g)  $SB_{TH}$  was calculated meaning that salt leaching from the soil column is assumed  $SM_{IRR}$ ,  $SM_{LCH}$  and  $SB_{TH}$  do not give information on the TSM of the soil. If we know the initial TSM of the soil, we can estimate the final TSM on the base of the input ( $SM_{IRR}$ ) and output ( $SM_{LCH}$ ) amounts of salts. The mean theoretical TSMs before (initial) and after (final) the irrigation season calculated for the soil columns of the lysimeters (0–1.0 m depth) for 2019 are illustrated in *Fig. 23*.

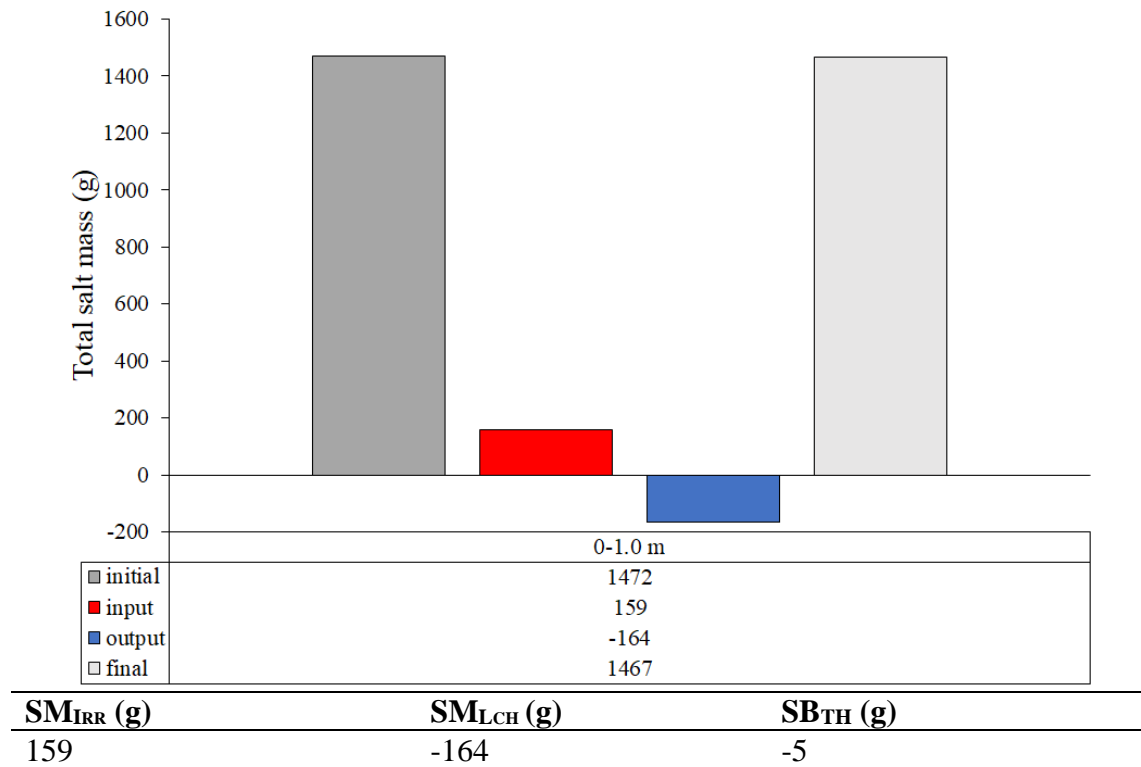


Figure 23. Mean theoretical salt mass of the soil columns of the lysimeters of the whole soil columns (0–1.0 m) in 2019

Legends:  $SM_{Irr}$  is the mean total dissolved salt mass in the irrigation water,  $SM_{Lch}$  is the mean total dissolved salt mass in the leachate,  $SB_{TH}$  is the mean theoretical salt balance

#### 4.1.4. Actual salt balance of the 0-0.6 m soil layer

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. 24).

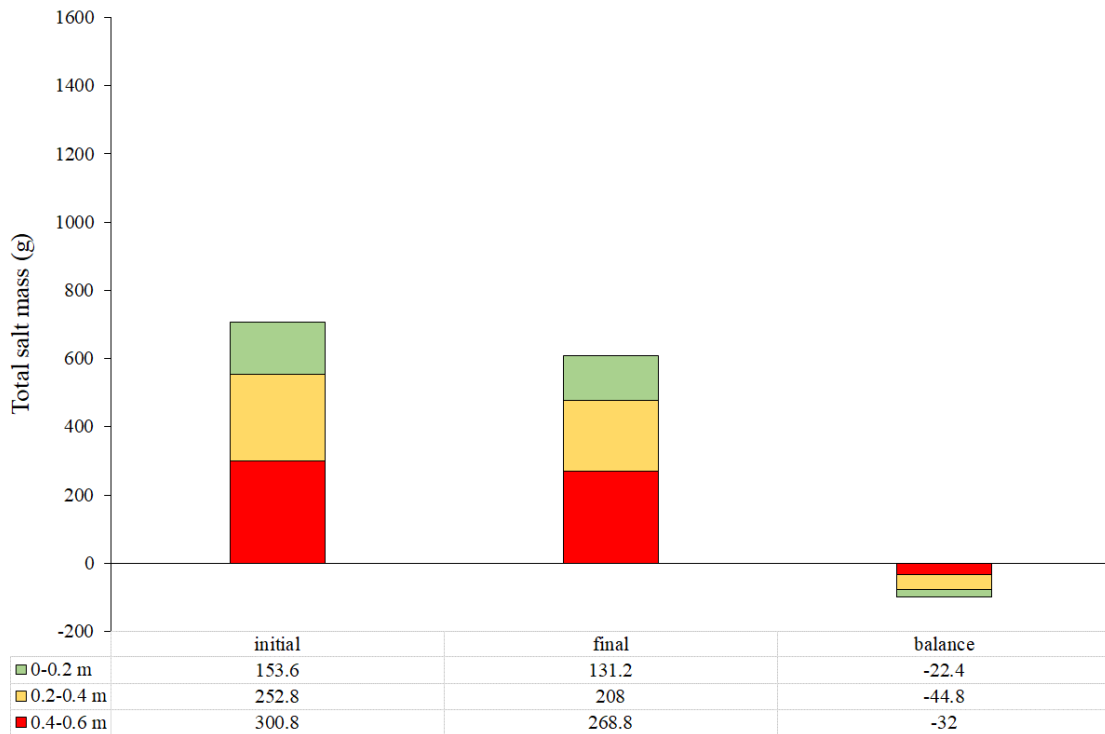


Figure 24. Mean actual salt balance of three soil layers (0–0.6 m depth) of the lysimeters in the irrigation season of 2019

We found leaching to be the dominant process during the irrigation season as the TSM values decreased in all the three examined soil layers (negative  $SB_{ACT}$ ). The upper 20 cm layer contained less salts than the lower two layers which had very similar salt contents. 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).

In our study, the determination of  $TSM_{INI}$ ,  $TSM_{FINAL}$  and  $SB_{ACT}$  of the soil in the three upper soil layers could not provide information on the salt status of the lower soil layer (0.6–1.0 m). Therefore, we combined the results of our  $SB_{ACT}$  and  $SB_{TH}$  calculations. This way, we determined the  $TSM_{INI}$ ,  $TSM_{FINAL}$  and  $SB$  values for the upper and lower soil layers (Table 12).

*Table 12.* Mean estimated salt masses (TSM) and balances (SB) of four layers of the soil columns for the irrigation season of 2019

Soil layer	Parameter		
	TSM <sub>INI</sub> (g)	TSM <sub>FINAL</sub> (g)	SB (g)
0-0.2 m	154	131	-22
0.2-0.4 m	253	208	-45
0.4-0.6 m	301	269	-32
0-0.6 m	708	608	-99
0.6-1.0 m	765*	859**	+94**

\*actual, \*\*theoretical

The negative SB (-99 g) of the upper 0.6 m of the soil column shows leaching, while the positive SB (+94 g) of the lower layer shows accumulation. Relocation of salts was taking place in the soil profile, the total amount of irrigation and the natural precipitation leached 100% equivalent of the input salts to the deeper layers and even 14% decrease of the initial TSM of the upper layers occurred due to leaching. The TSM increase of the lower layers was 12%. Traditional irrigation management, where water is not limiting, is to provide water such that the ratio of the depth of drainage to the depth of irrigation, the leaching strategy. The amount of additional water required to maintain a target salinity level, the leaching requirement (LR), is a function of crop sensitivity and irrigation water salinity (DUDLEY et al., 2008). Controlling or reducing salinity levels in the soil depends in the practices with water movement, which are amount of water, frequency and method of applying water, drainage and soil cultivation (REEVE and FIREMAN, 1967). In accordance with other studies (PEREIRA et al., 2014), our preliminary lysimeter experiments also revealed that improved soil structure combined with the optimization of irrigation (control of quantity, frequency) can mitigate the harmful effects of secondary salinization (ZSEMBELI et al., 2019b).

## **4.2. Results of the soil conditioning experiment set up in the lysimeters**

### **4.2.1. Effect of soil conditioners on electrical conductivity and salt content of the soil**

In the lysimeter experiment in 2019, we expected the EC<sub>a</sub> differentiating from the control due to soil conditioning. We assumed that the improved soil structure around the organic baskets due to soil conditioning results in more intensive leaching of the salts to the deeper layers, hence lower EC<sub>a</sub>. The dynamics of EC<sub>a</sub> in the upper soil layer (0-10 cm) showed

changes during the irrigation period indeed, but differences could be detected at certain points only (Fig. 25). Lower  $EC_a$  was characteristic to the soil treated with Explorer in three measuring dates and the untreated control showed the highest values in almost every case. Nevertheless, it can be concluded that these soil conditioners did not affect the general dynamics of EC in the soil, rainfall and irrigation water with its salt content were the main factors in the upper soil layer in this respect.

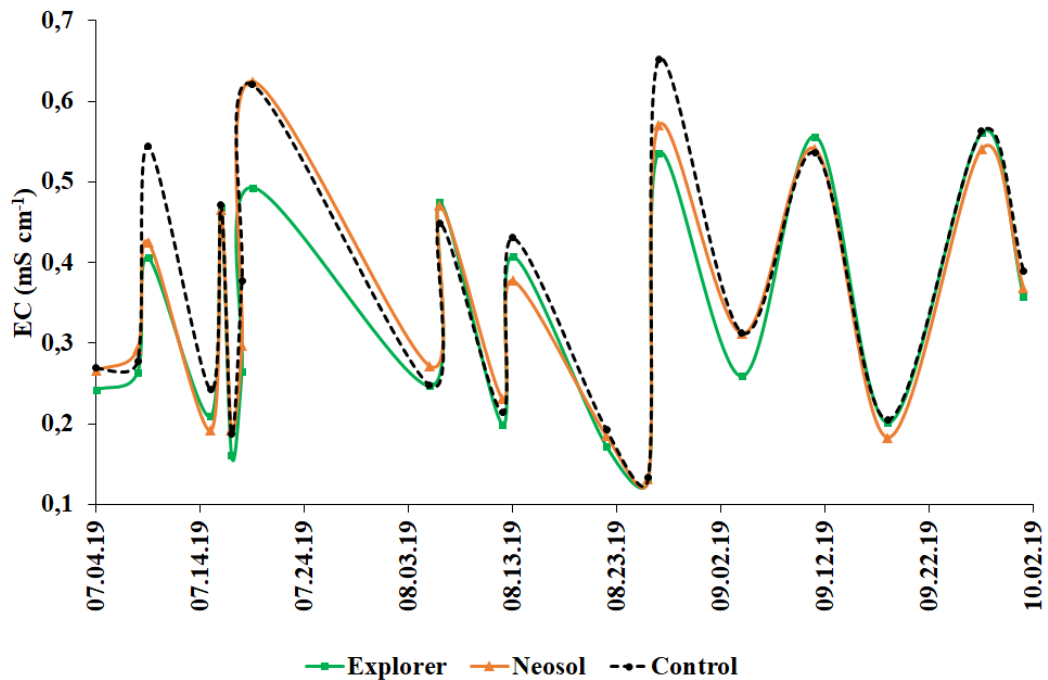


Figure 25. Average electrical conductivity measured in the upper soil layer (0–10 cm) of the lysimeters in the function of soil conditioning during the irrigation season (Karcag, 2019)

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. 26). 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 (see Chapter 4.3.).

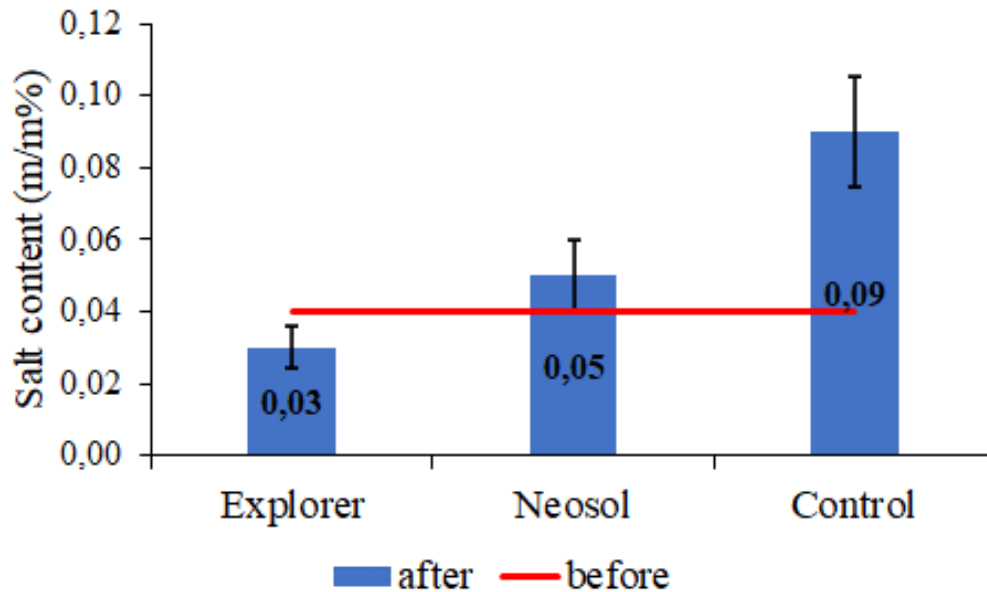


Figure 26. Average actual salt contents of the upper soil layer (0-20 cm) of the lysimeters in the function of soil conditioning before and after the irrigation season (Karcag, 2019)

#### 4.2.2. Effect of soil conditioners on the yields of chili

In 2019, the sowing of chili seeds took place on 8<sup>th</sup> May, the transplants were planted on 23<sup>rd</sup> May into the organic baskets and placed in the soil of the lysimeters. During the vegetation period of chili, the plants faced several problems that impeded their development: infestation by aphids, chlorosis, poor leaf turgor, infestation by *Nezara viridula*, *Homoptera*, resulting in dead leaves on several plants. Only one lysimeter of each treatment could be selected where all the plants survived and developed normally. Therefore, I can publish only the comparison of those three lysimeters without replications (I had no possibility to calculate the standard deviation from the replications). Nevertheless, I consider the yield results compared by descriptive analysis 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. Two parameters were studied: the total number of chili fruits in the three lysimeters in the function of soil conditioning are shown in *Fig. 27*, while the same comparison in terms of the total yields is in *Fig. 28*.

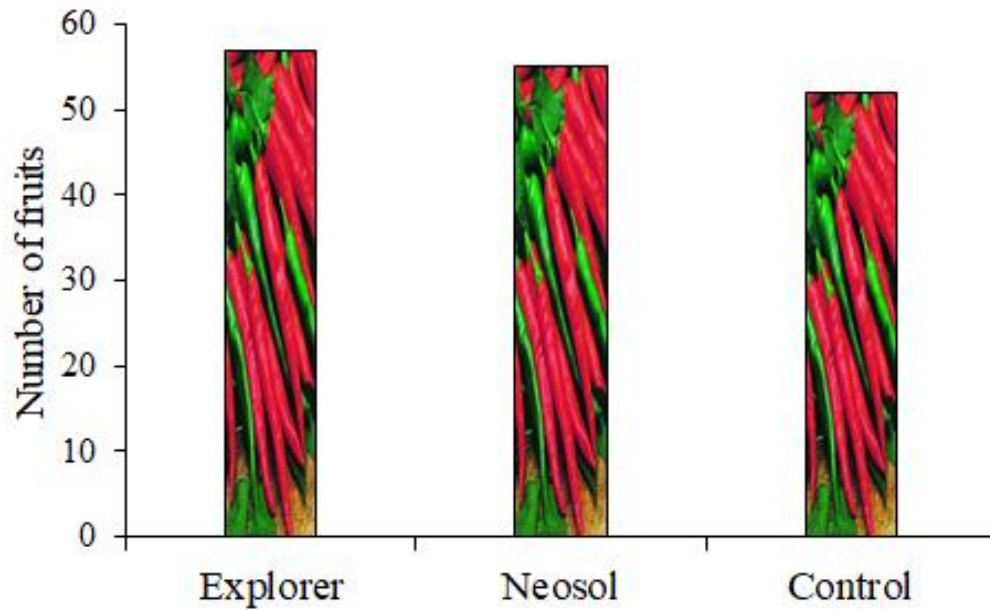


Figure 27. Total number of chili fruits in one lysimeter in the function of soil conditioning (Karcag, 2019)

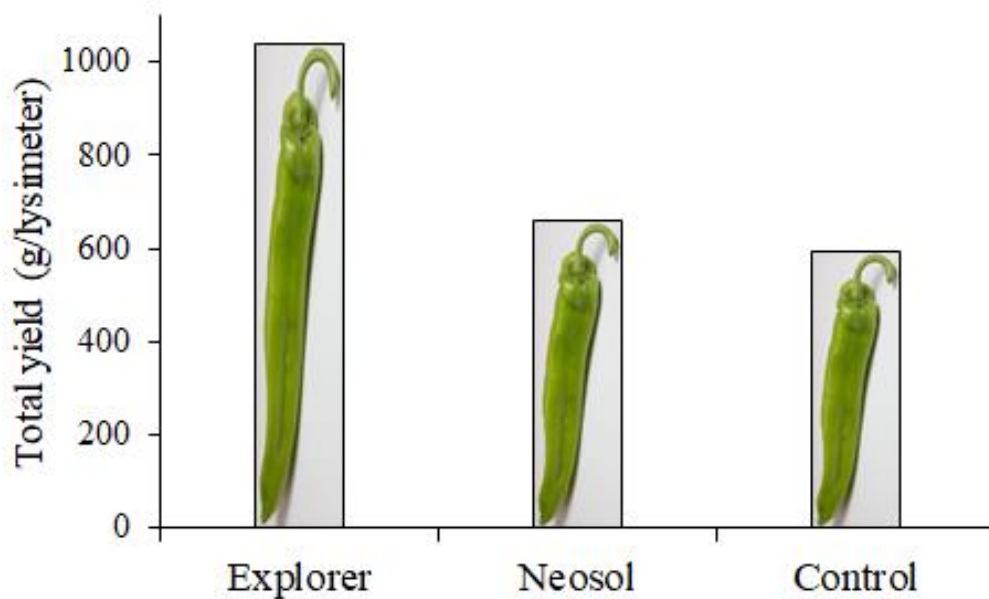


Figure 28. Total yield of chili in one lysimeter in the function of soil conditioning (Karcag, 2019)

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. Due to crop protection issues, the number of plants was a limiting factor in this experiment. That was one of the reasons while we wanted to extend my research to larger scale, namely in small plot conditions. Nevertheless, the yields ranged between 741 and 1297 g m<sup>-2</sup>

depending on the treatments, which can be considered normal. According to the Hungarian Central Statistical Office, the average yield of chili in Hungary in 2019 was 951 g m<sup>-2</sup>, so only Explorer provided yield above the average. For international comparison: SERMENLI and KAZIM (2010) reported 1593–1951 g m<sup>-2</sup> for chili produced in Turkey. In our experiment, the number of fruits per plant ranged between 52 and 57, which can be considered also normal as CHAKRABARTY and AMINUL ISLAM (2017) found that this parameter can vary in a high range according to the 20 varieties they investigated (17–266 fruits per plant).

### **4.3. Results of the small-plot experiment**

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 2022. 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.

#### **4.3.1. Effect of soil conditioners on the soil salt content**

Just like in the case of the lysimeter experiment (Chapter 4.1.4.), 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. The sampling was similar to the preliminary lysimeter experiment hence the samples were taken from the same three soil layers (0–0.2, 0.2–0.4, 0.4–0.6 m). Illustrating TSM<sub>INI</sub> and TSM<sub>FINAL</sub> 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 are shown in *Fig. 29*. The salt input of bean plots by irrigation was 58.7 g m<sup>-2</sup> in 2020 (*Table 8*). The input water that also determines the accumulation and leaching processes was 85 mm by

irrigation and 193.3 mm by natural precipitation during the irrigation period of beans (May–July) in 2020.

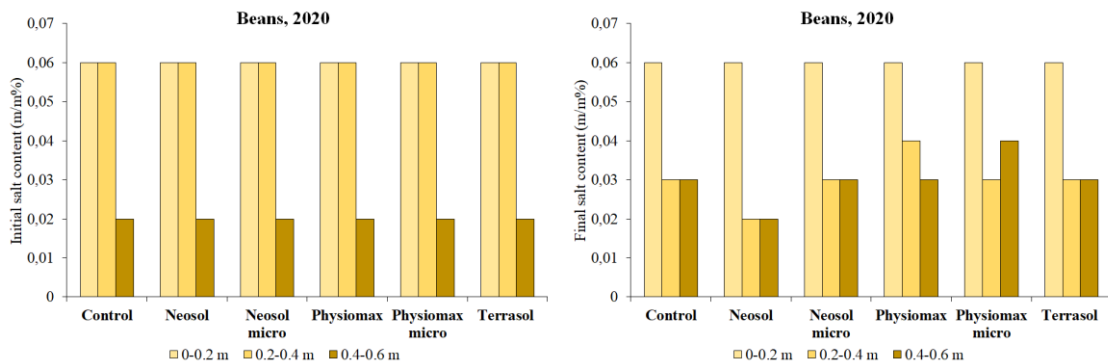


Figure 29. Average actual salt content of the 0-0.2, 0.2-0.4, 0.4-0.6 m soil layers in the small plots of beans in the function of soil conditioning before (left) and after (right) the irrigation season of 2020

For the whole 0.6 deep soil horizon slightly negative salt balance was characteristic in all the treatments and in the untreated control. Neosol full application had the most negative salt balance. In the upper 0.2 m layer, no changes were detected in any of treatments (0 balance), the total negative balances were due to the decrease in the 0.2–0.4 m layers: -0.03 m/m% for the Control, Neosol micro, Physiomax micro, Terrasol, -0.02 m/m% for Physiomax full, while -0.04 m/m% for Neosol full. In the lower soil layer (0.4–0.6 m), very small increase was found in all the treatments (0.01–0.02 m/m%), except for Neosol full, for that I calculated zero balance.

In the first year of the experiment, I did not expect significant effect of soil conditioning in terms of extended leaching in the bean subplots, especially because of the low amount of input salt ( $58.7 \text{ g m}^{-2}$ ), but Neosol full application showed promising results in this respect.

The salt profiles determined for the subplots covered with beans in 2021 are shown in Fig. 30. The salt input of bean plots by irrigation was  $152.7 \text{ g m}^{-2}$  in 2021 (Table 8). The input water was 170 mm by irrigation and 171 mm by natural precipitation during the irrigation period of beans (May–August) in 2021.

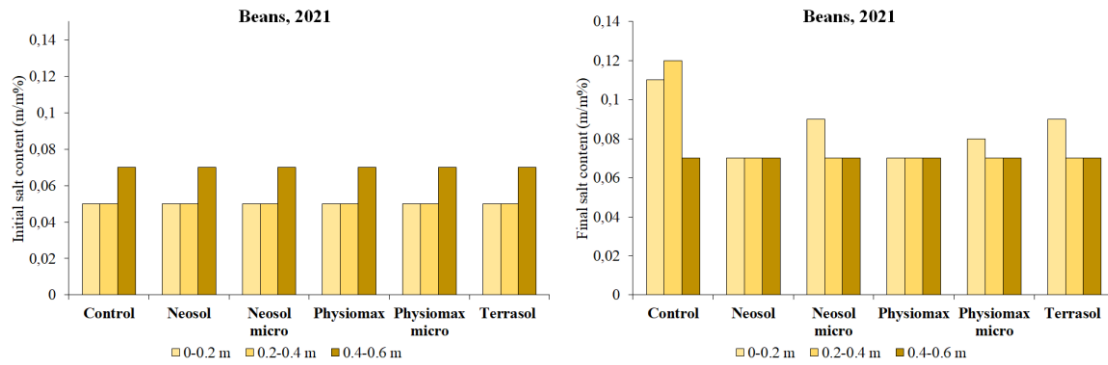


Figure 30. Average actual salt content of the 0-0.2, 0.2-0.4, 0.4-0.6 m soil layers in the small plots of beans in the function of soil conditioning before (left) and after (right) the irrigation season of 2021

By the second year of the experiment, we expected more extended effect of soil conditioning in terms of enhanced leaching after the irrigation period as higher amount of irrigation was applied (Table 8). Nevertheless, as Fig. 30 shows, by the beginning of the second irrigation period, the soils in all the treatments had the same salt profile due to the equalization effect of the leaching period (winter and early spring time). Especially the surface layer (0–0.2 m) could get rid of the accumulated salt by leaching to the deeper layers. In 2021, the salt input by irrigation  $170 \text{ g m}^{-2}$  in the bean subplots and the plants received less precipitation. In addition, I recognized positive balances in the upper and medium layers (0.02–0.06 m/m%), but 0 balance for the lower layer. For the upper layer (0–0.2m), Neosol and Physiomax full doses had a positive balance of +0.02 m/m%, Physiomax micro +0.03 m/m%, Neosol microdoses and Terrasol +0.04 m/m%, while Control had highest value with its +0.06 m/m%. In the middle layer (0.2–0.4 m), positive +0.02 m/m% salt balances were characteristic in all the treatments, except for Control which had appositive balance of +0.07 m/m%. Physiomax and Neosol application and microdoses showed promising results in that year. For the whole 0.6 m deep soil horizon, Physiomax and Neosol full applications had the lowest salt balances. In the lower 0.4-0.6 m layer, no changes were detected in any of treatments (0 balance).

The salt profiles of the subplots covered with peas in 2020 are shown in Fig. 31. The salt input of pea plots by irrigation was  $51.1 \text{ g m}^{-2}$  in 2020 (Table 8). The input water was 74 mm by irrigation and 117 mm by natural precipitation during the irrigation period of peas (May–July) in 2020.

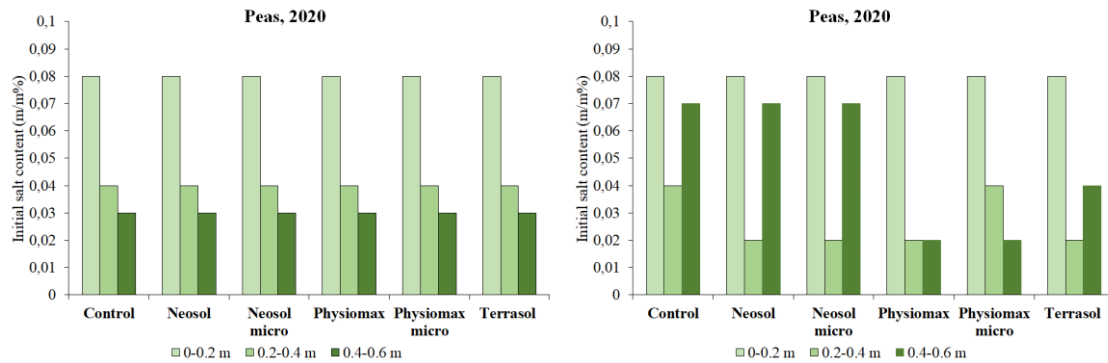


Figure 31. Average actual salt content of the 0-0.2, 0.2-0.4, 0.4-0.6 m soil layers in the small plots of peas in the function of soil conditioning before (left) and after (right) the irrigation season of 2020

Just like with beans, no significant effect of soil conditioning in terms of extended leaching was expected in the first year of pea, especially because of the low amount of input salt ( $51.1 \text{ g m}^{-2}$ , see *Table 8*). In the upper layer (0–0.2 m), no changes were detected in any of treatments (0 balance). In the middle layer (0.2–0.4 m), our results described a negative balance in Neosol full and micro doses, Terrasol and Physiomax ( $-0.02 \text{ m/m}\%$ ), meanwhile, Control and Physiomax microdoses had 0 balance. In the lower soil layer (0.4–0.6 m), positive balance (increase) was found in almost all the treatments ( $0.01\text{--}0.04 \text{ m/m}\%$ ), but Physiomax full application and microdoses showed promising results in this respect ( $-0.01 \text{ m/m}\%$ ). For the upper 0.4 m deep soil horizon, I recognized a slightly negative salt balance range characteristic to all the treatments. Meanwhile, in the in the lower layer (0.4-0.6 m), due to the salt mass movement during the irrigation period  $+0.04 \text{ m/m}\%$  salt balance was characteristic for the Control, Neosol, and Terrasol treatments, while Physiomax and Physiomax full application had slightly negative salt balances ( $-0.01 \text{ m/m}\%$ ).

The salt profiles of the subplots covered with peas in 2021 are shown in *Fig. 32*. The salt input of pea plots by irrigation was  $78.1 \text{ g m}^{-2}$  in 2021. The input water was 87 mm by irrigation and 102 mm by natural precipitation during the irrigation period of peas (May-July) in 2021.

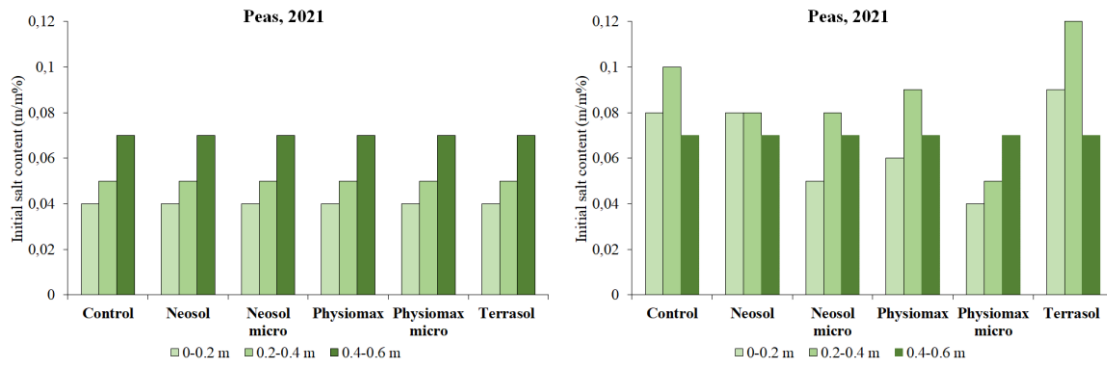


Figure 32. Average actual salt content of the 0-0.2, 0.2-0.4, 0.4-0.6 m soil layers in the small plots of peas in the function of soil conditioning before (left) and after (right) the irrigation season of 2021

In the second year of the experiment, the amount of input salt was  $78.1 \text{ g m}^{-2}$  (Table 8), which caused positive balances in the upper layer (0–0.2 m). Increased salt contents were measured in the Control and Neosol treatments (+0.04m/m%), in Terrasol (+0.05 m/m%), in Physiomax full dose (+0.02 m/m%), in Neosol microdose (+0.01 m/m%), while for Physiomax microdose 0 balance was calculated. In the medium layer (0.2–0.4 m), our results described positive balances due to the salt mass movement during the irrigation period: Terrasol +0.07 m/m%, Control +0.05%, Physiomax full dose +0.04 m/m%, Neosol full and microdoses +0.03 m/m%, only Physiomax micro had 0 balance. In the lower soil layer (0.4-0.6 m), neutral balance was found in all the treatments (0.0 m/m%). For the whole 0.6 deep soil horizon, I recognized a slightly positive salt balance characteristic to all the treatments with the exception of Physiomax microdose application which showed promising results (negative salt mass balance) in this respect.

The salt profiles of the subplots covered with chili in 2020 are shown in Fig. 33. The salt input of pea plots by irrigation was  $174.8 \text{ g m}^{-2}$  in 2020 (Table 8). The input water was 253 mm by irrigation and 213 mm by natural precipitation during the irrigation period of chili (June-September) in 2020.

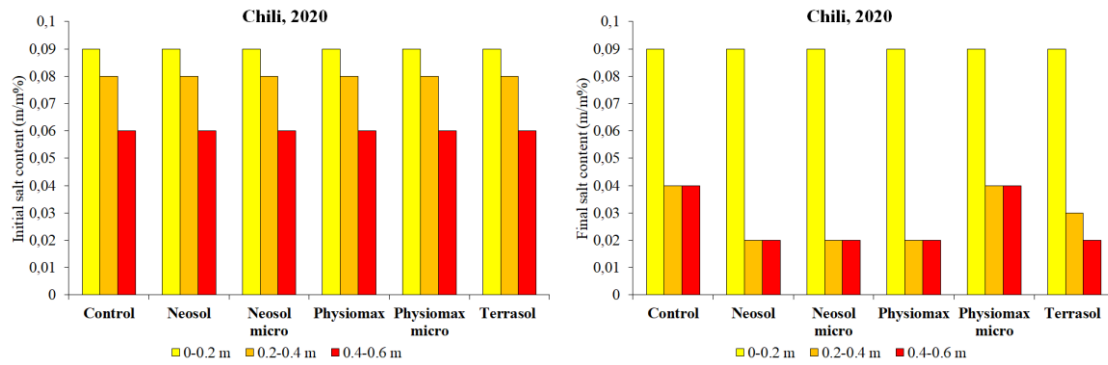


Figure 33. Average actual salt content of the 0-0.2, 0.2-0.4, 0.4-0.6 m soil layers in the small plots of chili in the function of soil conditioning before (left) and after (right) the irrigation season of 2020

In the first year of the chilli subplots, I recognized negative salt balances for all the treatments, which is especially interesting because of the high salt input ( $174.8 \text{ g m}^{-2}$ , see Table 8). Nevertheless, the high amount of input waters (466 mm) created a good chance for enhanced leaching, that must be the explanation of the negative salt mass balances. In the upper layer (0–0.2 m), no changes were detected in any of treatments (zero balance). In the medium layer (0.2–0.4 m), our results showed negative balances ranging between -0.04 and -0.06 m/m%. The salt mass movement generated by the high amount of input water during the irrigation period resulted in -0.04 m/m% salt balance for the Control, Physiomax micro, Physiomax full, Neosol full and microdoses, while -0.05 m/m% for Terrasol. In the lower soil layer (0.4–0.6 m), negative balance was found in all the treatments. -0.02 m/m % salt balance was found for Control and Physiomax microdoses, while the other treatments showed -0.04 m/m %, respectively. For the whole 0.6 deep soil horizon, Neosol full, Neosol micro, and Physiomax full applications had the most negative salt balances.

The salt profiles of the subplots covered with chili in 2021 are shown in Fig. 34. The salt input of pea plots by irrigation was  $172.4 \text{ g m}^{-2}$  in 2021 (Table 8). The input water was 192 mm by irrigation and 130 mm by natural precipitation during the irrigation period of chili (June–October) in 2021.

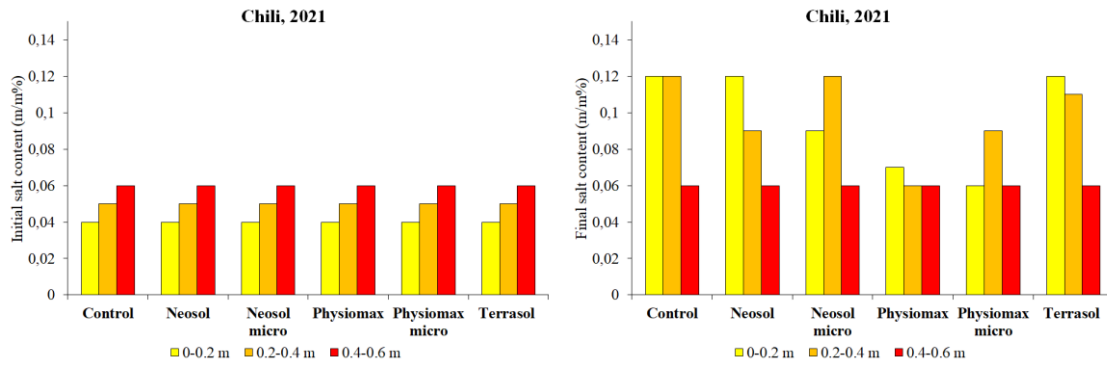


Figure 34. Average actual salt content of the 0-0.2, 0.2-0.4, 0.4-0.6 m soil layers in the small plots of chili in the function of soil conditioning before (left) and after (right) the irrigation season of 2021

In the second year of the experiment, the salt input by irrigation was almost the same ( $174.8 \text{ g m}^{-2}$  and  $172.4 \text{ g m}^{-2}$ , respectively). In the upper 0.2 m deep soil layer, increases in the salt mass were detected in all the treatments. The Control, Neosol and Terrasol had the most positive balances ( $+0.08 \text{ m/m}\%$ ), while Neosol micro had  $+0.05 \text{ m/m}\%$ , Physiomax full dose  $+0.03 \text{ m/m}\%$ , and Physiomax micro  $+0.02 \text{ m/m}\%$  balance. In the medium layer (0.2–0.4 m), also positive balances ranging from 0.01 up to 0.07 m/m% were found due to the salt mass movement during the irrigation period. The balances were  $+0.07 \text{ m/m}\%$  for the Control and Neosol micro,  $+0.06 \text{ m/m}\%$  for Physiomax micro and Neosol full dose,  $+0.04 \text{ m/m}\%$  for Terrasol, and  $+0.01 \text{ m/m}\%$  for Physiomax full dose. In the lower soil layer (0.4–0.6 m), neutral balance was found in all the treatments ( $0 \text{ m/m}\%$ ). All in all, Physiomax full application had the best salt balance which is a favourable result in this respect.

As it is described in Chapter 3.5.2., in 2022, I decided to measure the soil EC instead of taking soil samples. The actual electrical conductivity (averages of 3 repetitions) of the 0–0.2 and 0.2–0.4 m soil layers in the small plots of the three indicator crops in the function of soil conditioning during the irrigation season of 2022 are shown in Figures 38–40. 12,755 of water was irrigated on each small plot of beans, this way they received  $236 \text{ g m}^{-2}$  of salts by the end of the experiment in 2022 (Fig. 35). The average of the initial EC values of all the treatments at the top layer (0–0.2 m) was  $435 \mu\text{S cm}^{-1}$ , while at the time of the last measurement it was  $707.5 \mu\text{S cm}^{-1}$ .

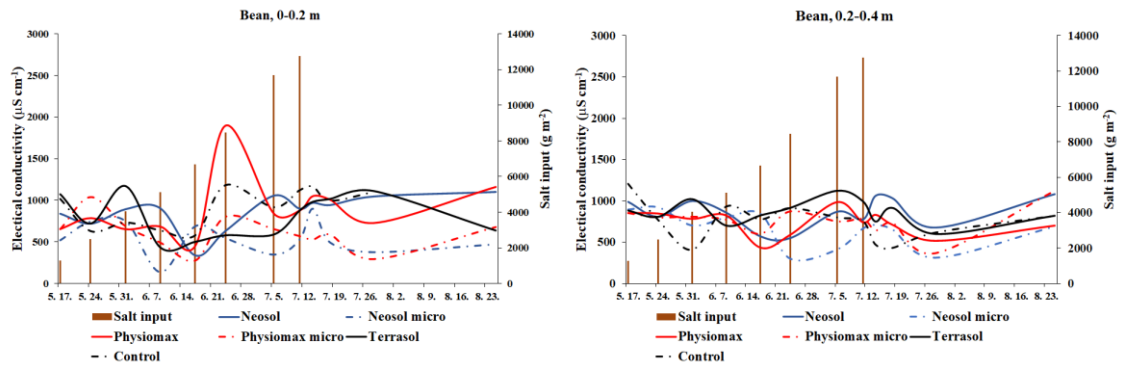


Figure 35. Average actual electrical conductivity of the 0-0.2 m (left) and 0.2-0.4 m (right) soil layers in the small plots of beans in the function of soil conditioning during the irrigation season of 2022

I detected an unusual EC activity for Physiomax full dose, a peak occurred during the last three irrigation events and then fell drastically. For Neosol micro an inverse peak was found right after the second irrigation event and then a moderate increase was experienced. The dynamics between the soil conditioners were hectic during the growing period and less hectic after the crops were removed from the soil. In fact, Neosol micro had less variation during the experiment than other treatments. For the second layer (0.2–0.4 m), the average initial EC was  $732 \mu\text{S cm}^{-1}$  and it ended with an average of  $768 \mu\text{S cm}^{-1}$ , both values were higher than in the upper soil layer. The EC dynamics were different after the plant had been removed, a decrease was experienced in the upper soil layer, while an increase in the lower layer even leaching was not probable as no natural precipitation and no irrigation took place after harvest.

11,642 L water was irrigated on each small plot of peas, this way they received  $216 \text{ g m}^{-2}$  of salts by the end of the experiment in 2022 (Fig. 36). The average initial EC at the top layer (0–0.2 m) was  $586 \mu\text{S cm}^{-1}$ , while at the time of the last measurement it was  $764.8 \mu\text{S cm}^{-1}$ . For Terrasol treatment, I identified 2 peaks during the first two and the last irrigation events and then a drastic decline. Moreover, Physiomax full dose as well as micro dose had a negative peak before the last two irrigation events. The Neosol full dose and micro dose dynamics were smooth during the growing period, but in fact, the control showed the least variation during the experiment.

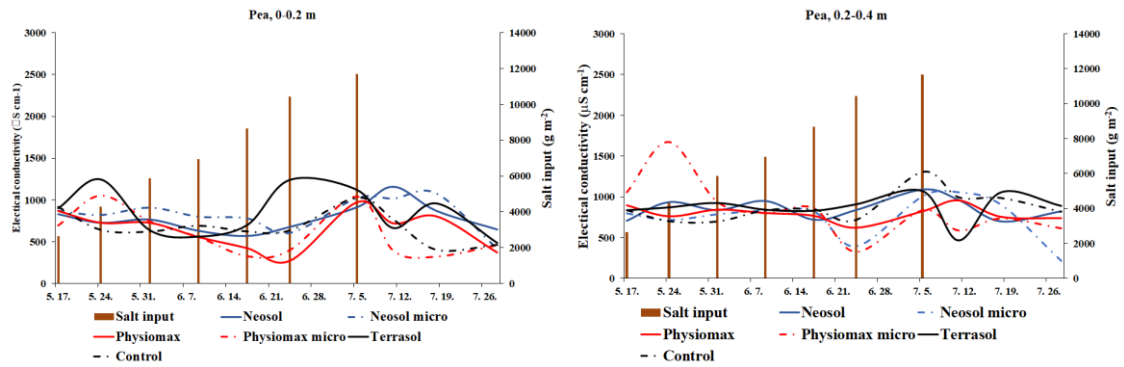


Figure 36. Average actual electrical conductivity of the 0-0.2 m (left) and 0.2-0.4 m (right) soil layers in the small plots of peas in the function of soil conditioning during the irrigation season of 2022

For the lower layer (0.2–0.4 m), the average initial EC was  $1,250 \mu\text{S cm}^{-1}$ , while the final average  $848 \mu\text{S cm}^{-1}$ . I detected an unusual EC activity for Physiomax micro dose: the peak after the first irrigation event was very high, maybe some measurement errors occurred. Moreover, Neosol micro dose had a negative peak by the end of the experiment. The EC dynamics of the untreated control was smooth during the experimental period showing less variation than other treatments.

21,256 L water was irrigated on each small plot of chili, this way they received  $393.6 \text{ g m}^{-2}$  of salts by the end of the experiment in 2022 (Fig. 37). The average initial EC at the top layer (0–0.2 m) was  $679 \mu\text{S cm}^{-1}$ , while at the time of the last measurement it increased up to  $892.9 \mu\text{S cm}^{-1}$ .

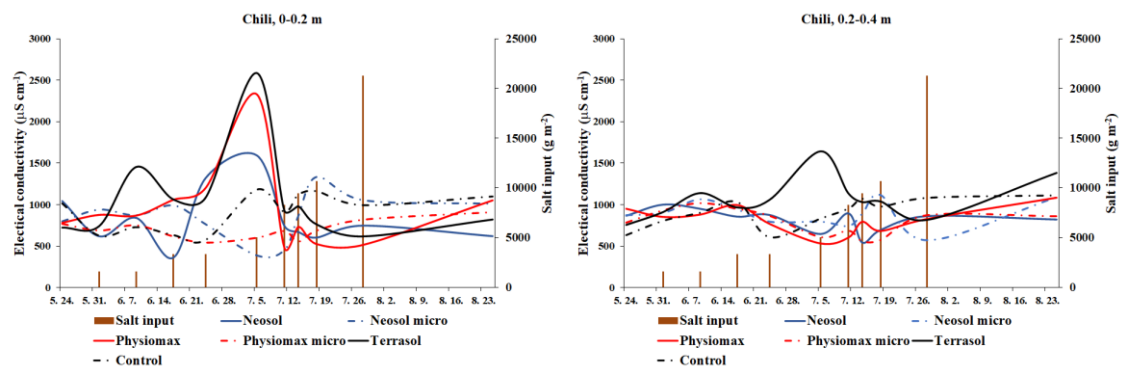


Figure 37. Average actual electrical conductivity of the 0-0.2 m (left) and 0.2-0.4 m (right) soil layers in the small plots of chili in the function of soil conditioning during the irrigation season of 2022

I detected several peaks in EC for Terrasol, Physiomax and Neosol, while a negative peak for Neosol micro dose. The EC dynamics of Physiomax micro dose were smooth during

the growing period and slowly increased after the crops were removed from the soil. For the second layer (0.2–0.4 m), the average of the initial EC values of all the six treatments was  $911 \mu\text{S cm}^{-1}$  and it ended with an average of  $973.8 \mu\text{S cm}^{-1}$ . Only Terrasol treatment showed high EC in that layer, even Physiomax and Neosol treatments had high EC values in the top layer at that time. Neosol application resulted in the lowest variation in EC dynamics during the investigation period.

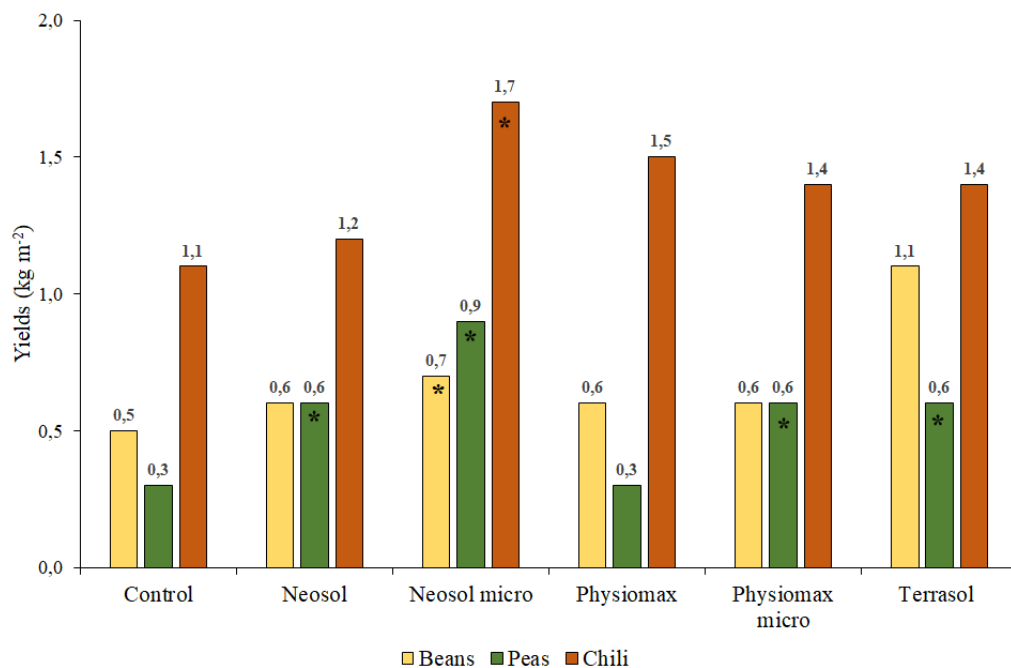
It can be concluded that regular EC measurements with Fieldscout EC-meter (*Fig. 15*) provided data that are suitable only to determine some trends in  $\text{EC}_a$  dynamics, like in this case, in the relation among irrigation, soil conditioner, and crop yield. Another possible approach with this device is to monitor and determine the critical  $\text{EC}_a$  at 0.4 m for the soil and crops with low to moderate salt tolerance and describe the dynamics between  $\text{EC}_a$  and crop. But for precise determination of salt dynamics and movement in the soil layers needs a more accurate device or to be substituted with  $\text{EC}_e$  measurements. Another specialty of my case was that several measurements could not be carried out at the lowest depth (0.4–0.6 m) as the soil was so dry and compacted that the probe could not be inserted into that depth. This is the reason why I analysed only the EC data measured at the depths of 0–0.2 and 0.2–0.4 m, respectively. Nevertheless, this instrument was useful to gain several experiences in terms of in situ EC measurements.

#### **4.3.2. Yield results in the small plot experiment**

The research of the effect of salt affection on yields of various crops has a long tradition at the Research institute of Karcag. Experiments similar to mine were carried out by BOCSKAI (1969), SIPOS and BOCSKAI (1968). HALÁSZ (1973) designed experiments with different doses and applied a statistical descriptive comparison between limestone dust, petroleum resin in a solonetz soil in large scale sunflower production. The commercial production of petroleum resin started about 1950 and was triggered by the rapid acceptance and expansion of coumarone-indene resins. In his study, 2-year-averages were compared and 40% yield increased by the joint application of 12 tons/hectare of limestone and 20 tons/hectare of petroleum resin.

Nowadays, with the new generation of soil conditioners SINKA et al. (2019) experienced (in a previous lysimeter experiments with sweet corn) an effective improvement by

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). 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 and salt tolerances. 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 short vegetation period, the differences in the yields due to the treatments were not considerable, while 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 yields of the three indicator crops irrigated with saline water under soil conditioning in 2020 are presented in *Fig. 38*.



*Figure 38.* 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

Regarding the yields of beans in 2020, the Terrasol compost treatment had the most positive effect, probably due to its high nutrient content. Bean yields were similar when soil condition was applied and somewhat higher than in the untreated control. Micro dose

application was found to be effective compared to the full dose application for both soil conditioners (especially for Neosol), which can be considered a promising result. Nevertheless, the analysis of variance of the bean yields of 2020 (*Table 13*) showed no significant difference between the means of the yield groups ( $0.23 > 0.05$ ).

*Table 13.* Results of ANOVA of the bean yields recorded in 2020

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.565	5	.113	1.614	.230
Within Groups	.840	12	.070		
Total	1.405	17			

Nevertheless, the post hoc test showed statistically significant positive effect of Neosol micro treatment compared to the control on the yields of beans in 2020 (*Appendix 1*).

According to my measurements, the best pea yield in 2020 was achieved by the micro dose application of Neosol (*Fig. 38*). 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 more 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 pea yields of 2020 (*Table 14*) showed strong significant difference between the means of the yield groups ( $0.00 < 0.05$ ).

*Table 14.* Results of ANOVA of the pea yields recorded in 2020

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.729	5	.146	18.757	.000
Within Groups	.093	12	.008		
Total	.823	17			

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 of peas in 2020 (*Appendix 2*). 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.

In the case of chili with the longest vegetation period, all the treatments showed a yield increasing effect compared to the untreated control (*Fig. 38*). We could figure out a difference between the standard (full) dose and the micro-dose applications of Neosol, the former one resulted in the highest yield of chili. The Physiomax treatments showed no considerable differences between the micro and full doses. The compost treatment did not bring extra yield of chili compared to soil conditioning. Nevertheless, the analysis of variance of the chili yields of 2020 (*Table 15*) showed no significant difference between the means of the yield groups ( $0.064 > 0.05$ ).

*Table 15. Results of ANOVA of the chili yields recorded in 2020*

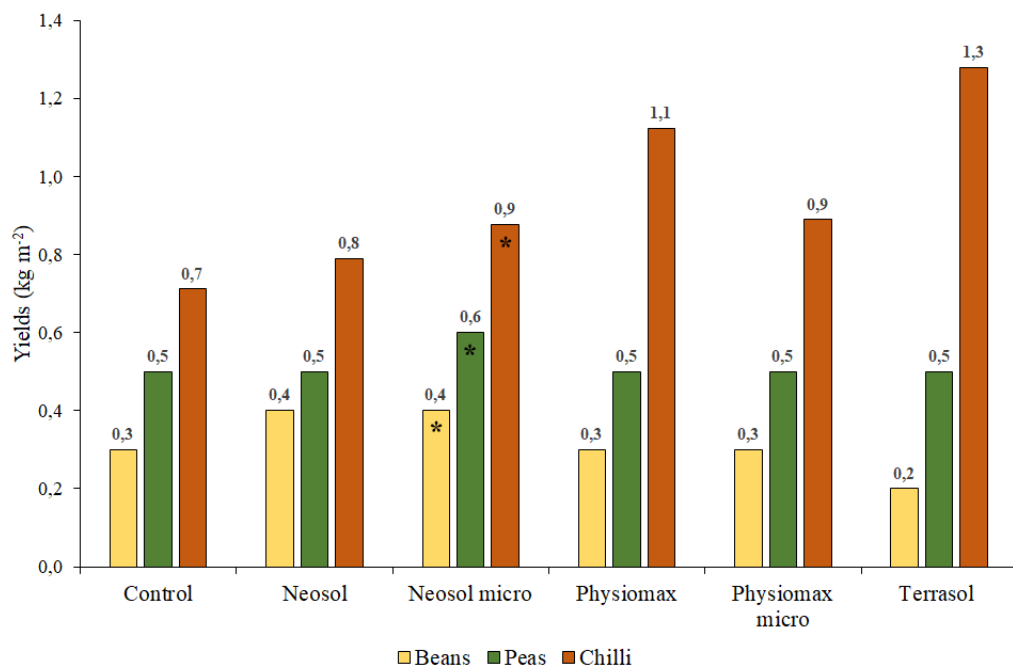
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.783	5	.157	2.846	.064
Within Groups	.660	12	.055		
Total	1.443	17			

Just like in the case of beans, the post hoc test showed statistically significant positive effect of Neosol micro treatment compared to the control on the yields of chili in 2020 (*Appendix 3*).

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%. ANQI 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. For example, the root architecture copes salinity better in sweet corn than the root of peas. Beans cannot cope salinity, but the compost addition increased its yield by 60% comparing with the control (*Fig. 38*). Terrasol compost 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). All these, especially the improved soil structure hence the increased leaching, contribute to the mitigation of the extent of secondary salinization.

In 2021, the small plot experiment was set up with the same treatments and indicator crops, but the crops were rotated from one plot to another in order to avoid the

concentration of pests and diseases. Nevertheless, the extent of salt accumulation due to the irrigation from the previous year was not predictable as leaching induced by the winter precipitation and the forecrop all affect the salinization process. The effect of soil salinity can be different due to the plant rotation. In other words, if the previous crop like beans is a nitrogen donator, it affects the yield of the next crop. In this case, the salt concentration in the irrigation period, the plant tolerance and the amount of rain do not affect the yield so much as in the previous year. Naturally, after several years of irrigation with saline water, lower yields can be expected, just like it happens in the gardens around Karcag. In the second year of our experiment, we were not definitely expecting lower yields due to the higher salt content of the soil, but the complex effect of the cropyear (weather), irrigation and soil conditioning could be studied. The yields of the three indicator crops irrigated with saline water under soil conditioning in 2021 are presented in *Fig. 39*.



*Figure 39.* 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*

In the second year (2021), we increased the salt income by irrigation of beans from 58.8 to 170 g m<sup>-2</sup>, which projected lower yields due to the effect of extended salt accumulation. Indeed, bean yields were 0.2–0.9 kg m<sup>-2</sup> (50% on average) lower. Interestingly and contrary to 2020, the Terrasol treatment resulted in the lowest yield that cannot be

explained as a negative effect of compost application. Nevertheless, beans were more affected by salt accumulation than the other indicator crops.

I did not find big differences in the yields in terms of the treatments, though the highest yields were found for Neosol, both for the full dose and micro dose treatments. No difference in yields of beans treated with the other soil conditioner was figured out compared with the control. The analysis of variance of the bean yields of 2021 (*Table 16*) showed no significant difference between the means of the yield groups ( $0.307 > 0.05$ ).

*Table 16.* Results of ANOVA of the bean yields recorded in 2021

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.184	5	.037	1.355	.307
Within Groups	.327	12	.027		
Total	.511	17			

Similarly to 2020, the post hoc test showed statistically significant positive effect only of Neosol micro treatment compared to the control on the yields of beans in 2021 (*Appendix 4*).

In the case of peas, the increase in the salt income by irrigation was doubled in 2021 compared to the previous year (from 50.9 to 104 g m<sup>-2</sup>). However, yield depression was found only for four treatments (Neosol full and micro dose, Physiomax micro dose, and Terrasol), the full dose application of Physiomax and the control treatments showed higher yields compared to the previous year resulting in only 8% increase on average, which is not considerable (*Fig. 39*). The differences cannot be explained with salt accumulation, but probably are in correlation with the applied crop rotation. Nitrogen releases from a legume crop occurs as ground plant residues, roots and nodules decompose. Usually about two-thirds of the nitrogen fixed through a legume crop becomes handy the subsequent growing season after a legume in a rotation (DEAKIN and BROUGHTON, 2009). In my opinion, the rotation had an influence on the next year crops in terms of nitrogen and salinity accumulation due to irrigation. More probably, peas could have the advantage from the shorter life cycle or period of irrigation, in which less salts could accumulate. Nevertheless, the comparison of the crop life cycle years is not so significant as the comparison of the treatments in each year. The analysis of variance of the pea yields of 2021 (*Table 17*) showed no significant difference between the means of the yield groups ( $0.260 > 0.05$ ).

*Table 17. Results of ANOVA of the pea yields recorded in 2021*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.104	5	.021	1.504	.260
Within Groups	.167	12	.014		
Total	.271	17			

The post hoc test showed statistically significant positive effect of Neosol micro treatment again compared to the control on the yields of peas in 2021 (*Appendix 5*).

Chili has the longest irrigation period, the increase in the salt income by irrigation was from 147.7 to 173 g m<sup>-2</sup> compared 2021 to 2020. Chili yields were 0.1–0.8 kg m<sup>-2</sup>, on the average 31% lower in 2021 (*Fig. 39*). Nevertheless, all the treatments showed yield increasing effect compared to the untreated control. Micro dose application of Neosol showed a little advantage compared to full dose application, while Physiomax full dose treatment had in favour to micro dose. Regarding soil conditioning, the trend in their yield increasing effect was the same in both years. The compost treatment brought a bit higher yield of chili compared to soil conditioning. The analysis of variance of the chili yields of 2021 (*Table 18*) showed no significant difference between the means of the yield groups ( $0.380 > 0.05$ ).

*Table 18. Results of ANOVA of the chili yields recorded in 2021*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.872	5	.174	1.167	.380
Within Groups	1.793	12	.149		
Total	2.665	17			

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 (*Appendix 6*).

The yields of the three indicator crops irrigated with saline water under soil conditioning in 2022 are presented in *Fig. 40*. 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 of 236 g m<sup>-2</sup>, which could project lower yields due to the effect of extended salt accumulation. Nevertheless, bean yields were 0.8-1.8 kg m<sup>-2</sup> (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.

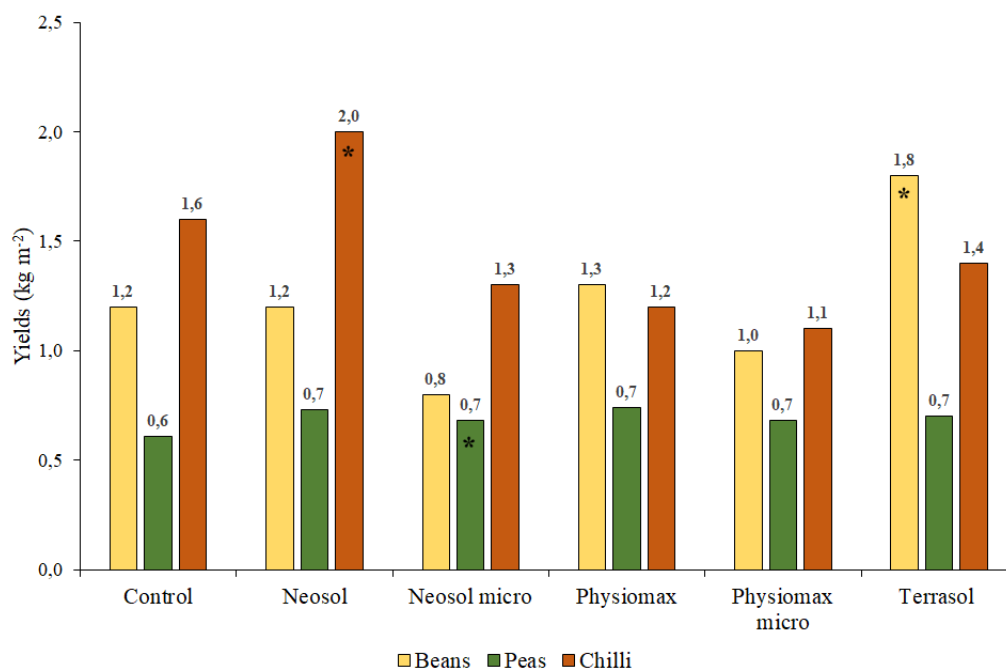


Figure 40. Yields of the indicator crops in terms of the different soil conditioning treatments in 2022

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

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 (Table 19) showed no significant difference between the means of the yield groups ( $p > 0.05$ ). This means that the null hypothesis could be rejected.

Table 19. Results of ANOVA of the bean yields recorded in 2022

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.133	5	.227	11.027	.000
Within Groups	.247	12	.021		
Total	1.380	17			

Similarly, to 2021, the post hoc test showed statistically significant positive effect only for the Terrasol treatment compared to the control on the yields of beans in 2022 (Appendix 7).

In the case of peas, the increase in the salt income by irrigation was doubled in 2021 compared to the previous year (from 104 to 216 g m<sup>-2</sup>). However, yield depression was not significantly found only for Physiomax micro dose which was similar to the control. The full dose application of Physiomax and the control treatments showed higher yields compared to the previous year resulting in only 4% increase on average, which is not considerable. Nevertheless, the comparison of the crop life cycle years is not so significant as the comparison of the treatments in each year. The analysis of variance of the pea yields of 2022 (*Table 20*) showed significant difference between the means of the yield groups, (0.173>0.05). Low F-value (1.876) means that the group means cluster together more tightly than the within-group variability. The distance between the means is small to the random error within each group. For 2022, I could not conclude that Neosol micro yield of peas was truly different at the population level.

*Table 20. Results of ANOVA of the pea yields recorded in 2022*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.151	5	.030	1.876	.173
Within Groups	.193	12	.016		
Total	.344	17			

The post hoc test showed statistically significant positive effect of Neosol micro treatment again compared to the control on the yields of peas in 2022 (*Appendix 8*).

In 2022, chili yields were 1–1.8 kg m<sup>-2</sup>, on the average 50% higher than in 2021. The increase in the salt income by irrigation was from 173 to 393 g m<sup>-2</sup> compared 2021 to 2022. Nevertheless, control showed higher yields compared to Physiomax micro dose. Micro dose application of Neosol showed a little disadvantage compared to full dose application. Physiomax full dose treatment had in favour to micro dose. The Neosol full treatment and control showed higher yields of chili compared to former years. The analysis of variance of chili yields of 2022 (*Table 21*) showed no significant difference between the means of the yield groups (0.001<0.05).

*Table 21. Results of ANOVA of the chili yields recorded in 2022*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.923	5	.185	10.067	.001
Within Groups	.220	12	.018		
Total	1.143	17			

The post hoc test showed again that if there is no statistically significant difference between the yield groups, only Neosol micro treatment had some positive effect compared to the control (*Appendix 9*).

#### **4.3.3. Evaluation of the yield results in the small plot experiment**

Based on the three years data, I observed an inverse correlation between the increment of salt input and the yield loss. 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. For example, a crop with a shorter vegetation period, which is irrigated for a shorter period, is harvested (removed) earlier and the chance and time that the salts are leached to the lower layers in the root zone is larger and longer, respectively. In contrast, the longer the vegetation period, the longer the irrigation and more salt remain in the root zone and the shorter the natural leaching process.

In order to summarize and evaluate the complex effect of salt input by irrigation, soil conditioners and soil conditioning dosing, the yield differences compared to the control treatment are indicated in *Tables 22-24* for the three investigated crops. The different salt inputs represent the years and amounts of irrigation water (and the length of the irrigation period), while the colours indicate if there was a positive, negative or no effect of the treatments on the yields compared to the control. This visualization is useful as the dominant colour expresses well the expectable effect of each particular treatment and crop. The crops have different plasticity to compensate the effect of salinity and the soil conditioners. We were expecting a positive effect in the yield for all the crops with different salt concentrations. That would have meant that all the cells of the tables are green. Naturally, the more years will be studied, the more precise effect on the yields can be determined.

For bean production, under the studied circumstances, all the treatments resulted in positive reaction when the salt input was low, but when it was increased, only Neosol application brought higher yields compared to the control (*Table 22*). Based on 3 years

of the experiment, micro dose application of Neosol can be ranked to the first place and can be recommended as the most effective method to mitigate the harmful effect of secondary salinization. In addition, Terrasol had a better performance in the 3th year than all the soil conditioners, which means that in that dry year with high amount of irrigation water hence salt input, the plant nutritive effect of compost application was dominant over the mitigation of salinization.

*Table 22. Reaction of beans to the annual salt input by irrigation*

Salt input (g m <sup>-2</sup> )	Yield difference to control (%)					
	Control	Neosol	Neosol mi- cro	Physiomax	Physiomax micro	Terrasol
58.7	0	20	40	20	20	120
152.7	0	33.3	33.3	0.0	0.0	-33.3
210.1	0	0.0	-33.3	8.3	-16.7	50
Rank	-	<b>1</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>2</b>

*Legends: Green colour means positive (>10%), red negative (<0%), yellow neutral (no) effect (0–10%)*

For pea production under the studied circumstances, four treatments resulted in positive reaction when the salt input was low, but when it was increased, only Neosol micro application brought higher yields compared to the control (*Table 23*).

*Table 23. Reaction of peas to the annual salt input by irrigation*

Salt input (g m <sup>-2</sup> )	Yield difference to control (%)					
	Control	Neosol	Neosol mi- cro	Physiomax	Physiomax micro	Terrasol
51.1	0	100	200	0	100	100
78.1	0	0.0	20.0	0.0	0.0	0.0
161.9	0	23.3	13.3	23.3	-3.3	16.7
Rank	-	<b>2</b>	<b>1</b>	<b>5</b>	<b>4</b>	<b>3</b>

*Legends: Green colour means positive (>10%), red negative (<0%), yellow neutral (no) effect (0–10%)*

Based on 3 years of the experiment, micro dose application of Neosol is ranked to the first place and can be recommended as the most effective method to mitigate the harmful effect of secondary salinization.

For chili production under the studied circumstances, all the treatments resulted in positive reaction, even in the 2 years, the salt input by irrigation was high (*Table 24*). Based on 3 years of the experiment, Neosol application resulted in the higher yields hence it is ranked to the first place. Micro dose application of Neosol and Terrasol are ranked to the second and third places and can be also recommended to mitigate the harmful effect of secondary salinization.

Table 24. Reaction of chilli to the annual salt input by irrigation

Salt input (g m <sup>-2</sup> )	Yield difference to control (%)					
	Control	Neosol	Neosol mi- cro	Physiomax	Physiomax micro	Terrasol
174.8	0	9.0	55.0	36.0	27.0	27.0
172.4	0	12.7	25.4	60.3	27.0	82.5
151.2	0	25.7	-17.9	-22.1	-28.6	-14.3
<b>Rank</b>	<b>-</b>	<b>4</b>	<b>2</b>	<b>1</b>	<b>5</b>	<b>3</b>

Legends: Green colour means positive (>10%), red negative (<0%), yellow neutral (no) effect (0–10%)

We discovered that mainly Physiomax is not really suitable for the vegetable crops that not salt tolerant (beans, peas), but micro dosing of Neosol was very effective. In the case of chilli with low salt tolerance, Physiomax had higher rank, while Neosol was less effective.

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

In order to quantify and evaluate the joint effect of soil moisture content and EC<sub>a</sub>, we differentiated 2 types of salt tolerance of the indicator crops: with no salt tolerance (NT), and low salt tolerance (LT). The PCC values determined by the EC<sub>a</sub> and moisture content of the 0-0.1 m soil layer in the function of soil conditioning are illustrated in Figures 41–46.

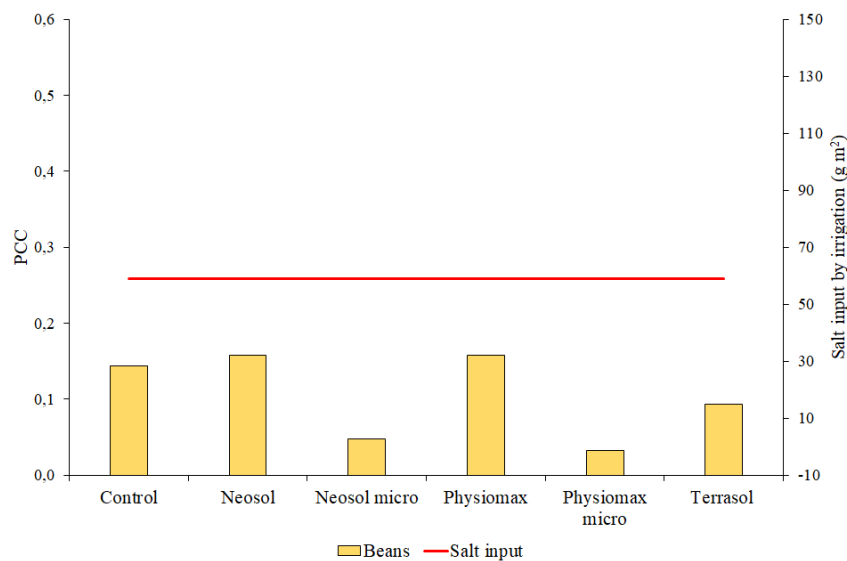


Figure 41. Person's correlation coefficients determined by EC<sub>a</sub> and moisture content of the 0–0.1 m soil layer in the function of soil conditioning for beans in 2020

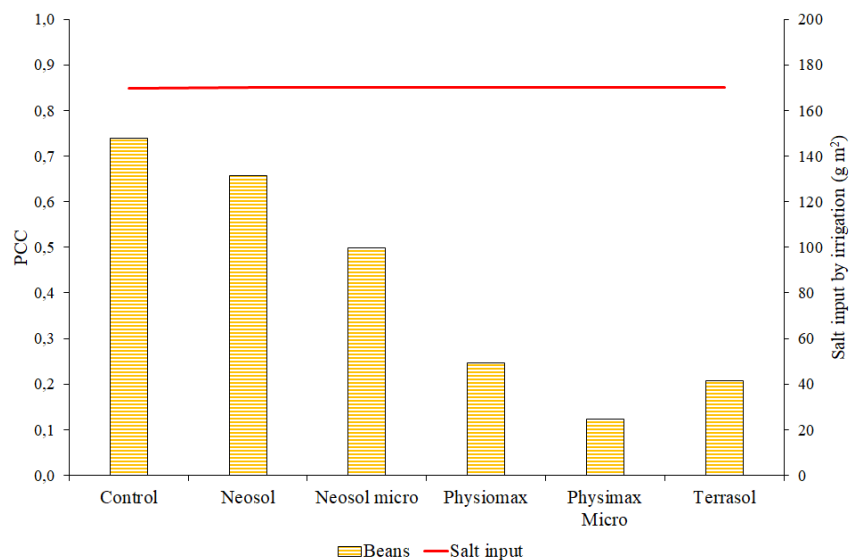


Figure 42. Person's correlation coefficients determined by  $EC_a$  and moisture content of the 0–0.1 m soil layer in the function of soil conditioning for beans in 2021

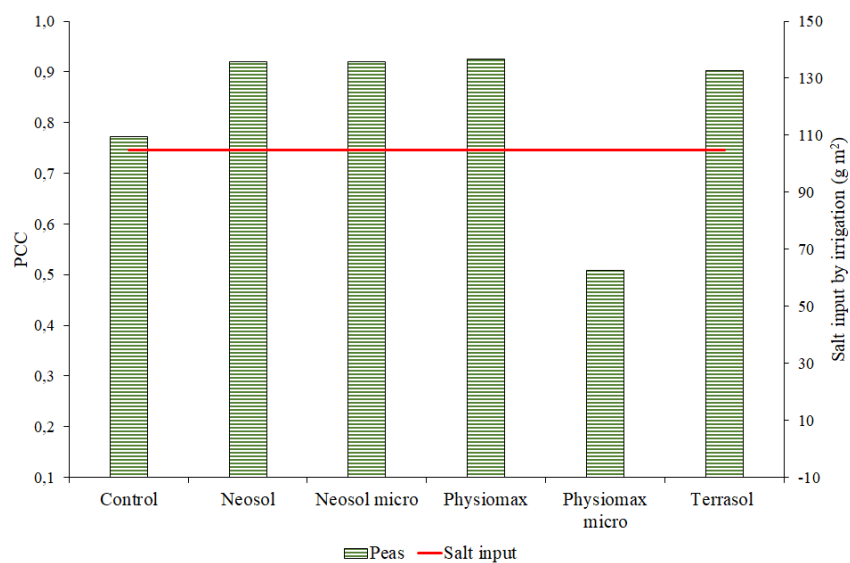


Figure 43. Person's correlation coefficients determined by  $EC_a$  and moisture content of the 0–0.1 m soil layer in the function of soil conditioning for peas in 2020

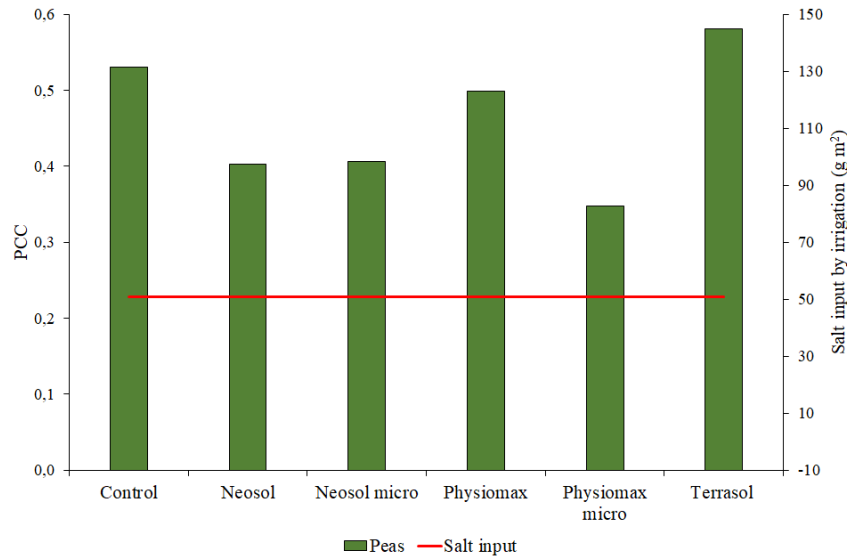


Figure 44. Person's correlation coefficients determined by  $EC_a$  and moisture content of the 0–0.1 m soil layer in the function of soil conditioning for peas in 2021

I 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 (Fig. 41–42). Beans has a symbiotic association with bacteria, which fix nitrogen, which helps to reduce pH and causing changes in the root zone and it affects the correlation between soil moisture content and  $EC_a$  in the top layer. Meanwhile peas cannot cope salinity as beans, but the compost addition increased yield by 60% comparing with the control (Fig. 43–44). 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, 2020; ZSEMBELI et al., 2019b).

Chili is a LT crop and also was tested at different salt inputs and with soil conditioners (Fig. 45–46). SINKA et al. (2019) experienced (in a previous lysimeter experiments with sweet corn) an effective improvement by 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).

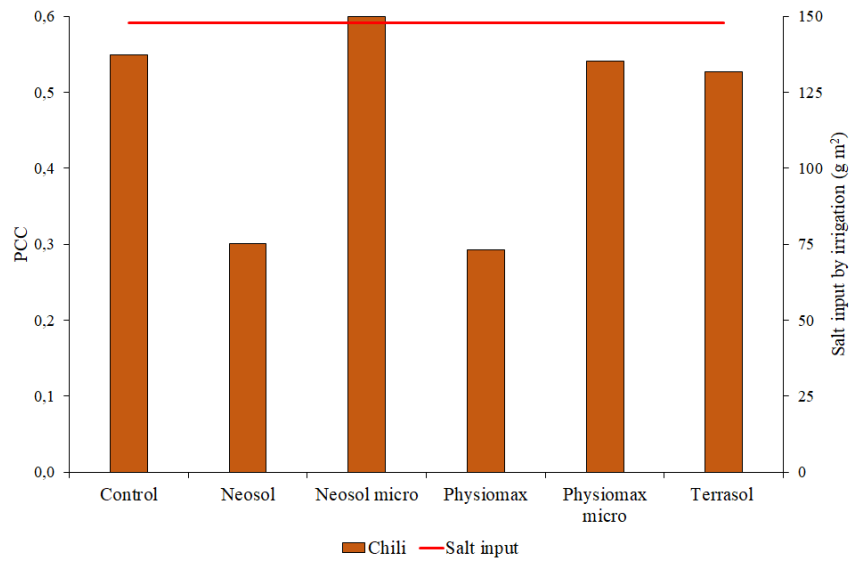


Figure 45. Person's correlation coefficients determined by  $EC_a$  and moisture content of the 0–0.1 m soil layer in the function of soil conditioning for chili in 2020

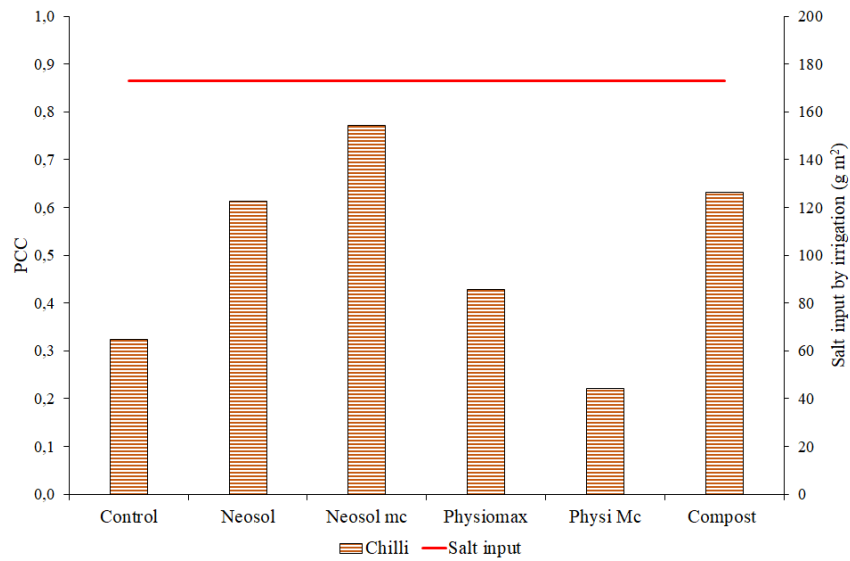


Figure 46. Person's correlation coefficients determined by  $EC_a$  and moisture content of the 0–0.1 m soil layer in the function of soil conditioning for chili in 2021

We identified that Terrasol biocompost is beneficial to mitigate the effect of secondary salinization 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 suppress the harmful effect of

salinization under non-tolerant crops under salty water irrigation in clay soils (FOTH and TURK, 1972; AL-HARBI et al., 2020; 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 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 improves 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.

Based on my results, I 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 was increased by adding higher amounts of salts getting down to the root zone. We expected a different correlation due to soil conditioners and biotic interactions in the soil (FOTH and 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 (SMITH and HEWITT, 1975). In contrast, KARUCZKA (1998), KARUCZKA and ZSEMBELI (1996) mentioned that weather characteristics are in a closer correlation with groundwater balance than precipitation or irrigation. Therefore, in a positive salt balance, the salts attached in the soil could be absorbed by plants instead of the fertilizers and the salt from irrigation. Salinity is an abiotic risk that can cause damage in vegetable crops. In Karcag, water is a limiting factor for normal leaching techniques. FILEP et al. (1981) and NYIRI and FEHÉR (1981) studied the

effects of amendments in salt affected soils, but the amount and kind of amendments were best ascertained by soil test and experimentation. BLASKÓ (1999) explored the alternatives where he mentions various levels of reclamation and also compared with different data gained on other soil types. His research was based on the soil EC and moisture content in order to understand the process of secondary salinization including drainage and chemical reclamation with lime dust, sulfuric acid, petroleum resin adding heavy machinery with deep loosening in sodic salt affected soils.

I also found a positive correlation between  $EC_a$  and soil moisture in the investigated meadow chernozem soil. This correlation is useful to monitor the soil health and risk of salt affected conditions. In addition, there is a close relation between salt movement, ground water movement and the moisture status of the soil profile. The salt movement takes place in the 0.5–0.8 m soil layer (FILEP et al, 1981). The 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 next experiments, it would be interesting to evaluate deeper soil layers in terms of the PCC index. For this purpose, soil moisture probe has to be able to reach deep layers.

The interactive nature affecting nutrient availability, uptake and distribution are topics that are highly complex of salinity or other stresses (MARSCHNER, 1995; WANG et al., 2003). Salt stress is a significant problem for agriculture systems by suppressing crop yield potential (HARMON and DAIGH, 2017). It is known that the presence of salinity adds a new level of complexity to the mineral nutrition of crops (GRATTAN and GRIEVE, 1999). We identify from literature the potential yields depending on salinity, almost all crops show sensitivity to high salt levels but it differs the consequences between species and may differ in response to each of these salinizing systems (*Table 25*, LIANG et al., 2018).

*Table 25.* Crop tolerance and yield potential of selected crops as influenced by soil salinity and nutrition deficiency. (AYERS and WESTCOT, 1985) EC = (dS/m) at 25 °C

Crop	Yield Potential 100% (EC)	Yield Potential -50% (EC)	EC Interval during the experiment (EC)	Literature review of the principal nutrient factor under salinization for the indicator crop
Tomato	1.7	5.0	0.7-4.9	Increased the Fe and Zn concentration in the shoots (MAAS et al., 1972; MARTINEZ et al., 1987). Deficiency in K <sup>+</sup> (SONG and FUJIYAMA, 1996)
Carrot	0.7	3.0	0.7-4.9	Nitrogen deficiency (RAVIKOVITCH and PORATH, 1967)
Parsley	1.5	3.8	0.7-4.9	Deficiency on N, K, P and Ca (CHONDRAKI et al., 2012)
Celery	1.2	6.6	0.7-4.9	Deficit of Ca in early stages (PADROSSI et al., 1999)
Chilli	1.0	3.4	0.9-4.2	Ca, Mn, Zn deficiency (GRATTAN and GRIEVE, 1999; AKTAS et al., 2004)
Peas	0.7	2.5	0.8-4.2	Deficiency Mn, K and S content in the straw (DAHIYA and SINGH, 1976; MOR and MANCHANDA, 1992). Increased the Fe concentration in the shoots (DAHIYA and SINGH, 1976). Decrease in shoot NO <sup>-3</sup> concentration (MARTINEZ and CERDA, 1989)
Beans	0.7	2.4	1.1-4.4	Increase Zn concentration in shoot, Mn decreases in straw (DOERING et al., 1984)
Maize	1.1	3.9	0.5-5.0	Increase Zn concentration in shoot decrease in shoot NO <sup>-3</sup> and Mn (MARTINEZ and CERDA, 1989; IZZO et al., 1991; RAHMAN et al., 1993)

In many crops, salinity reduced P-concentration in plant tissue by 20% to 50% (SONG and FUJIYAMA, 1996; LOPEZ and SATTI, 1996). Phosphate availability is reduced in saline soils not only because of ionic strength effects that reduce the activity of phosphate but also because phosphate concentrations in soil solution are tightly controlled by sorption processes and by the low-solubility of Ca and P minerals (SHARPLEY et al., 1992). Another mineral that is important for plant nutrition is aluminium. This element is important for the stimulation of root growth and increases the uptake of macro nutrients. It also stimulates alkaline phosphate activity and organic P-uptake. The toxicity of this element depends on the pH of the soil, but in the soil of the experimental plots in the IEG was around 6.5–6.7, where AlOH<sup>2+</sup> and Al(OH)<sub>2</sub><sup>+</sup> were not as toxic to plants as other types of Al (*Table 31*, BOJÓRQUEZ-QUINTAL et al., 2017).

Due to the effects of saline irrigation crops suffer losses up >50% in the harvest season. However, the differences in crops yields are related to the physiological strategies from each type of plant. Root system architecture and expansion is mostly regulated by water and nutrient uptake efficiency. Under salinity stress in particular, both root hair length and density of root hairs per unit surface area decreased 25% to 40% (ROBIN et al. 2016). ANQI 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. For example, the root architecture copes salinity better in maize than the root of peas. Another observation is on yields between tomato and maize had also different root architecture, but tomato is moderate tolerant to salinity and cope salt stress around 4 dS/m. Meanwhile, celery is also a moderate salt tolerant, but the performance in yield had loses <50%. PADROSSI et al. (1999) mentioned the damages cause by salinity in germination and early stages in shoots and stems in celery due to Ca<sup>2+</sup> deficiency. Therefore, the transplant is recommended after early stages.

#### **4.4. Results of the pot experiment**

The pot experiment was set up based on a preliminary study carried out in 2018 aiming to determine the effect of the application of two soil conditioners on soil respiration characterized by CO<sub>2</sub>-emission (ZSEMBELI *et al.*, 2017). In harmony with the secondary salinization experiment described in chapter 4.1., two soil conditioners (Physiomax, Solactive) and one control treatment were applied. We assumed a positive effect of soil conditioning on the microbiological activity of the soil inducing more intensive soil respiration manifested in increased CO<sub>2</sub>-concentration above the treated pots than in the control treatment. Nevertheless, we found no representative difference between the treatments, but markedly higher CO<sub>2</sub>-concentrations were measured for each treatment after irrigation was applied (*Fig. 47*). Therefore, I considered very important to repeat the experiment with the soil conditioners I applied in the small-plot experiment.

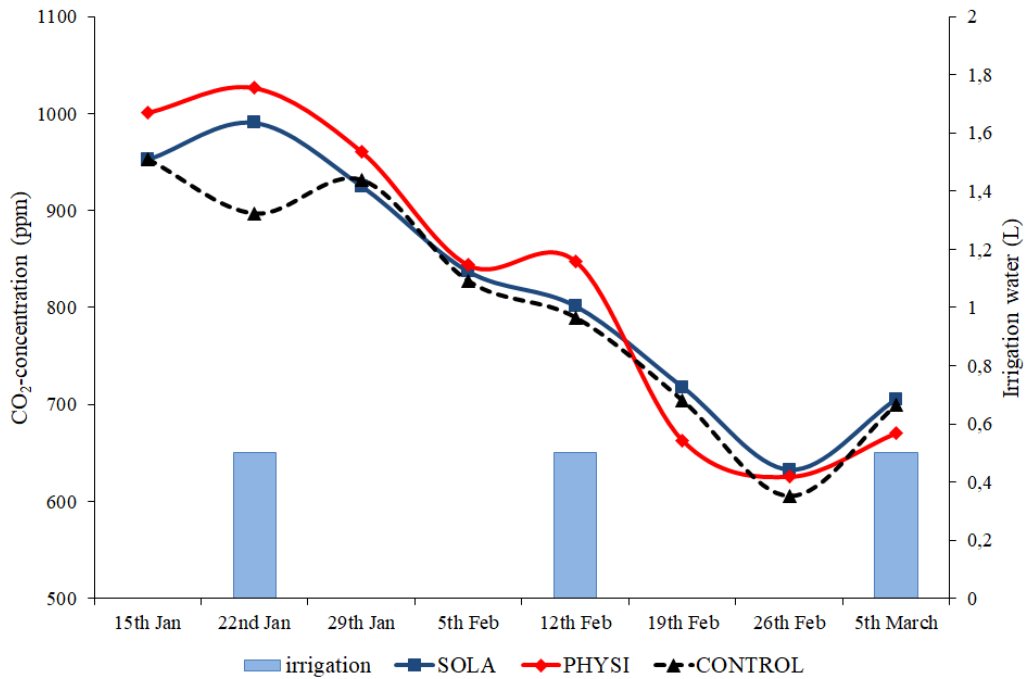


Figure 47. Concentration of CO<sub>2</sub> emitted from the soil in the function of soil conditioning (Karcag, 2018)

In 2022, I set the new pot experiment in April, and I measured CO<sub>2</sub> concentrations (to calculate CO<sub>2</sub> emissions), the actual electric conductivity (EC<sub>a</sub>), and determined soil moisture content (based on the change of the weight of the pots) on a weekly basis. The CO<sub>2</sub> emission values of the soil determined in the pot experiment are illustrated in Fig. 48.

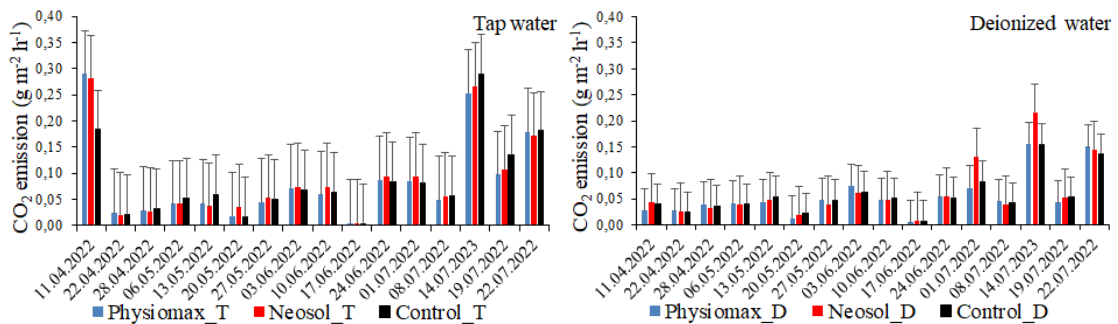


Figure 48. CO<sub>2</sub> emission of the soil determined in the pot experiment (Karcag, 2022)

The CO<sub>2</sub> emissions are not seemed to be different in terms the treatments, low values with high standard deviations were characteristic for the soil conditioning treatments as well as the untreated control pots. A statistical analysis was done to determine if there are really no significant differences in CO<sub>2</sub> emitted from the soils treated with the two tested soil conditioners (Neosol and Physiomax) and the non-treated control. The result is shown

in *Table 26*. I found no statistically significant differences among the treatments in both cases (both irrigation waters) indeed ( $F < F_{critical}$ ).

*Table 26*. Results of ANOVA of CO<sub>2</sub> emitted from the soils treated with the two tested soil conditioners in the pot experiment (Karcag, 2022)

<i>Factors</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>F crit.</i>
Among treatments with tap water	0.00016	2.0	0.00008	0.01218	0.988	3.204
Among treatments with deionized water	0.00046	2.0	0.00023	0.11125	0.895	3.204

n=3

An increase was induced by a trial treatment with Solactive on the 14<sup>th</sup> of July. The idea of the Solactive treatment was coming from a former study carried out at RIK in 2016 (ZSEMBELI et al., 2017). That experiment was conducted by measuring soil respiration, under controlled conditions, over a 16-week-long period. During the initial phase of the experiment, compost was added to non-salt-affected soil in differing qualities (0, 25, 50 t ha<sup>-1</sup>), and each sample was irrigated with a solution containing different salt concentrations (0, 600, 1800 mg/l) with three test replications. At the 13<sup>th</sup> week, Solactive, a soil conditioner rich in N, S and Ca was added equally to each soil sample. 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<sub>2</sub> 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. Similarly, somewhat higher emissions were characteristic to the pots irrigated with tap water during the whole investigation period. In order to figure out if this difference is significant, another statistical analysis was done. The average of CO<sub>2</sub> emission of the soil determined in the pots irrigated with tap water was 0.087 g m<sup>-2</sup> h<sup>-1</sup>, while 0.059 g m<sup>-2</sup> h<sup>-1</sup> for the pots irrigated with deionized water, hence the difference was statistically significant with LSD= 0.0221 g m<sup>-2</sup> h<sup>-1</sup> (*Table 27*).

Table 27. Results of ANOVA of CO<sub>2</sub> emitted from the soils irrigated with tap and deionized water in the pot experiment (Karcag, 2022)

<i>Factors</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>F crit.</i>
Between input waters	0.0012282	0.0012282	126.4844	0.000356	7.708647

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. The occurrence of salt load (secondary salinization) was obvious by the end of the experiment, white salty cover appeared on the soil surface irrigated with tap water (*Fig. 49*).

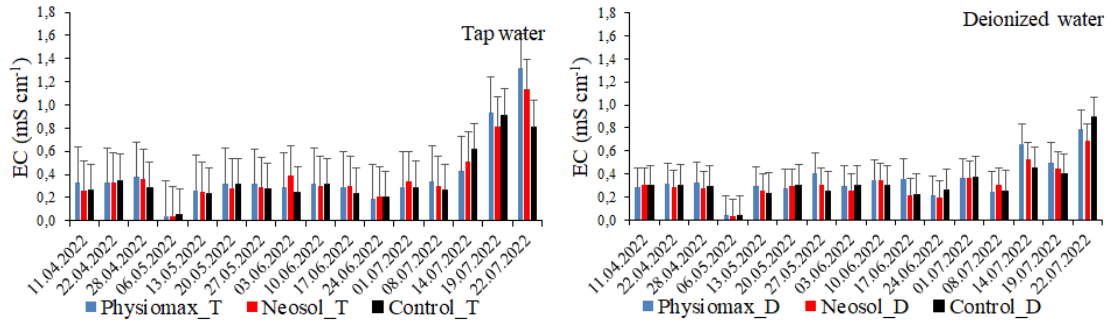


Figure 49. The soil surfaces irrigated with tap water (left) and deionized water (right) in the pot experiment (Karcag, 2022)

It is known that the incorporation of fertilizers, especially if moisture and temperature are optimum, will alter the soil air composition considerably (SAHOO and SREEJA, 2010). Even though, the research review from RATH and ROUSK (2015) mentioned that the salinity is an important factor for microbial respiration. 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<sub>2</sub> efflux.

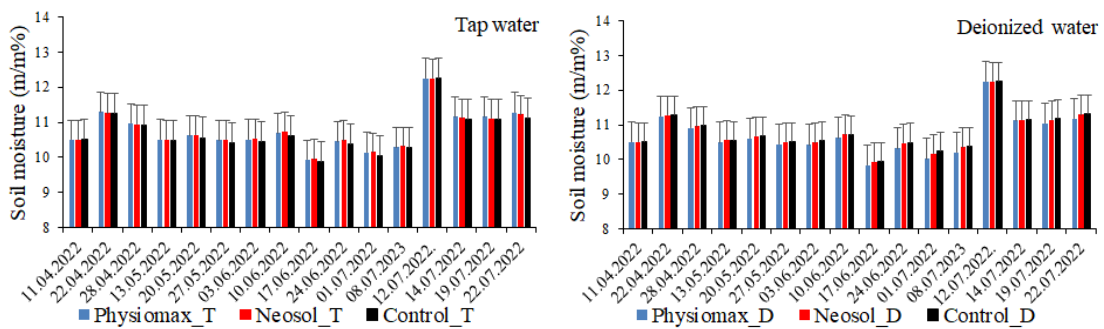
Similarly, to the CO<sub>2</sub> emission values, the EC<sub>a</sub> values were also regularly measured and analysed as I supposed that the irrigation with the saline tap water increases the salt content of the soil of the pots, while deionized water have no impact on soil EC<sub>a</sub> (there

was no chance for leaching as the pots were closed at the bottom). The  $EC_a$  values of the soil determined in the pots irrigated with tap water and with deionized water are illustrated in *Fig. 50*.



*Figure 50.* Electrical conductivity ( $EC_a$ ) of the soil measured in the pot experiment (Karcag, 2022)

The dynamics of the  $EC_a$  values showed similar trends till the end of the experiment, even higher values were expected from the soil irrigated with the saltier tap water. At the last phase of the pot experiment (second half of July), the increased irrigation resulted in higher  $EC_a$  values in the case of tap water irrigation as it involved higher salt input. Interestingly, this was not characteristic to the first three months of the experiment, maybe due to the relatively low soil moisture contents (~10-12 m/m%) maintained during that period (*Fig. 51*) and the salt movement by capillary rise induced by intensive evaporation.



*Figure 51.* Moisture content of the soil measured in the pot experiment (Karcag, 2022)

The statistical analyses were also done to evaluate the differences in terms of the soil conditioning treatments and the irrigation waters. The average of  $EC_a$  values of the soil determined in the pots irrigated with tap water was  $0.377 \text{ mS cm}^{-1}$ , while  $0.335 \text{ mS cm}^{-1}$  for the pots irrigated with deionized water, hence the difference was statistically not significant with  $LSD= 0.03297 \text{ mS cm}^{-1}$  (*Table 28*).

Table 28. Results of ANOVA of EC<sub>a</sub> of the soils irrigated with tap and deionized water in the pot experiment (Karcag, 2022)

<i>Factors</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>F crit.</i>
Between input waters	0.002727	0.002727	5.861951	0.072673	7.708647

*n=3*

The EC<sub>a</sub> values were not seemed to be different in terms the treatments either, similar values with high standard deviations were characteristic for the soil conditioning treatments as well as the untreated control pots. The result of the statistical analysis is shown in Table 29. I found no statistically significant differences among the treatments in both irrigation waters (F<F critical).

Table 29. Results of ANOVA of EC<sub>a</sub> of the soils treated with the two tested soil conditioners in the pot experiment (Karcag, 2022)

<i>Factors</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>F crit.</i>
Among treatments with tap water	0.01720	2	0.00860	0.122968	0.885	3.204
Among treatments with deionized water	0.01258	2	0.00629	0.228592	0.797	3.204

*n=3*

On the base of these results, it can be concluded that the two investigated soil conditioners had no considerable positive effect on the CO<sub>2</sub> 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<sub>2</sub> emission values characterized the soil irrigated with saline (tap) water compared to the irrigation with deionized water, but these differences were not statistically significant. I measured a bit higher EC<sub>a</sub> values in the pots irrigated with tap water, but differences were not statistically significant either.

It is a proven fact that under natural (field) circumstances, the CO<sub>2</sub> emission from the soil is mainly determined by the soil status and the weather conditions among the environmental factors. According to our previous experiences gained in field and pot experiments, soil moisture content is the dominant factor determining the microbiological activity of the soil, but in the recent pot experiment, soil moisture content was maintained within a narrow range, therefore its impact could not be figured out. The experiment was carried out during an extremely hot and dry summer that resulted in high evaporation loss and even the high amount of irrigation waters could not provide optimal moisture content for the microbes of the soil.

## 5. CONCLUSIONS

### 5.1. Validation of my hypotheses

Several experiments and analyses have been involved in my doctoral project since 2018 giving a broad basis of conclusions. I was following the duplex intention of the research team I belonged at RIK to divulge practical science to local farmers and produce international knowledge by publication of scientific papers. It is an honour to contribute and participate with compromised researchers in agriculture to solve actual problems. 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 with soil conditioning. The hypothesis was tested in simple drainage lysimeter and small-plot experiments (described in Chapters 3.3., 3.4., and 3.5.). The results we gained justified this hypothesis. First of all, the  $EC_w$  were measured and calculated the salt content of the water and we measured the salt accumulation in the soil during the irrigation season (Chapter 4.1.). We discovered that the salts getting into the soil by irrigation can be leached with minimizing irrigation and applying soil conditioners (Chapter 4.2.). 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 assess salt mass balance in the soil profile. We could understand how the soil salt mass dynamics worked during the irrigation period and in the leachate period. The amount of water we used in the irrigation period was minimized enough to maintain the soil moisture content at 16% giving sufficient water supply for the crops in such a heavy textured soil. Finally, the effect of soil conditioners was tested by measuring the  $EC_e$ , determining the soil EC profiles and figuring out the patterns differ from the control (*Fig. 17*).

The third principal hypothesis considering that the moisture content and the actual electric conductivity ( $EC_a$ ) of the soil are such variables that can function as an indicator for secondary salinization was tested in a small-plot experiment. I analysed the yields of different indicator crops and evaluated different techniques of the application of microdoses. 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 the 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 (Chapter 3.2.1). 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 studied soil conditioner has an efficiency depending on the salt input range and salt tolerance of the plant.

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 tested and validated this hypothesis by means of a pot experiment carried out in 2018 and 2022 (Chapters 3.6. and 4.4.). We concluded that  $CO_2$  emission showed temporal declines in time during the experiment and found no difference among the effect of the soil conditioners. In 2022, we proved that the difference between salty irrigation and with deionized water in this respect (Chapter 4.4.) was leading to the

acceptance of this hypothesis, although the opposite correlation was found than expected and the differences were not statistically significant.

## **5.2. Fulfilment of my research aims**

The general aim of my studies was to adapt mitigation techniques for the long-term sustainability for horticultural production and understand the dynamics of salinization in horticulture production. The fulfilment point was to understand the genesis of salt affected soils through different topics, like the geological aspects in the Great Hungarian Plain (Chapter 2.1.3.); irrigation and plant nutrition; crop evapotranspiration and dual crop coefficient under soil water stress conditions. Furthermore, as a practical approach, we carried out an irrigation experiment, where we treated a potentially salt affected soil with soil conditioners, and we used three vegetable crops in order to find a method that can indicate the effect of soil conditioners under irrigation with saline water. As a part of this research, I quantified soil salt content dynamics and salt balance and completed one of the goals of this study by adapting and developing methods to the specific agroecological conditions under study (Chapter 4.1.1.). I 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. I differentiated the soil conditioners depending on their application doses. I established that microdoses of biosynthetic conditioners, especially Neosol, can be as effective as standard (full) doses with the considerable advantage of much lower application costs (Chapter 4.3.2.). The specific aims of my research were also fulfilled which is justified by the conclusions detailed below.

We identified and determined the length of two periods, namely the irrigation period and the leaching period, during a year. The irrigation period is when the soil retains water and the leaching period is when precipitation removes salts from the soil layers by gravity. Therefore, we adapted techniques to monitor salinity process to assess salt management, we adapted the Wilcox equation to assess the salt mass balance and dynamics from one year experiment. More importantly, we adapted a calculation in order to measure the salt mass balance of the soil profile (0-1m) using simple drainage lysimeters (Chapter 3.3.2.). However, if there are not measures to monitor and mitigate the salinization process in the root zone, the soil ecosystem and the crop production could be affected by salinization.

The upcoming levels of salt inputs by irrigation could be calculated during time and prolongate the ecosystem functions that are supporting the vegetable production and soil biodiversity.

By determining the correlation among the actual soil EC, soil moisture content, and soil conditioning, the process of secondary salinization could be quantified by means of a new index developed for this reason. We can conclude that the results of the lysimeter studies from 2018-2020 showed a positive correlation between the parameters of  $EC_a$  and the soil moisture content in the soil profile. This principal result let us draw the conclusion that salinization process can be measured and monitored very well even in simple drainage lysimeters.

In the simple drainage lysimeter experiment, we calculated and studied the effect of microdoses of soil conditioning (Chapter 4.2.), while in the small-plot experiment, we identified the necessities of the crops and soil cultivation (Chapter 4.3.). The elaborated a combined technique of (microdose) soil conditioning based on the principle of micro irrigation and soil cultivation depending of the demands of the crops was found to be effective and rational.

Upon further analyses, we fulfilled the aims to determine and quantify the efficiency of microdose application of soil conditioners and comparing them to full dose and compost applications. I established that microdoses of Neosol increase the yields during the irrigation period with salty water to non-salt tolerant crops, while compost application increments the yield during salty irrigation of plants with low salt tolerance (*Tables 22-24* in Chapter 4.3.3).

I could justify the statement about the negative correlation between plant tolerance and the yields of some vegetable crops with different salt tolerance under secondary salinization and quantified the differences for the studied conditions. I also concluded that the higher the  $EC_a$  than the crop EC limit, the lower the crop yield (Chapter 4.3.4.).

I proved that three different factors including the frequency and amount of irrigation, quality (salt content) of water and soil temperature determine the correlation of  $CO_2$  emission from the soil (referring to its microbiological activity) and secondary

salinization in different degrees. In my opinion, the given experimental conditions just indicated the situation of the starting point of salt-affected soils. In addition, even higher CO<sub>2</sub> emission values characterized the soil irrigated with saline water compared to the irrigation with deionized water, but these differences were not statistically significant (Chapter 4.4).

The research team I worked with at the Research Institute of Karcag are investing solutions to mitigate salt accumulation, prevent and produce vegetable crops under saline irrigation in order to aid the local farmers and hobby gardeners with practical but scientifically based advices. It is known that to adapt to crucial problems is necessary to harmonize the diagnostic criteria, definitions and analytical methods that are used to determine the salinity and sodicity status of soils in a scientific way. Fulfilling the aims of this project, I am convinced that small scale farming could face the coming droughts and still be efficient in productivity and minimize the harmful effect of salty irrigation and climate change.

## 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 ( $\sim 1,000 \text{ mg L}^{-1}$  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 ( $-0.01 \text{ m/m\%}$ ), while Neosol just a slightly positive ( $+0.01 \text{ m/m\%}$ ) 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 ( $-0.05 \text{ m/m\%}$ ) 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 ( $12\text{-}20 \text{ g m}^{-2}$  instead of  $20\text{-}33 \text{ g m}^{-2}$ ) accommodating to different vegetable crops.
3. Based on the well-known correlation between the moisture content and the actual electric conductivity ( $\text{EC}_a$ ) 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  $\text{CO}_2$  emission from the soil, hence its microbiological activity, was 50% higher ( $0.087 \text{ g m}^{-2} \text{ h}^{-1}$ ) when irrigated with saline water compared to deionized water ( $0.058 \text{ g m}^{-2} \text{ h}^{-1}$ ), but it was not influenced by soil conditioning.

## 7. 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. 52*).



*Figure 52. Preparing a condibag for micro soil conditioning*

The recommended doses of micro-dose application of the soil conditioners are summarized in *Table 30*. Not only the vegetable crops that were the material of my doctoral dissertation are involved, but other ones as well since I carried out another experiment aiming to determine the effect of soil conditioning on the yields of tomato, carrot, parsley, celery, and sweet corn. The recommended doses expressed in  $\text{g m}^{-2}$  were calculated based on the number of plants produced in  $1 \text{ m}^2$  taking row and plant spacing into account.

Table 30. Recommendation for micro-dose application of soil conditioners based on my research

Vegetable crop	Salt tolerance	Full dose recommended by the producers (g m <sup>-2</sup> )		Recommended micro-dose (g m <sup>-2</sup> )		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

I do not consider my first approach including organic (recycled paper) baskets filled with soil practical enough for the application in the gardens around Karcag. 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.

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 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 21<sup>st</sup> 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.

## 8. SUMMARY

No climatic zone in the world is free from salinization, where there is irrigation for agriculture exist the risk of secondary salinization. The negative effects are induced by human activities like the development of large-scale irrigation projects. Different circumstances can cause secondary salinization like; irrigation with salty water; rising the water table of saline aquifers; clear the land of native vegetation; leaching and discharge of industrial salts or waste water into the river system. In addition, risk increases when the irrigation is made without knowledge and the initiatives to produce high yields is the major soil degradation threat affecting over 10% of the total irrigated land in the world. The consequences of improper irrigation programmes may create 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; compaction and waterlogging.

Much of the food we consume and the trend for vegetable-based food in the future can lead to mismanaged irrigation. Watering of crops is one of the major soil degradation causes in the majority of the sub-developed countries, where water is in a polemic and critical situation. In many cities, untreated water coming from urban areas is used for agricultural irrigation means the only solution. 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 are considered the most vulnerable group to climate change due to the pressure of consuming goods and services that ecosystem provides; the low capacity to adapt to climate change; dependence on rain season; location of the small holders which are exposed to a variety of climate hazards and the negative impacts on productivity.

The research project I was involved at the Research Institute of Karcag aims to mitigate the effect of secondary salinization (which is a considerable issue in Hungary) and develop innovate soil cultivation techniques which can be useful for agriculture including vegetable production in the semiarid regions of Hungary. In this study, I had investigated different types of irrigation and lysimeters, also, I utilized different probes to measure the variants which were involved in the salinization process. I recognized the effect of soil

conditioners on various soil properties and the leaching process as the effect of irrigation. We categorized the soil moisture profile, we analysed soil and the leachate samples originating from simple drainage lysimeters. Based on the achievements gained from the lysimeter studies, irrigation experiments were started that provide a great opportunity to study the effect of salinization on the soil and crops in various small-plot experiments with exact and well-defined circumstances.

The principal aim of my studies was to understand the dynamics of salt affection in order to adapt mitigation techniques for the long-term sustainability for horticultural production. We carried out an irrigation experiment, where we treated a potentially salt affected soil with soil conditioners, and we used three vegetable crops in order to find a method that can indicate the effect of soil conditioners under irrigation with saline water. As a part of this research, I quantified soil salt content dynamics and salt balance and completed one of the goals of this study by adapting and developing methods to the specific agroecological conditions under study. I 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. I differentiated the soil conditioners depending on their application doses. I established that micro-doses of biosynthetic conditioners can be as effective as standard (full) doses with the considerable advantage of much lower application costs. My research work consisted of four experiments dedicated to secondary salinization by irrigation, the application of soil conditioners and their effects on the soil and the indicator crops.

My research work consisted of four experiments dedicated to secondary salinization by irrigation, the application of soil conditioners and their effects on the soil and the indicator crops:

- an experiment in simple drainage lysimeters to determine the effects of irrigation with saline water on the salt dynamics of the soil,
- a preliminary experiment in lysimeters including soil conditioning,
- a small-plot experiment in the Irrigation Experimental Garden,
- a pot experiment.

First, a preliminary experiment in lysimeters including soil conditioning was implemented. We discovered that the salts getting into the soil by irrigation can be leached with minimizing irrigation and applying soil conditioners. The  $EC_e$  profiles determined for the soils of the treatments reflect the distribution of the salts in the different soil layers, the irrigation water applied contained appreciable quantities of soluble salts and could lead to salinity problems by time. The comparison of the salt profiles of the treatment Sola and the control showed that the salts were not leached down at all from the upper layer. The soil profile of Physi reflected the action of a salt leaching down to the bottom (80-100 cm). The salt profile of Sola+Physi showed leaching of the salts, but it was less efficient than the other soil conditioner. Physi treatment had the best improvement in the vegetative growth and yield of chili, while Sola+Physi treatment had the worst performance on the fruits. The effect of the soil conditioners had better performance in the vegetative part of the plants.

The second experiment was in simple drainage lysimeters to determine the effects of irrigation with saline water on the salt dynamics of the soil profile. We gained results from the monitoring of salt input during one year and the adaptation of calculation to assess salt mass balance in the soil profile. We could understand how the soil salt mass dynamics worked during the irrigation period and in the leachate period. Finally, the effect of soil conditioners was tested by measuring the  $EC_e$ , determining the soil salt profiles and figuring out the patterns differ from the control. The soil EC was found to be dependent on the soil moisture content due to the high salt content of the irrigation water. We found leaching to be the dominant process during the irrigation season as the TSM values decreased in all the three examined soil layers (negative  $SB_{ACT}$ ). The upper 20 cm layer contained less salts than the lower two layers which had very similar salt contents. As the determination of  $TSM_{INI}$ ,  $TSM_{FINAL}$  and  $SB_{ACT}$  of the soil in the three upper soil layers could not provide information on the salt status of the lower soil layer (0.6–1.0 m), I combined the results of our  $SB_{ACT}$  and  $SB_{TH}$  calculations determining the  $TSM_{INI}$ ,  $TSM_{FINAL}$  and  $SB$  values for the upper and lower soil layers.

Thirdly, we set up a complex small-plot experiment in the Irrigation Experimental Garden (IEG). 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. In the first year of the experiment, Neosol full application showed promising results for

bean production, while in the second year with higher salt input, Physiomax and Neosol application and microdoses were the best. For peas, both types of Physiomax application and Terrasol use showed the best results, while in the second year, the increased salt input resulted positive salt balances except for Physiomax micro dose application. Chili behaved totally different in the two investigated years: in 2020, all treatments had negative salt balance, while all were positive in 2021. I ranked the investigated amendments in terms of their yield increasing effect. For beans and peas Neosol micro dose, while for chili, Terrasol compost application was the best.

I also studied the moisture content and the actual electric conductivity ( $EC_a$ ) of the soil. These variables are positively correlated and can function as an indicator for secondary salinization. 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.

Based on the pot experiment with soil conditioning and irrigation to monitor  $CO_2$  emission, I concluded that  $CO_2$  emission declines in time during the experiment and found no difference among the effect of the soil conditioners. I proved that three factors do really matter in the correlation of  $CO_2$  emission from the soil (referring to its microbiological activity) and secondary salinization. These three factors are the frequency of irrigation, quality (salt content) of water and soil temperature.

As the main conclusion of my studies, I 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. I differentiated the soil conditioners depending on their application doses. I established that micro-doses of biosynthetic conditioners can be as effective as standard (full) doses with the considerable advantage of much lower application costs. Fulfilling the aims of this project, I am convinced that small scale farming could face the coming droughts and still be efficient in productivity and minimize the harmful effect of salty irrigation and climate change.

## 10. LIST OF PUBLICATIONS RELATED TO THE DISSERTATION



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Candidate: Garcia Arzu Rivera  
Doctoral School: Kálmán Kerpely Doctoral School  
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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 helyzetek 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.  
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19. Tuba, G., Kiss, J., **Rivera, G. A.**, Czeller, K., Kovács, G., Zsembeli, J.: A fák és a köztesnövény vízfelhasználási konkurenciájának vizsgálata egy agrárerdészeti rendszer első évében.  
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18 January, 2023



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## DECLARATION

*This dissertation enables to obtain the doctoral (Ph.D.) degree of the University of Debrecen prepared by the Kálmán Kerpely Doctoral School of the University of Debrecen.*

*Debrecen, 23/01/2023*

.....  
*signature of the candidate*

## DECLARATION

*I certify that Arzu Rivera Garcia doctoral candidate carried out his work under my direction in the abovementioned Doctoral School between 2019 and 2022. The independent creative activity of the candidate is decisive for the results included in the dissertation; the dissertation is the independent work of the candidate. I suggest the acceptance of the dissertation.*

*Debrecen, 23/01/2023*

.....  
*signature of the supervisor*

## APPENDIX

Appendix 1. Results of the post hoc test of bean yields recorded in 2020

Multiple Comparisons						
Dependent Variable: beans_2020 LSD						
(I) treatments	(J) treatments	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
control	Neosol	-.43333	.21602	.068	-.9040	.0373
	Neosol micro	-.53333*	.21602	.030	-1.0040	-.0627
	Physiomax	-.30000	.21602	.190	-.7707	.1707
	Physiomax micro	-.20000	.21602	.373	-.6707	.2707
	Terrasol	-.43333	.21602	.068	-.9040	.0373
Neosol	control	.43333	.21602	.068	-.0373	.9040
	Neosol micro	-.10000	.21602	.652	-.5707	.3707
	Physiomax	.13333	.21602	.549	-.3373	.6040
	Physiomax micro	.23333	.21602	.301	-.2373	.7040
	Terrasol	.00000	.21602	1.000	-.4707	.4707
Neosol micro	control	.53333*	.21602	.030	.0627	1.0040
	Neosol	.10000	.21602	.652	-.3707	.5707
	Physiomax	.23333	.21602	.301	-.2373	.7040
	Physiomax micro	.33333	.21602	.149	-.1373	.8040
	Terrasol	.10000	.21602	.652	-.3707	.5707
Physiomax	control	.30000	.21602	.190	-.1707	.7707
	Neosol	-.13333	.21602	.549	-.6040	.3373
	Neosol micro	-.23333	.21602	.301	-.7040	.2373
	Physiomax micro	.10000	.21602	.652	-.3707	.5707
	Terrasol	-.13333	.21602	.549	-.6040	.3373
Physiomax micro	control	.20000	.21602	.373	-.2707	.6707
	Neosol	-.23333	.21602	.301	-.7040	.2373
	Neosol micro	-.33333	.21602	.149	-.8040	.1373
	Physiomax	-.10000	.21602	.652	-.5707	.3707
	Terrasol	-.23333	.21602	.301	-.7040	.2373
Terrasol	control	.43333	.21602	.068	-.0373	.9040
	Neosol	.00000	.21602	1.000	-.4707	.4707
	Neosol micro	-.10000	.21602	.652	-.5707	.3707
	Physiomax	.13333	.21602	.549	-.3373	.6040
	Physiomax micro	.23333	.21602	.301	-.2373	.7040

\* The mean difference is significant at 0.05 level

Appendix 2. Results of the post hoc test of pea yields recorded in 2020

Multiple Comparisons						
Dependent Variable: peas_2020 LSD						
(I) treat-ments	(J) treatments	Mean Differ-ence (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
control	Neosol	-.26667*	.07201	.003	-.4236	-.1098
	Neosol micro	-.56667*	.07201	.000	-.7236	-.4098
	Physiomax	.03333	.07201	.652	-.1236	.1902
	Physiomax micro	-.26667*	.07201	.003	-.4236	-.1098
	Terrasol	-.30000*	.07201	.001	-.4569	-.1431
Neosol	control	.26667*	.07201	.003	.1098	.4236
	Neosol micro	-.30000*	.07201	.001	-.4569	-.1431
	Physiomax	.30000*	.07201	.001	.1431	.4569
	Physiomax micro	.00000	.07201	1.000	-.1569	.1569
	Terrasol	-.03333	.07201	.652	-.1902	.1236
Neosol mi-cro	control	.56667*	.07201	.000	.4098	.7236
	Neosol	.30000*	.07201	.001	.1431	.4569
	Physiomax	.60000*	.07201	.000	.4431	.7569
	Physiomax micro	.30000*	.07201	.001	.1431	.4569
	Terrasol	.26667*	.07201	.003	.1098	.4236
Physiomax	control	-.03333	.07201	.652	-.1902	.1236
	Neosol	-.30000*	.07201	.001	-.4569	-.1431
	Neosol micro	-.60000*	.07201	.000	-.7569	-.4431
	Physiomax micro	-.30000*	.07201	.001	-.4569	-.1431
	Terrasol	-.33333*	.07201	.001	-.4902	-.1764
Physiomax micro	control	.26667*	.07201	.003	.1098	.4236
	Neosol	.00000	.07201	1.000	-.1569	.1569
	Neosol micro	-.30000*	.07201	.001	-.4569	-.1431
	Physiomax	.30000*	.07201	.001	.1431	.4569
	Terrasol	-.03333	.07201	.652	-.1902	.1236
Terrasol	control	.30000*	.07201	.001	.1431	.4569
	Neosol	.03333	.07201	.652	-.1236	.1902
	Neosol micro	-.26667*	.07201	.003	-.4236	-.1098
	Physiomax	.33333*	.07201	.001	.1764	.4902
	Physiomax micro	.03333	.07201	.652	-.1236	.1902

\* The mean difference is significant at 0.05 level

Appendix 3. Results of the post hoc test of chili yields recorded in 2020

Multiple Comparisons						
Dependent Variable: chili_2020 LSD						
(I) treatments	(J) treatments	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
control	Neosol	-.40000	.19149	.059	-.8172	.0172
	Neosol micro	-.50000*	.19149	.023	-.9172	-.0828
	Physiomas	-.30000	.19149	.143	-.7172	.1172
	Physiomas micro	-.50000*	.19149	.023	-.9172	-.0828
	Terrasol	-.66667*	.19149	.005	-1.0839	-.2495
Neosol	control	.40000	.19149	.059	-.0172	.8172
	Neosol micro	-.10000	.19149	.611	-.5172	.3172
	Physiomas	.10000	.19149	.611	-.3172	.5172
	Physiomas micro	-.10000	.19149	.611	-.5172	.3172
	Terrasol	-.26667	.19149	.189	-.6839	.1505
Neosol micro	control	.50000*	.19149	.023	.0828	.9172
	Neosol	.10000	.19149	.611	-.3172	.5172
	Physiomas	.20000	.19149	.317	-.2172	.6172
	Physiomas micro	.00000	.19149	1.000	-.4172	.4172
	Terrasol	-.16667	.19149	.401	-.5839	.2505
Physiomas	control	.30000	.19149	.143	-.1172	.7172
	Neosol	-.10000	.19149	.611	-.5172	.3172
	Neosol micro	-.20000	.19149	.317	-.6172	.2172
	Physiomas micro	-.20000	.19149	.317	-.6172	.2172
	Terrasol	-.36667	.19149	.080	-.7839	.0505
Physiomas micro	control	.50000*	.19149	.023	.0828	.9172
	Neosol	.10000	.19149	.611	-.3172	.5172
	Neosol micro	.00000	.19149	1.000	-.4172	.4172
	Physiomas	.20000	.19149	.317	-.2172	.6172
	Terrasol	-.16667	.19149	.401	-.5839	.2505
Terrasol	control	.66667*	.19149	.005	.2495	1.0839
	Neosol	.26667	.19149	.189	-.1505	.6839
	Neosol micro	.16667	.19149	.401	-.2505	.5839
	Physiomas	.36667	.19149	.080	-.0505	.7839
	Physiomas micro	.16667	.19149	.401	-.2505	.5839

\* The mean difference is significant at 0.05 level

Appendix 4. Results of the post hoc test of bean yields recorded in 2021

Multiple Comparisons						
Dependent Variable: beans_2021 LSD						
(I) treat-ments	(J) treatments	Mean Dif-ference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
control	Neosol	-.20000	.13472	.163	-.4935	.0935
	Neosol micro	-.33333*	.13472	.029	-.6269	-.0398
	Physiomas	-.16667	.13472	.240	-.4602	.1269
	Physiomas mi-cro	-.23333	.13472	.109	-.5269	.0602
	Terrasol	-.13333	.13472	.342	-.4269	.1602
Neosol	control	.20000	.13472	.163	-.0935	.4935
	Neosol micro	-.13333	.13472	.342	-.4269	.1602
	Physiomas	.03333	.13472	.809	-.2602	.3269
	Physiomas mi-cro	-.03333	.13472	.809	-.3269	.2602
	Terrasol	.06667	.13472	.630	-.2269	.3602
Neosol mi-cro	control	.33333*	.13472	.029	.0398	.6269
	Neosol	.13333	.13472	.342	-.1602	.4269
	Physiomas	.16667	.13472	.240	-.1269	.4602
	Physiomas mi-cro	.10000	.13472	.472	-.1935	.3935
	Terrasol	.20000	.13472	.163	-.0935	.4935
Physiomas	control	.16667	.13472	.240	-.1269	.4602
	Neosol	-.03333	.13472	.809	-.3269	.2602
	Neosol micro	-.16667	.13472	.240	-.4602	.1269
	Physiomas mi-cro	-.06667	.13472	.630	-.3602	.2269
	Terrasol	.03333	.13472	.809	-.2602	.3269
Physiomas micro	control	.23333	.13472	.109	-.0602	.5269
	Neosol	.03333	.13472	.809	-.2602	.3269
	Neosol micro	-.10000	.13472	.472	-.3935	.1935
	Physiomas	.06667	.13472	.630	-.2269	.3602
	Terrasol	.10000	.13472	.472	-.1935	.3935
Terrasol	control	.13333	.13472	.342	-.1602	.4269
	Neosol	-.06667	.13472	.630	-.3602	.2269
	Neosol micro	-.20000	.13472	.163	-.4935	.0935
	Physiomas	-.03333	.13472	.809	-.3269	.2602
	Physiomas mi-cro	-.10000	.13472	.472	-.3935	.1935

\* The mean difference is significant at 0.05 level

Appendix 5. Results of the post hoc test of pea yields recorded in 2021

Multiple Comparisons						
Dependent Variable: peas_2021 LSD						
(I) treatments	(J) treatments	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
control	Neosol	-.06667	.09623	.502	-.2763	.1430
	Neosol micro	-.16667	.09623	.109	-.3763	.0430
	Physiomax	.03333	.09623	.735	-.1763	.2430
	Physiomax micro	.06667	.09623	.502	-.1430	.2763
	Terrasol	.00000	.09623	1.000	-.2097	.2097
Neosol	control	.06667	.09623	.502	-.1430	.2763
	Neosol micro	-.10000	.09623	.319	-.3097	.1097
	Physiomax	.10000	.09623	.319	-.1097	.3097
	Physiomax micro	.13333	.09623	.191	-.0763	.3430
	Terrasol	.06667	.09623	.502	-.1430	.2763
Neosol micro	control	.16667	.09623	.109	-.0430	.3763
	Neosol	.10000	.09623	.319	-.1097	.3097
	Physiomax	.20000	.09623	.060	-.0097	.4097
	Physiomax micro	.23333*	.09623	.032	.0237	.4430
	Terrasol	.16667	.09623	.109	-.0430	.3763
Physiomax	control	-.03333	.09623	.735	-.2430	.1763
	Neosol	-.10000	.09623	.319	-.3097	.1097
	Neosol micro	-.20000	.09623	.060	-.4097	.0097
	Physiomax micro	.03333	.09623	.735	-.1763	.2430
	Terrasol	-.03333	.09623	.735	-.2430	.1763
Physiomax micro	control	-.06667	.09623	.502	-.2763	.1430
	Neosol	-.13333	.09623	.191	-.3430	.0763
	Neosol micro	-.23333*	.09623	.032	-.4430	-.0237
	Physiomax	-.03333	.09623	.735	-.2430	.1763
	Terrasol	-.06667	.09623	.502	-.2763	.1430
Terrasol	control	.00000	.09623	1.000	-.2097	.2097
	Neosol	-.06667	.09623	.502	-.2763	.1430
	Neosol micro	-.16667	.09623	.109	-.3763	.0430
	Physiomax	.03333	.09623	.735	-.1763	.2430
	Physiomax micro	.06667	.09623	.502	-.1430	.2763

\* The mean difference is significant at 0.05 level

Appendix 6. Results of the post hoc test of chili yields recorded in 2021

Multiple Comparisons						
Dependent Variable: chili_2021 LSD						
(I) treatments	(J) treatments	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
control	Neosol	-.23333	.31564	.474	-.9211	.4544
	Neosol micro	-.70000*	.31564	.047	-1.3877	-.0123
	Physiomax	-.40000	.31564	.229	-1.0877	.2877
	Physiomax micro	-.26667	.31564	.415	-.9544	.4211
	Terrasol	-.50000	.31564	.139	-1.1877	.1877
Neosol	control	.23333	.31564	.474	-.4544	.9211
	Neosol micro	-.46667	.31564	.165	-1.1544	.2211
	Physiomax	-.16667	.31564	.607	-.8544	.5211
	Physiomax micro	-.03333	.31564	.918	-.7211	.6544
	Terrasol	-.26667	.31564	.415	-.9544	.4211
Neosol micro	control	.70000*	.31564	.047	.0123	1.3877
	Neosol	.46667	.31564	.165	-.2211	1.1544
	Physiomax	.30000	.31564	.361	-.3877	.9877
	Physiomax micro	.43333	.31564	.195	-.2544	1.1211
	Terrasol	.20000	.31564	.538	-.4877	.8877
Physiomax	control	.40000	.31564	.229	-.2877	1.0877
	Neosol	.16667	.31564	.607	-.5211	.8544
	Neosol micro	-.30000	.31564	.361	-.9877	.3877
	Physiomax micro	.13333	.31564	.680	-.5544	.8211
	Terrasol	-.10000	.31564	.757	-.7877	.5877
Physiomax micro	control	.26667	.31564	.415	-.4211	.9544
	Neosol	.03333	.31564	.918	-.6544	.7211
	Neosol micro	-.43333	.31564	.195	-1.1211	.2544
	Physiomax	-.13333	.31564	.680	-.8211	.5544
	Terrasol	-.23333	.31564	.474	-.9211	.4544
Terrasol	control	.50000	.31564	.139	-.1877	1.1877
	Neosol	.26667	.31564	.415	-.4211	.9544
	Neosol micro	-.20000	.31564	.538	-.8877	.4877
	Physiomax	.10000	.31564	.757	-.5877	.7877
	Physiomax micro	.23333	.31564	.474	-.4544	.9211

\* The mean difference is significant at 0.05 level

Appendix 7. Results of the post hoc test of bean yields recorded in 2022

Multiple Comparisons						
Dependent Variable: beans_2022 LSD						
(I) treatments	(J) treatments	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
control	Neosol	-,03333	,11706	,781	-,2884	,2217
	Neosol micro	,20000	,11706	,113	-,0551	,4551
	Physiomax	,06667	,11706	,580	-,1884	,3217
	Physiomax micro	,13333	,11706	,277	-,1217	,3884
	Terrasol	-,56667*	,11706	,000	-,8217	-,3116
Neosol	control	,03333	,11706	,781	-,2217	,2884
	Neosol micro	,23333	,11706	,069	-,0217	,4884
	Physiomax	,10000	,11706	,410	-,1551	,3551
	Physiomax micro	,16667	,11706	,180	-,0884	,4217
	Terrasol	-,53333*	,11706	,001	-,7884	-,2783
Neosol micro	control	-,20000	,11706	,113	-,4551	,0551
	Neosol	-,23333	,11706	,069	-,4884	,0217
	Physiomax	-,13333	,11706	,277	-,3884	,1217
	Physiomax micro	-,06667	,11706	,580	-,3217	,1884
	Terrasol	-,76667*	,11706	,000	-1,0217	-,5116
Physiomax	control	-,06667	,11706	,580	-,3217	,1884
	Neosol	-,10000	,11706	,410	-,3551	,1551
	Neosol micro	,13333	,11706	,277	-,1217	,3884
	Physiomax micro	,06667	,11706	,580	-,1884	,3217
	Terrasol	-,63333*	,11706	,000	-,8884	-,3783
Physiomax micro	control	-,13333	,11706	,277	-,3884	,1217
	Neosol	-,16667	,11706	,180	-,4217	,0884
	Neosol micro	,06667	,11706	,580	-,1884	,3217
	Physiomax	-,06667	,11706	,580	-,3217	,1884
	Terrasol	-,70000*	,11706	,000	-,9551	-,4449
Terrasol	control	,56667*	,11706	,000	,3116	,8217
	Neosol	,53333*	,11706	,001	,2783	,7884
	Neosol micro	,76667*	,11706	,000	,5116	1,0217
	Physiomax	,63333*	,11706	,000	,3783	,8884
	Physiomax micro	,70000*	,11706	,000	,4449	,9551

\* The mean difference is significant at 0.05 level

Appendix 8. Results of the post hoc test of pea yields recorded in 2022

Multiple Comparisons						
Dependent Variable: peas_2022 LSD						
(I) treatments	(J) treatments	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
control	Neosol	-.16667	.10364	.134	-.3925	.0591
	Neosol micro	-.23333*	.10364	.044	-.4591	-.0075
	Physiomax	-.06667	.10364	.532	-.2925	.1591
	Physiomax micro	-.10000	.10364	.354	-.3258	.1258
	Terrasol	.03333	.10364	.753	-.1925	.2591
Neosol	control	.16667	.10364	.134	-.0591	.3925
	Neosol micro	-.06667	.10364	.532	-.2925	.1591
	Physiomax	.10000	.10364	.354	-.1258	.3258
	Physiomax micro	.06667	.10364	.532	-.1591	.2925
	Terrasol	.20000	.10364	.078	-.0258	.4258
Neosol micro	control	.23333*	.10364	.044	.0075	.4591
	Neosol	.06667	.10364	.532	-.1591	.2925
	Physiomax	.16667	.10364	.134	-.0591	.3925
	Physiomax micro	.13333	.10364	.223	-.0925	.3591
	Terrasol	.26667*	.10364	.024	.0409	.4925
Physiomax	control	.06667	.10364	.532	-.1591	.2925
	Neosol	-.10000	.10364	.354	-.3258	.1258
	Neosol micro	-.16667	.10364	.134	-.3925	.0591
	Physiomax micro	-.03333	.10364	.753	-.2591	.1925
	Terrasol	.10000	.10364	.354	-.1258	.3258
Physiomax micro	control	.10000	.10364	.354	-.1258	.3258
	Neosol	-.06667	.10364	.532	-.2925	.1591
	Neosol micro	-.13333	.10364	.223	-.3591	.0925
	Physiomax	.03333	.10364	.753	-.1925	.2591
	Terrasol	.13333	.10364	.223	-.0925	.3591
Terrasol	control	-.03333	.10364	.753	-.2591	.1925
	Neosol	-.20000	.10364	.078	-.4258	.0258
	Neosol micro	-.26667*	.10364	.024	-.4925	-.0409
	Physiomax	-.10000	.10364	.354	-.3258	.1258
	Physiomax micro	-.13333	.10364	.223	-.3591	.0925

\* The mean difference is significant at 0.05 level

Appendix 9. Results of the post hoc test of chili yields recorded in 2022

Multiple Comparisons						
Dependent Variable: chili_2022 LSD						
(I) treatments	(J) treatments	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
control	Neosol	-.43333*	.11055	.002	-.6742	-.1925
	Neosol micro	-.10000	.11055	.384	-.3409	.1409
	Physiomax	.23333	.11055	.056	-.0075	.4742
	Physiomax micro	.23333	.11055	.056	-.0075	.4742
	Terrasol	.03333	.11055	.768	-.2075	.2742
Neosol	control	.43333*	.11055	.002	.1925	.6742
	Neosol micro	.33333*	.11055	.011	.0925	.5742
	Physiomax	.66667*	.11055	.000	.4258	.9075
	Physiomax micro	.66667*	.11055	.000	.4258	.9075
	Terrasol	.46667*	.11055	.001	.2258	.7075
Neosol micro	control	.10000	.11055	.384	-.1409	.3409
	Neosol	-.33333*	.11055	.011	-.5742	-.0925
	Physiomax	.33333*	.11055	.011	.0925	.5742
	Physiomax micro	.33333*	.11055	.011	.0925	.5742
	Terrasol	.13333	.11055	.251	-.1075	.3742
Physiomax	control	-.23333	.11055	.056	-.4742	.0075
	Neosol	-.66667*	.11055	.000	-.9075	-.4258
	Neosol micro	-.33333*	.11055	.011	-.5742	-.0925
	Physiomax micro	.00000	.11055	1.000	-.2409	.2409
	Terrasol	-.20000	.11055	.096	-.4409	.0409
Physiomax micro	control	-.23333	.11055	.056	-.4742	.0075
	Neosol	-.66667*	.11055	.000	-.9075	-.4258
	Neosol micro	-.33333*	.11055	.011	-.5742	-.0925
	Physiomax	.00000	.11055	1.000	-.2409	.2409
	Terrasol	-.20000	.11055	.096	-.4409	.0409
Terrasol	control	-.03333	.11055	.768	-.2742	.2075
	Neosol	-.46667*	.11055	.001	-.7075	-.2258
	Neosol micro	-.13333	.11055	.251	-.3742	.1075
	Physiomax	.20000	.11055	.096	-.0409	.4409
	Physiomax micro	.20000	.11055	.096	-.0409	.4409

\* The mean difference is significant at 0.05 level