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TREATED WASTEWATER IRRIGATION: EXPERIMENTAL RESULTS AND LESSONS LEARNED

Špela ŽELEZNIKAR[1*], Gašper LESKOVAR[1], Nina KACJAN MARŠIČ[1], Tjaša GRIESSLER-BULC[2], Damijana KASTELEC[1], Marina PINTAR[1]

[1]Biotechnical faculty, Department of Agronomy, Jamnikarjeva 101, 1000 Ljubljana, Slovenia
[2]Faculty of Health Sciences, Zdravstvena pot 5, 1000 Ljubljana, Slovenia
*Corresponding author: spela.zeleznikar@bf.uni-lj.si

ABSTRACT

The identification and introduction of new, alternative sources of water for irrigation is a growing trend in many countries around the world, including Slovenia. To obtain larger quantities of clean drinking water, the use of treated wastewater (TWW) for irrigation can reduce the consumption of the primary natural water resource. Irrigation with TWW is increasing due to population growth and the associated increase in wastewater volumes, as well as the need to adapt to climate change. In order to study the impact of using wastewater for irrigation on soils, plants and crops, an experimental field with 30 lysimeters was established in the Central Municipal Wastewater Treatment Plant (CMWWTP) in Ajdovščina, Slovenia. In this paper, we present the results of the first experiments with pumpkin conducted at the Ajdovščina WWTP. We investigated the effects of irrigation with differently treated irrigation water sources from the WWTP compared to irrigation with tap water as a control. Presented results are outcomes of a short-term experiment. To fully understand and investigate the effects of TWW application on soils, plants and yields the study should include multi-year trials and more frequent irrigation.

Keywords: *irrigation, water source, treated wastewater, pumpkin, soil.*

INTRODUCTION

Water is an extremely important natural resource. Agriculture is one of the main consumers of water, accounting for 80% of total water use according to current estimates, with water use for irrigation expected to increase by an additional 15% by 2030 (SDG Report, 2019). In order to obtain more clean drinking water, new alternative sources of water for irrigation are currently actively sought and introduced around the world. One of these is the use of TWW. TWW is defined as "water that has undergone at least secondary treatment and disinfection and is reused after leaving the treatment plant" (Hashem and Qi, 2021). It can be used for irrigation of agricultural and other areas (environmental and recreational), for industrial reuse, or for municipal purposes (urban sanitation and firefighting). De

Carlo et al. (2020) state that the use of TWW as a source for irrigation has economic and environmental benefits. The need to apply certain types of fertilisers to the soil is reduced or even eliminated because it contains organic matter and nutrients that are beneficial to plants. However, TWW use also poses risks, as it can increase soil salinity and increase the levels of microorganisms and other modern pollutants in the soil (Gao et al., 2021; De Carlo et al., 2020; Ganjegunte et al., 2018).

Water resources for irrigation are limited in many places, both in Slovenia and around the world. Therefore, in areas where there are no other water sources, the use of TWW for irrigation could be a new, alternative water source. However, irrigation with TWW requires a number of additional restrictions and quality controls of the TWW used, which are not required when using conventional water sources for irrigation. To test the suitability and find new water sources for irrigation, we are conducting experiments presented in this paper and planning new ones for the future.

In our study, we aimed to determine the suitability of TWW (application and comparison of different TWW treatment methods) for irrigation at the Ajdovščina (Slovenia) waste water treatment plant (WWTP) lysimeter station. Authors were also interested in the concentration of heavy metals in soils and plants irrigated with TWW, and the influence of TWW on the electrical conductivity (EC) and pH of the outflow from the lysimeters.

MATERIALS AND METHODS

The Ajdovščina WWTP in Slovenia operates as a conventional flow-through system with pre-denitrification and anaerobic stabilisation of the sludge in the digesters. It consists of two lines, a water line and a sludge line. In addition to the installations that is part of the conventional WWTP an algae system and a constructed wetland are also installed at the location.

The study on irrigation with different TWW was conducted as a block experiment with five treatments in six replicates. The treatments consisted of four different irrigation water sources: water from a constructed wetland (CW), water treated with algae technology (AT), water from the WWTP with additional fertilisation (WWTPf) and water from the WWTP without fertilisation (WWTPnf). As the fifth treatment, tap water as control (C) was used. The experiment was carried out in 30 lysimeters buried in the soil with a size of 400 mm × 1000 mm, each equipped with two soil sensors for water content and salinity of the soil. The lysimeters were filled with previously analysed soil from the area surrounding the WWTP. The pH and EC of the different water sources used for irrigation were also analysed. A plant of Hokkaido pumpkin *(Cucurbita maxima Duchesne)*, cv. 'Shishikura', one of the most important pumpkin species for agriculture, was planted in each lysimeter. Hokkaido pumpkins were planted on May 31, 2019, and fertilised with 31 g KAN (39%), 44 g of Hypekorn fertiliser (0:26:0), and 84 g K2SO4 per plant. Additional fertilisation was applied on June 21, 2019 and July 24, 2020 with 31 g KAN per plant.

Irrigation was carried out according to the needs of the plants using available data for reference evapotranspiration. Which was 487.4 mm during the growing season, and precipitation, where 169.4 mm of precipitation fell during the experiment according to the nearest weather stations. Irrigation was carried out at an interval of three days. It was less than the above calculation required, but there were no visible signs of water deficit on the plants. The first week, irrigation was manual (13.6 l/plant), then drip irrigation (one drip per plant/lysimeter) at seventeen rates (68 l/plant) was used. The pH, EC, and volume of water draining from the lysimeters were measured in the lysimeter outflow between July 10, 2019 and August 28, 2019. Harvesting of the crop (pumpkins), plants, and soil samples was conducted on September 3, 2019.

RESULTS AND DISCUSSION

Concentrations of metals arsenic (As), cadmium (Cd), copper (Cu), molybdenum (Mo), nickel (Ni), lead (Pb), zinc (Zn), cobalt (Co), and chromium (Cr) in soil were monitored. The metal content in soils is mainly influenced by the soil parent material, atmospheric deposition, manure and slurry application, various plant protection products and mineral fertilisers.

Most of the metals analysed, with the exception of Cu and Ni, did not exceed the immission limit values (Official Gazette of the Republic of Slovenia No. 68/96 dashed line, Figure 1), and there were no statistically significant differences in the average metal content in soil between treatments (Figure 1). Albdaiwi et al. (2022) and Kumar et al. (2021) confirmed similar results and concluded that continuous irrigation with TWW did not lead to accumulation of metals in soil and did not exceed the World Health Organisation (WHO) limit values. Higher Cu concentrations in the soil may be due to human influences (plant protection measures in the cultivation of vines and peaches in the area of the Ajdovščina WWTP) (Murtaza et al., 2015; Zupan et al., 2008). Higher Ni values are attributed to naturally high soil concentrations resulting from rock weathering in the area where the experiment was conducted (Zupan et al., 2008).

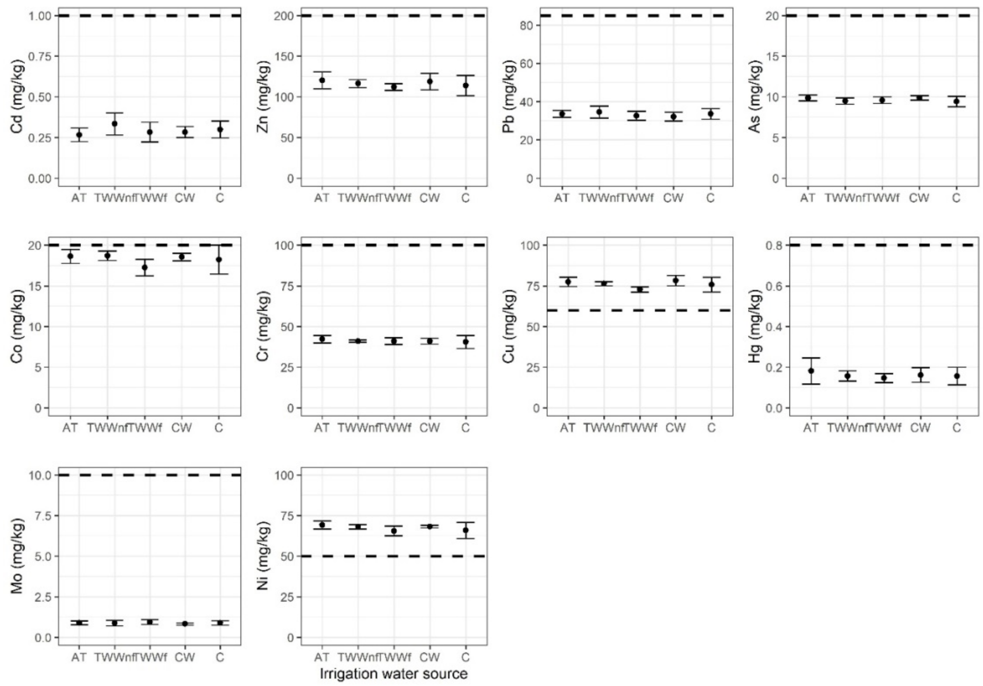

Figure 1: Average metal contents in lysimeters soils (mg/kg) for different irrigation water used with associated 95% confidence intervals at the Ajdovščina WWTP, sampled on 3 September 2019. The dashed line represents the immission limit value for metals in soil (Official Gazette of the Republic of Slovenia No. 68/96).

Metal content was also measured in samples from different parts of the plant. These data were analysed as a two-factorial experiment, with irrigation water representing one of the factors studied and the plant part representing the other. The results of the statistical analysis showed that there was no interaction between the irrigation method and the accumulation of metals in different parts of the plant (Figure 2). For all metals, there were statistically significant differences in the average metal content between the different plant parts. This was confirmed also in other studies, where Ofori et al. (2021) and Roba et al. (2016) found that plants and different plant parts have different bioaccumulation capacities. This mainly depends on the type of plant, the type of metal, and the type of soil. The accumulation of metals in plants and their transfer through the food chain to the human body represents the main risk for the development of various diseases when contaminated plants are consumed (Rai et al., 2019). Ofori et al. (2021) state that irrigation with TWW can increase the content of some metals in soils and plants, and their accumulation can lead to toxicity when concentrations are above limits.

Current dietary guidelines prescribe limits for metal concentrations in pumpkin fruit only for Cd and Pb. Mean Cd and Pb levels were statistically significantly lowest in fruit, but the confidence interval for these mean values included the 0.05 mg/kg fresh weight limit for fruit according to current Food and Agriculture

Organisation (FAO) and WHO (2019) dietary guidelines. Mean Zn and As content was statistically significantly higher in roots than in fruits and green parts, which were not statistically significantly different. Mean Co content in pumpkin fruit was statistically significantly lower than in the other two plant parts. The fruits contained more Cr, Cu, Mo and Ni on average than the roots and green part. Regarding the used irrigation water sources used for irrigation, statistically significant differences were found only for Cu and Mo. For Cu, higher contents were found on average when irrigated with TWWnf compared with TWWf and C. For Mo, on the other hand, the average content was higher with AT than with TWWf. The literature also suggests that metal contents can vary significantly in different plant parts irrigated with TWW. Hussain et al. (2019) and Kumar et al. (2021) indicate that several factors influence the transport and accumulation of metals in different plant parts. These include the concentration of these metals in the soil and the soil type, as well as the time of harvest and the stage of fruit maturity.

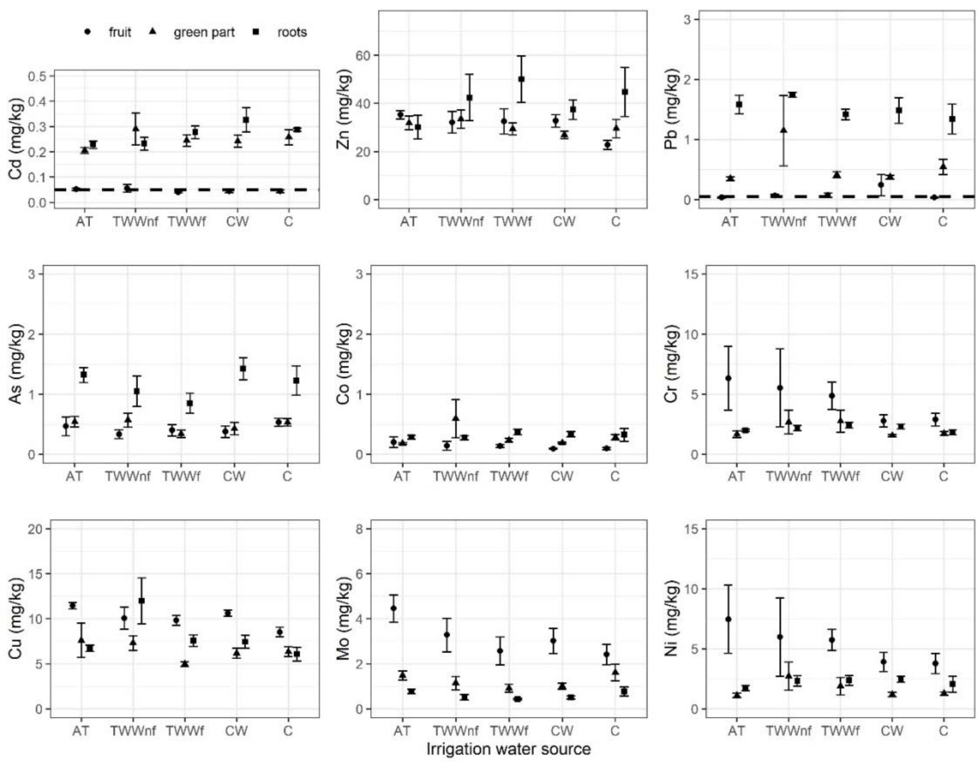

Figure 2: Mean metal contents (mg/kg) with associated standard error in roots, fruits, and the green part of the plant (stems and leaves) for different irrigation water source used. The dashed line represents the currently applicable limits for metal content in pumpkin fruits for human consumption (FAO/WHO, 2019).

In addition to monitoring metal accumulation in soil and in different parts of the irrigated crops, it is also necessary to study the EC and pH levels in the TWW. EC is an important indicator of irrigation water quality and a limiting factor for the choice of crops to irrigate, since some crops are more or less sensitive to EC (Drechsel et al., 2022). Therefore, we monitored EC and the pH of the outflow from the lysimeters and determined if there were differences between the different TWW sources. Figure 3 shows that the pH of outflows from the lysimeters does not differ by irrigation water source, although the irrigation waters used have different pH. The most likely reasons for this are the precipitations during the experiment, which had a dilution effect, and the fact that the outflow must pass through the entire length of the lysimeter.

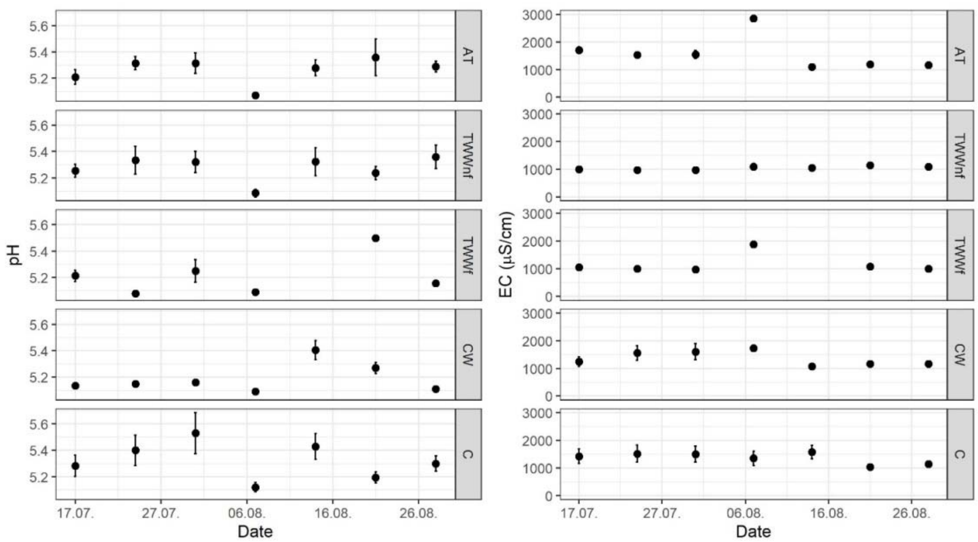

Figure 3: Time series of measurements of mean pH (left) and EC (µS/cm) (right) with associated standard error at the outflow of the lysimeters irrigated with different TWW sources, from July 17 to August 28, 2019.

CONCLUSION

After three months of irrigation, we found that there are no differences between irrigation with different TWW sources in metal concentrations and different plant parts, and there are no statistically significant differences between treatments in pH and EC values, while the treatment with TWWnf is statistically significantly lower than the treatments with C and AT. Our results are outcomes of a short-term experiment. To fully understand and investigate the effects of TWW application on plants, yields, and soils, the study should include multi-year trials and more frequent irrigation. Results show that the concept and practice of using TWW for irrigation has both advantages and disadvantages. There are advantages to using TWW for irrigation, but there are also environmental, health, and economic challenges. From our experimental experience, the main disadvantages are the risk of soil salinization and the increase of metal concentrations in the soil. However, the protection and saving of water resources, the supply of nutrients and the impact on farm profitability are the main advantages of irrigation with TWW.

Irrigation with TWW has impacts on soils, water resources, and public health. However, the nature and severity of the impacts depend not only on the quality of the TWW, but also on the characteristics of the irrigated soils, the morphology and physiology of the irrigated crops, the irrigation method and farming practices and the climate. Nevertheless, the use of TWW for irrigation can contribute to sustainable water use and lead towards the promotion and development of sustainable agriculture.

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