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Effect of sufficient and deficit irrigation with different salt inputs on the yield of cucumber

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SUMMARY

Soil salinisation is considered one of the major environmental hazards threatening agricultural productivity and can be accentuated by climate change as well as the use of low-quality water in irrigation. This is the case in our study area which is affected by secondary salinisation due to the use of saline irrigation water for horticultural production. Deficit irrigation technique is implemented especially in arid and semiarid regions due to its potential to optimise water productivity while maintaining or increasing crop yield. The main objective of this study was to compare the effect of irrigation with sufficient (SD) and deficit (DD) doses. This research was carried out in Karcag in 2020. Cucumber was grown on a meadow chernozem soil and was irrigated with SD and DD of two irrigation water qualities. Soil moisture was monitored and crop yields were recorded. Despite the differences in quality and quantity of water, the application of less water by DD maintained the same yield as SD. We found a non-significant difference between the average soil moisture contents under the treatments (15.5 v/v% for SD and 13.5 v/v% for DD). Deficit irrigation can be an efficient technique due to its potential for improving water use efficiency, maintaining sufficient soil moisture content favourable for proper crop development and yield.

Keywords: *saline water; deficit irrigation; secondary salinisation*

INTRODUCTION

Freshwater is a precious resource not only essential for the survival of any entity belonging to the ecosystem but also presents the primordial source for the development of modern society. Its availability, although, rare all over the world, is increasingly becoming acute leading to its sustainable use as a major water policy challenge for the future. Globally, agriculture is considered the largest water consumer sector, with 90% of human water consumption needed to produce food (Falkenmark and Rockström, 2004), where in the semi-arid and arid zones, agricultural water consumption exceeds 70–80% of the total (Fereres and Soriano, 2007). Irrigation is implemented in many regions of the world and especially in those under arid and semi-arid climates to overcome such shortages related to rainfall and its uneven distribution, although, this action might exert additional stress under the water bodies and aquifers that are already depleting for the purpose of maintaining/increasing the food security to cope with the growing population and their needs (Pulido-Bosch et al., 2018). Furthermore, agricultural sector is affected by the effects of global warming and the climate change makes it more vulnerable system threatening farmers' livelihoods and our food supply. As a consequence, the agricultural community seems to be under the mercy of this resource.

However, the necessity of applying irrigation took attention besides of arid and semi-arid regions, the humid and subhumid areas where drought periods have been witnessed what made the rainfall supplement necessary to stabilize the production (Fereres and Soriano, 2007; Zsembeli et al., 2019a). It is, therefore, clear that this practice is becoming mandatory and widely used despite its negative effects that promote secondary salinisation. Karcag region in the Great Hungarian Plain, for example, is characterised by the widespread of horticultural activities in hobby gardens all around the town that had been practiced for 300 years, that nowadays, its soils are considered affected with secondary salinisation (Zsembeli et al., 2011).

In nature, the soil is non-renewable and vital resource providing essential support for ecosystems, human life, and society (Morvan et al., 2008). Its dynamism consists of retaining various bio-physiochemical processes ensuring the development of vegetation. Such abnormal change of one of these processes may generate imbalance within the soil leading to modifying of the overall soil properties. Soil salinisation among several factors including climate variability, extreme events, soil compaction, soil contamination, erosion, loss of organic matter, inappropriate soil/water management practices, severely manifests in soil degradation (Mohamed et al., 2019). This hazard is witnessed all over the world threatening agricultural productivity and sustainability (Okur and Örçen, 2020). Thus, soil monitoring seems to be essential for its conservation and its sustainability to provide to the ecosystem different goods and services.

On the other hand, owing to water scarcity, the recourse of using of saline groundwater in several regions of the world especially those in arid environments has become necessary to the farmers, in order to fill the water gaps and meet their crop water requirements (Ondrasek et al., 2011). Nevertheless, this practice due to agricultural intensification and climate change seems to increase the magnitude of soil salinity in the long term.

The soil salinisation phenomenon in agricultural lands is mainly caused by poor water quality (saline water) like the case of Karcag region. The risk of soil

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salinisation could be reduced when applying deficit irrigation strategy even with saline water. This can be proved through the evaluation of the soil salt balance. Applying less water by deficit irrigation is a technique that saves water resource but also it has the potential to control of soil salinity by reducing the ingress of salts by irrigation water without having negative effects on the crop growth and yield (Sidhu et al., 2021; Chai et al., 2014).

The challenge, and at the same the main goal, of this project was to apply the concept of deficit irrigation proving its potential in saving water, using two different saline irrigation water (well water originating from the groundwater and the tap water) while maintaining sufficient soil moisture for the crop development. In this study, the effects of irrigation with saline water on the chosen indicator crop, cucumber (*Cucumis sativus* L), particularly its produced biomass were evaluated.

MATERIALS AND METHODS

Our study is based on the preliminaries that the use saline water for irrigation in the region of Karcag has been widespread, causing secondary salinisation for a long time (Zsembeli et al., 2011). Through this research work, we proposed the use of deficit irrigation strategy, a new strategy having the potential to optimise water productivity in horticulture. This technique has been used and tested in many research studies especially in dry areas where water is a limiting factor for crop development, and we wanted to adopt it to our agroecological conditions. The plot experiment dedicated to study the effect of deficit irrigation with different quality irrigation waters on cucumber yields was set up on an 84 m^2 area in the irrigation experimental garden in the Research Institute of Karcag (RIK). The research was carried out during the two seasons (spring and summer) of 2020.

The irrigation experiment included 12 plots (1 m x 6 m each) in 2 blocks separated with 3 m spacing. Four treatments (2 irrigation doses and 2 irrigation water qualities) in three replicates were set up on a meadow chernozem soil, which is one of the three characteristic soil types of the region (Rivera et al., 2020).

Cucumber (*Cucumis sativus* L.) was applied as the indicator crop of the experiment. Using cucumber as a crop growth indicator when applying the concept of deficit irrigation with saline water, we aim to examine the effects of this strategy using such poor water on the harvested yield and the crop quality. A high reason for choosing specifically this crop represents by its moderate sensitivity to salt stress (FAO, 2002), hence yield drop is predicted due to a higher degree of secondary salinisation.

Cucumber (*Cucumis sativus* L.) belongs to the cucurbits or *Cucurbitaceae* family and the *Cucumus* genus. It is originated first from India, later on it was world widely cultivated and become one of the fourth popular grown vegetables after tomatoes, cabbage, and onions (Shetty and Wehner, 2002; Martinez et al., 2006). Cucumber is considered thermophilic and frost-susceptible crop (Shetty and Wehner, 2002), and grows at any time during the year. Also, it is characterised by a short growing cycle (Wehner and Guner, 2004), with shallow root system that makes it relatively sensitive to soil moisture depletion. Especially during the flowering and fruiting stages, cucumbers require high amount of water, as the fruits rich of around 95% of water (Arshad, 2017).

On 27th April, the seeds were sown (*Figure 1*) 3 cm deep into the soil in each row of the plots spacing the plantings approximately 20 cm apart. The plants were grown for 4 months and watered by hand regularly. On 9th June, flowers had started to form progressively. Thus, in order to protect the growing plants from exposure to different diseases, a fungicide treatment (Amistar) was applied. Later on, the soil surface was hoed from weeds to avoid any kind of competition and a trellis net (*Figure 1*) was settled down acting to support the growing crop in upright position. This technique makes easier to undertake all the necessary care related to crop production while taking advantage of the sunlight and efficient air circulation.

Figure 1. **Sowing the cucumber seeds (left) and the trellis net system (right) in the experiment (Karcag, 2020)**

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Additionally, to enhance the development of emerging seedlings, some essential nutrients was supplied by using a starter fertiliser. Once the fertiliser was given and the growing plants were protected, and after 18 days of the flowering stage, small cucumber fruits started to appear on the 26th June. At the end of June, once the cucumber plants had fully developed, the last stage of the growing season established, hence the harvesting period began. From this point, picking the cucumbers lasted till the end of August, and during that period, we harvested the fruits 20 times. Yield data were collected including the number and weight of the fruits.

This experiment was fed with two types of irrigation water: aquifer water coming from a drilled well directly near to the experimental plots and the local tap water, respectively. These waters are basically coming from a similar source (aquifers), although, their salt content is different: 600–700 mg L^{-1} salt concentration is characteristics to the well waters in the region, while 900–1000 mg L^{-1} salt concentration is characteristics to the tap water in the local drinking water network of Karcag.

The cucumber rows in two plots received well water (WW), where one of them with sufficient dose (SD), while the other one with deficit dose (DD) which was the half of DS. The last two plots were irrigated with tap water (TW) where one plot received SD, while the other one DD. Applying two doses of irrigation seeks to call into question either the water quality or the quantity is the limiting factor in cucumber production under the given agroecological conditions.

Irrigation water was supplied to the crop from plastic watering cans by hand. The frequency of irrigation was determined based on the actual soil water content. In order to schedule the irrigation, first we estimated the field capacity (FC) of the investigated meadow chernozem soil that equals 36 v/v%. In the case of SD treatment, we wanted to maintain a more or less stable soil moisture content sufficient for the indicator crop which corresponds about one third of FC (Zsembeli et al., 2019b), hence we irrigated when the actual soil moisture content decreased under 12 v/v% as the targeted threshold. The actual soil moisture content was determined based on daily field measurements by an SMT-100 portable soil moisture meter. Taking the surface area of the rows that was actually irrigated (2 m^2) into account, 20 litres of irrigation water corresponding to 10 mm of water input was the basic amount of water irrigated as SD, while half of it in the case of DD treatment for both waters. The total water input and its composition applied in the irrigation experiment are summarised in *Table 1*.

During the whole irrigation period (April–August, 2020), both water types were analysed in the laboratory of RIK in order to evaluate their quality, particularly their salinity. Knowing the salt concentration and the amount of the irrigation water characterising the four water quality/dosage treatments, the total salt input got onto the soil surface of each plot can be calculated as their product (*Table 2*).

Table 1. **Composition of total water inputs during the irrigation period (27/04–13/08, 2020)**

Dosage treatment	Irrigation (mm)	Natural precipitation (mm)	Total water input (mm)
Sufficient dose (SD)	237.5	328.3	565.8
Deficit dose (DD)	127.5*	328.3	455.8

* same doses were applied at sowing time making DD 54% of SD

Table 2. **Total salt inputs during the irrigation period (27/04–13/08, 2020)**

Water quality/ dosage treatment	Irrigation (L)	Average salt concentration of the irrigation water (mg L^{-1})	Total salt input (g m^{-2})
WW/SD	475	610	144.9
WW/DD	255	610	77.8
TW/SD	475	950	225.6
TW/DD	255	950	121.1

Legends: WW: well water, TW: tap water, SD: sufficient dose, DD: deficit dose

For data processing and visualisation were done by Microsoft Excel programme. In order to verify if there are significant differences among treatments in terms of yields and soil moisture contents, we used SPSS 27.0.1.0 statistical software running one-way analysis of variance (ANOVA) and boxplot analyses.

RESULTS AND DISCUSSION

As the result of the scheduled irrigation, the actual soil moisture contents of the SD and DD treatments, regardless the salt content of the soil, were varying as shown in *Figure 2*.

Naturally, the actual soil moisture status of the plots was not only determined by the irrigation doses but by the amount of natural precipitation, therefore, seemingly there is no considerable differences between the treatments, although the average soil moisture content of the SD plots was 15.5 v/v%, while of the DD plots was 13.5 v/v%. The statistical analysis of the soil moisture data showed no statistically significant difference between the irrigation dose treatments at

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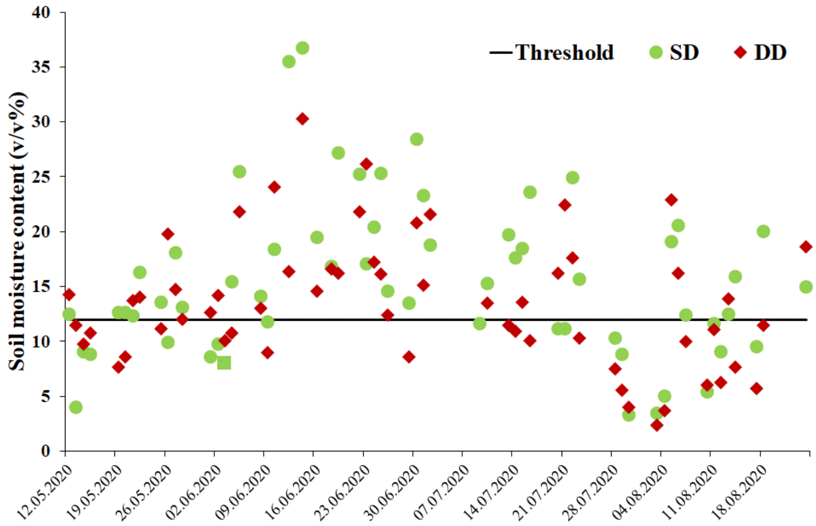
0.05 level (*Table 3*). Based on these data, deficit irrigation ensured a soil moisture status similar to sufficient irrigation that was intended to maintain the soil moisture content close to filed capacity under the investigated conditions.

Figure 2. **Average actual soil moisture content of the soil of the plots during the irrigation period in 2020**



Legends: SD: sufficient dose, DD: deficit dose

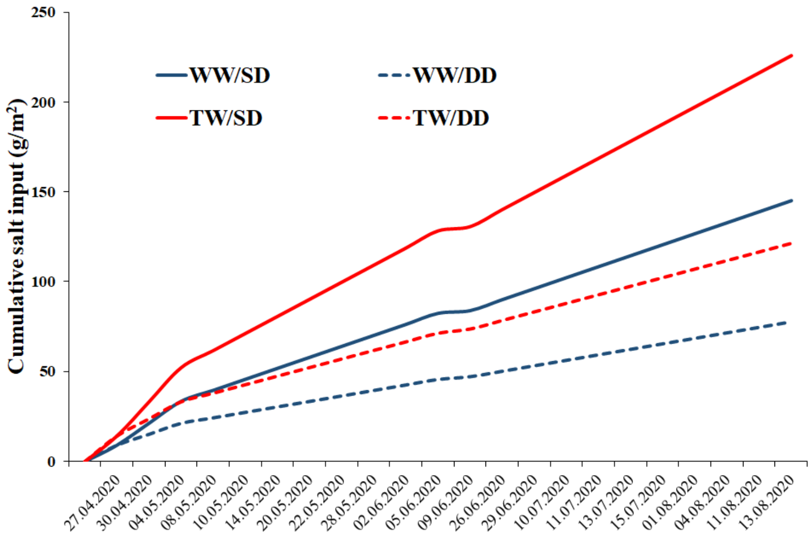
Table 3. **Results of ANOVA of soil moisture content data in the function of irrigation doses**

	Sum of Squares	df	Mean Square	F	Sig.
Between SD and DD	1.378	1	1.378	0.032	0.859
Within SD and DD	3970.028	91	43.627		
Total	3971.406	92			

Legends: SD: sufficient dose, DD: deficit dose

Obviously, the higher dose (SD) of the more saline tap water (TW) represented the highest salt load (225.6 g m^{-2}), three times higher than the lowest salt load (77.8 g m^{-2}) being in conjunction with the deficit dose (DD) of the less saline well water (WW). The other two combinations – lower irrigation dose (DD) with higher salt content (TW) and higher irrigation dose (SD) with lower salt content (WW) – resulted in quite similar salt loads (121.1 g m^{-2} and 144.9 g m^{-2}, respectively) on the soil surface of the dedicated plots. For better visualisation, the differences in the dynamics of the salt inputs by irrigation among the treatments are shown in *Figure 3*.

Figure 3. **Cumulative salt inputs by irrigation in terms of the treatments during the irrigation period of 2020**



Legends: WW: well water, TW: tap water, SD: sufficient dose, DD: deficit dose

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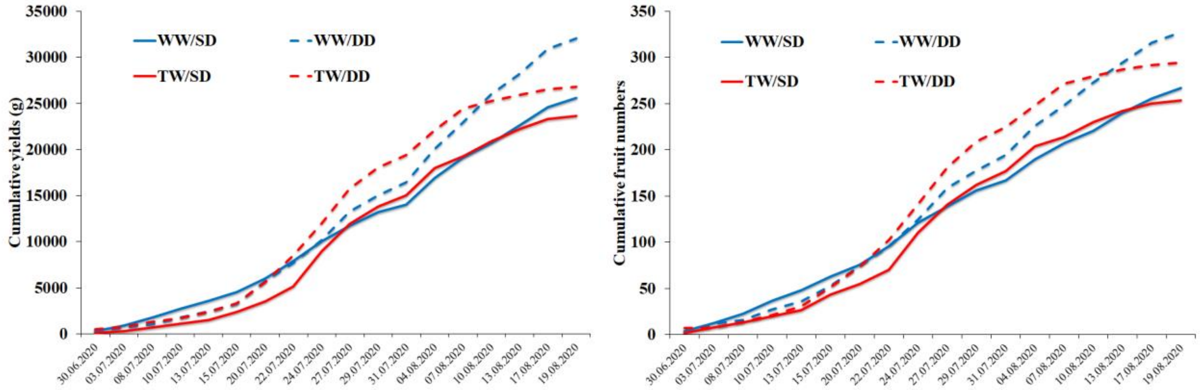
In fact, the duration of the irrigation period also determines the salt loads, the longer the irrigation period, the higher the difference in the salt input dynamics. This statement has its particular significance when the amount of natural precipitation fallen in the vegetation period of cucumber (or other vegetables) is lower and irrigation supplies the majority of the water demand of the investigated crop. Further studies in this respect may provide more information about the combined effect of the amount and quality (salt concentration) of irrigation water applied in vegetable production.

During the harvesting period (June–August), we picked the fruits by hand 20 times. At each time, the fruit yield and number per plot were measured and counted, respectively. The results for both cucumber yields and fruit numbers in the function of the irrigation treatments are presented in *Figure 4*. We used cumulative values for the illustration in order to have a view of the dynamics of these two quantitative parameters of cucumber that determines it presence possibility in the market.

Figure 4. **Cumulative fruit yields (left) and numbers (right) of cucumber, 2020**

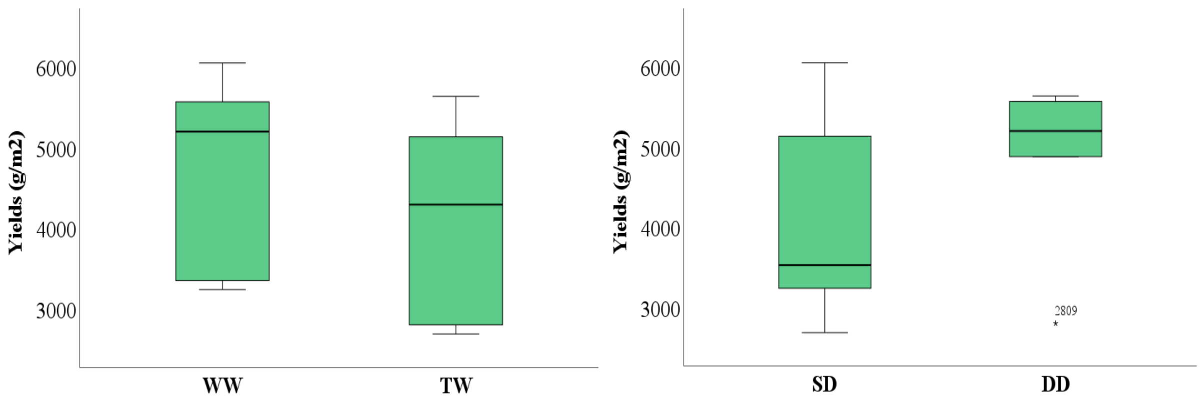


Legends: WW: well water, TW: tap water, SD: sufficient dose, DD: deficit dose

We can clearly see that both graphs are similar, and there is no significant difference either of the curve between the different treatment types and doses. This similarity highlights the crop yield was basically determined by the number of the fruits, not by the weight of them. In other words, the fruits had similar sizes, but the treatments basically effected on the number of the cucumber fruits. Both graphs reveal that the highest crop fruit mass and number harvested during the harvest time corresponds to the deficit (half) dose of well water treatment which involved the lowest salt input. In harmony with this effect, the lowest harvested crop mass and number corresponds to the highest salt input by sufficient dose of tap water irrigation.

According to the boxplot analysis of the effect of irrigation water quality (salt content) and dose on cucumber yields, no statistically difference could be figured out comparing these treatments (*Figure 5*), though their averages differ in the same way as it was described above concerning the cumulative fruit yields.

Figure 5. **Yields of cucumber in the function of water quality (left) and irrigation dose (right)**



Legends: WW: well water, TW: tap water, SD: sufficient dose, DD: deficit dose

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Nevertheless, we can establish that the amounts of salts in the water had influenced the cucumber yield, thus, when applying additional doses of the same water type, the crop receives automatically additional salt mass as well. Hence, more salts by irrigation water results in reducing the crop biomass by hindering its normal growth. However, the harvesting period was wetter than the average, especially in July extremely high amount of precipitation (139.3 mm) was registered. This could affect the development of the cucumbers as we can see the change of the curve by time following two different irrigation events with different intensities and quantities.

In general, saline soils occur in areas where water is the primary carrier of salts and this was found to be valid for the studied area too. In fact, the salinity of the soil influences its physicochemical properties, by adversely affecting the relevant ecological balance of a certain region (Chhabra, 1996). It is proved as well, by many scientists that salinity of the irrigation water influences not only the soil properties but also the growing crops under such circumstances. This is done by inhibiting their growth and development and leads to their death under extreme salinity levels (Plaut et al., 2013). Furthermore, the plant growth can be affected by osmotic effects, specific ion effects, toxic ion effect and foliar absorption of salt constituents (Qadir and Oster, 2004; Shainberg and Letey, 1984).

The inherent salinity problems of irrigation emphasis the must of mitigating theses negative effects by managing the quality of the water resource and/or implementing alternative management strategies that aim the conservation of all natural resources. Among these management practices, deficit irrigation, a new strategy gained attention for the last decade thanks to its potential of minimising the pressure on the water resource while ensuring a stable and/or improving crop biomass. In this context, and throughout this study, we tried to prove the efficiency of this strategy using poor water quality.

CONCLUSIONS

We evaluated the impacts of deficit irrigation with saline water on the yields of cucumber. The results showed that the fruit numbers and yields showed similar curves for all the treatments, which highlights on the fact that the fruits had quite similar sizes but their number was influenced by the treatments.

Considering all these results, we could conclude that deficit irrigation strategy proved its potential for saving water while maintaining a sufficient soil moisture content favourable for a proper crop development. Although, under drought conditions, irrigation with water loaded with high quantity of salts may add an additional stress for the growing crop. Therefore, knowledge about the level of the crop sensitivity to water deficit and salt tolerance as well as the climatic conditions is primordial to successfully apply the deficit irrigation strategy. Therefore, we suggest continuing the research study we were involved but with a more precise and controlled deficit strategy, which is basically based on the knowledge of crop response to water stress.

It was also interesting that the yield of the crop biomass with the application of full irrigation and with deficit irrigation was similar. This proves the potential of DI, not only in saving water, but also without negative effects on the crop yield. Although, the different salt load by the irrigation water used resulted in the difference in the yields.

The challenge of the agricultural sector that consists of increasing the productivity of water use, with less water use and the least compromise on crop yields and soil salinisation is actual. Deficit irrigation strategy meet perfectly with these conditions. It consists of limiting the application of water to crops, aiming to optimise and stabilise water productivity, rather than optimising yields.

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