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THE EFFECTS OF WASTEWATER IRRIGATION ON AGRICULTURAL SOILS

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ABSTRACT

In arid and semi-arid areas, wastewater is often recovered for crop irrigation, contributing to the sustainable agriculture. Although positive effects have been observed on crop yields (50-80% growth) due to wastewater nutrients, the reuse of untreated wastewater harms both the environment and human health. Soil is mostly affected by excess salts, sodium, nutrients and heavy metals in wastewater. High salinity affects the upper layer of soil (0–30 cm); sodium and chlorine reduce crop yields by 40%; high content of organic matter in wastewater decreases soil pH, and heavy metals and pathogens enter the food chain. Irrigation technology is also important: sodium and salinity are higher in sprinkler than in furrow or subsurface irrigation; subsurface drip irrigation is more effective in reducing soil pathogens than surface drip irrigation. This paper examines the effects of wastewater irrigation on soil salinity, sodium, heavy metals and pathogen contamination.

INTRODUCTION

Earth contains about 1351 million km^3 of water, of which only 3% are fresh water resources suitable for human consumption (drinking purposes) and for irrigation of agricultural crops. The growing shortage of freshwater resources is currently one of the most important limiting factors for people's well-being, crop production, and food and energy security.

Globally, 40% of the total land area is arid, semi-arid and dry-sub-humid, while 10% of the European territory and 14% of the European population are currently affected by water scarcity. It is estimated that approximately 1.2 billion people currently live in watersheds facing physical water deficit, another 1.6 billion live in water-deficient areas where water supply works are not available at affordable prices, and by 2025 about 3.5 people around the world will face water shortages (Ungureanu et al., 2020).

Agriculture requires huge amounts of water, which can be obtained directly from rainfall or indirectly from a variety of sources, such as rivers, streams and wells, but these water sources are not always available or qualitatively adequate. Agriculture is the largest global user of freshwater (70%) for crop cultivation and animal husbandry (Jasim et al., 2016), registering a 100% increase over the last century. Considering the aspects mentioned above, but also the fact that by 2050, the global food production must increase by at least 70% to feed an estimated population of 9 billion people (Cossio et al., 2019), it becomes increasingly obvious that food security is already threatened by the negative impact of climate change and water scarcity in some parts of the world.

The need for water for irrigated agriculture can be ensured only through a proper distribution and management of water resources available to mankind (De Fraiture et al., 2010; Springer and Duchin, 2014). Either from a need imposed by the water deficit in some areas, or from the perspective of environmental protection and respect for the principles of sustainable development, farmers have begun to capitalize on crop irrigation an unconventional water source, namely domestic, municipal, industrial or agro-zootechnical wastewater. The volume of wastewater represents 50-80% of domestic wastewater consumption (Hussain et al., 2019), and the global discharge of wastewater is estimated at over 400 billion m^3/year (Zhang and Chen, 2017). Globally, every day, more than 200 million farmers in 44 countries use more than 15 million m^3 of treated wastewater to irrigate their crops (Ungureanu et al., 2020).

In many situations, the easy access of farmers to the large volumes of wastewater allowed the change of agricultural models, from seasonal cultivation to agriculture throughout the year, so to several harvests per year. Farmers can thus produce high-demand crops for the market, such as vegetables, which require a constant supply of water for irrigation, and can improve crop yields. In addition, using nutrient-rich wastewater reduces or eliminates the need for chemical fertilizers (Jaramillo and Restrepo, 2017; Chojnacka et al., 2020), so farmers can grow crops at lower costs.

MATERIAL AND METHOD

Depending on the development, the available infrastructure and technologies in each country, wastewater is applied treated, diluted, or even untreated for the irrigation of agricultural crops, energy crops and orchards. If wastewater is used directly in agriculture, without first being subjected to the most complete treatment processes for the elimination of pollutants of mechanical, biological and chemical nature, there will be negative consequences on environmental factors (soil and natural water being the most exposed), irrigated crops, as well as the health of people working in agriculture and those who consume irrigated products with wastewater (Figure 1).

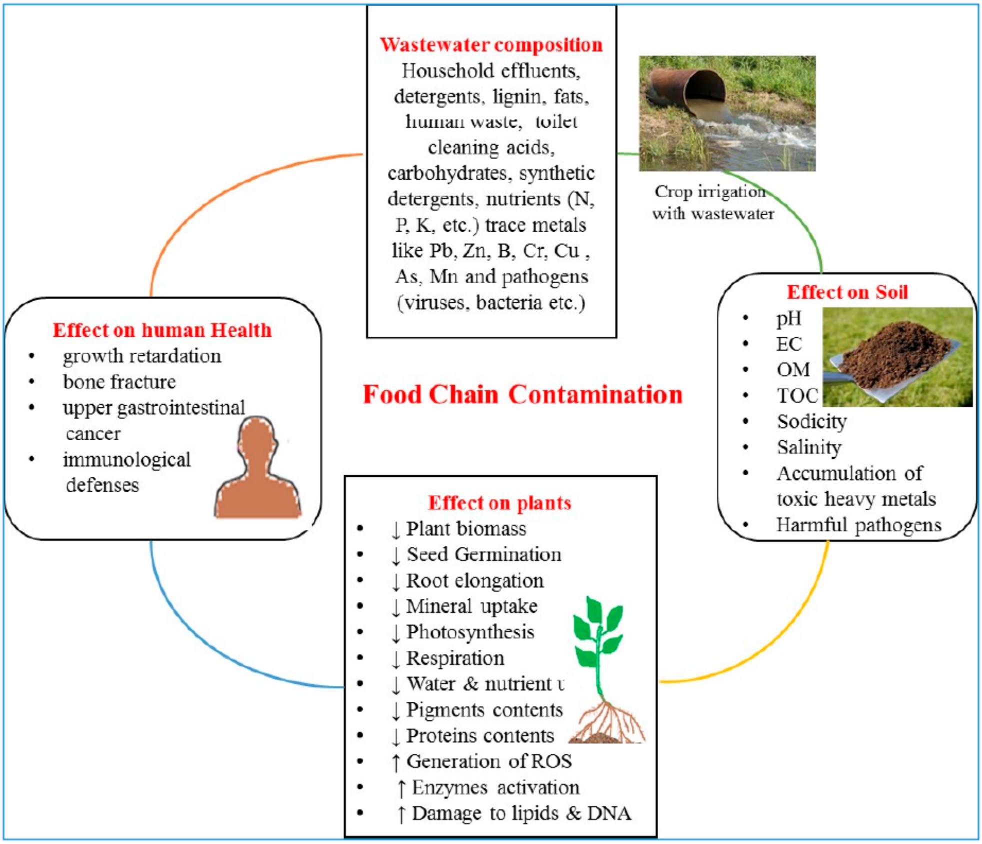

Figure 1. Impact of wastewater irrigation on agricultural soil, crops and human health (Khalid et al., 2018)

The complete treatment of wastewater and the capitalization of effluents in agriculture significantly reduce the risks and can be beneficial for agricultural production in terms of nutrient content of these valuable water resources.

RESULTS AND DISCUSSIONS

The probability of occurrence and magnitude of the negative effects of wastewater pollutants on soil and crops vary depending on the concentration, solubility and toxicity of pollutants, climatic conditions, rate and frequency of application of wastewater as irrigation water, type of crop and expected productivity, initial soil properties, level technological and socio-economic status of farmers.

The various techniques available for the application of irrigation water help to reduce or minimize some of these negative effects (Ungureanu et al., 2020).

Soil pH

Soil pH influences the cation exchange capacity, the availability of nutrients and metals, as well as the mineralisation of organic matter. After 60 years irrigation with with secondary-treated municipal wastewater and dairy wastewater, in arable or in grazed pastoral soils was observed the increase of soil pH (Becerra-Castro et al., 2015). However, there are also reports of notable decreases of soil pH (Bedbabis et al., 2014) under long-term wastewater irrigation (15, 20 and 40 years) in agricultural soils cultivated with lettuce, fodder and orange (Khai et al., 2016; Gurjar et al., 2017). Excessive concentrations of organic matter in wastewater decreases soil pH. Variations of soil pH are important because they determine the number and diversity of soil microorganisms, which in turn influences the health of the soil and crop productivity.

Salinity

Wastewater contains higher concentrations of more soluble salt than freshwater, and irrigation with wastewater results in increased soil salinization or increased sodium ions relative to other cations (Ganjegunte et al., 2018). As the salinity increases in the treated wastewater used for irrigation, the probability of occurrence of soil, water, and crop issues also increases (Pedrero et al., 2010).

Salts in wastewater come from detergents, chemicals used during the treatment process and other sources. Saline wastewater contains excess levels of soluble salts and total disolved solids, sodic wastewater contains excess sodium, and saline-sodic wastewater contain both excessive salt and sodium. Soil salinity is evaluated via electrical conductivity and sodium adsorption ratio, which refers to infiltration problems and soil saturation with sodium (Gharaibeh et al., 2016). If excessive salt is not removed, it may particularly accumulate in the topsoil (0–30 cm) due to high rates of evaporation. Soil salinization increases the osmotic pressure in the root zone, increases the oxidative stress and ion toxicity, and reduces the microbial diversity in the soil, being a limiting factor for the use of soil for crop cultivation and crop productivity. When using saline wastewater, techniques can be employed to reduce the salt content of these waters. For example, wastewater can be diluted with freshwater, a practice that enables the farmers to increase the volume of available water for irrigation. If highly sodium wastewater is used as irrigation water, then calcium-based amendments should be applied to mitigate sodium effects on soils and crops.

Sodicity

Wastewaters usually have high concentrations of sodium compared to other cations. If salts are associated with sodicity, the soils become dispersive to generate colloidal suspensions, which get mobilized in the environment, threatening water quality in streams and drainage waters (Minhas et al., 2020).

Sodicity decreases the stability of soil aggregates, leads to clay dispersion with subsequent collapse of soil structure (Warrington et al., 2007), increases soil compaction, decreases soil permeability and hydraulic conductivity (Becerra-Castro et al., 2015), resulting in waterlogging, poor plant performance, decreased leaching, and salinization (Muyen et al., 2011).

Heavy metals

Chemical pollutants are a cause for concern especially in those countries at the beginning of industrial development, where industrial effluents enter domestic wastewater and natural water flows. Potentially toxic trace elements include, but are not limited to, mercury, lead, arsenic, copper, cadmium, manganese. Farmers use wastewater that contains these industrial contaminants for irrigation, mainly due to lack of options. The problem of trace elements and heavy metals in wastewater for most developing countries is mainly related to the mixing of domestic, agricultural, livestock and industrial wastewater in the same sewage system.

Different properties of the soil, such as pH, texture, type of oxyhydroxides and the amount of organic matter, but also the type of vegetable crops irrigated with wastewater, generally determine the transport of traces of heavy metals and metalloids from the soil to plants (Qadir et al., 2010; Li et al., 2017). The accumulation of even small amounts of metals in soil, plants and food is a particular challenge in areas where long-term wastewater irrigation is practiced, due to chronic exposure of consumers of food from wastewater irrigated crops with content of heavy metals (Mahmood and Malik, 2014; Khalid et al., 2018; Chaoua et al., 2019).

Most treated or partially treated wastewater usually has low levels of traces of heavy metals and usually falls within the permissible limits for irrigation water quality. Many studies have estimated that treated or partially treated wastewater can be used safely for up to a century without adverse effects on soil, crops, groundwater or the food chain (Elgallal et al., 2016). On the other hand, untreated wastewater used in irrigation contains high levels of trace elements and heavy metals so they are most likely to accumulate in the agricultural soil and enter the food chain. In general, the concentrations of heavy metals in plant tissues increase with the concentrations of metals in irrigation water, and heavy metals accumulate in higher concentrations in the roots than in the leaves of plants.

If high levels of metals are recorded in food plants, then irrigation with untreated wastewater should be completely avoided. Remaining heavy metals in the environment is dangerous in the long run, given their long half-life (for example, 1460 days for lead and 200 days for cadmium) (Perez-Lopez et al., 2008). There is evidence that after 50–100 years of irrigation with wastewater, the level of toxic heavy metals in the soil has exceeded the maximum allowed limits.

Pharmaceutical products

Once in the environment, pharmaceuticals (antibiotics, hormones and other products for human or animal use) can undergo natural processes such as biodegradation, sorption or dilution (Christou et al., 2017), which reduce their concentrations in water or soil, or can be taken up by plants. The transformation products resulting from these processes are most often more soluble and polar than the parent compound and therefore more mobile. In this context, the European Medicines Agency states that any traces of processing products that exceed the concentration of the original compound by 10% should be investigated to determine the possible effects on ecosystems.

Pharmaceutical compounds from untreated wastewater used for irrigation can be a threat to agricultural soil, as their accumulation in the soil for many years can affect soil microorganisms and worms, favoring the development of antibiotic-resistant microorganisms.

When crops irrigated with treated wastewater are intended for human or animal consumption, the risk is the possible introduction into the food chain of undesirable substances and the health effects of pharmaceuticals, but also the effects of these products when combined with traces of metals are not yet fully known (De Santiago-Martin et al., 2019). To date, extensive studies are not available on the prevalence and fate of pharmaceuticals in wastewater in irrigated agriculture, in terms of their potentially negative effects on the terrestrial ecosystem, crop uptake and the potential impact on human health through the food chain (Elgallal et al., 2016).

Pathogens

In many developing countries, most wastewater is rarely treated and, as a result, contains high levels of excreted pathogens, such as bacteria, viruses, protozoa and intestinal worm eggs. Many of the pathogens have the ability to survive in the environment (soil, water, crops) long enough to allow transmission to humans.

The survival of pathogens in soil or crops is highly variable and depends on humidity, shade, ambient temperature and the organic content of the environment in which they are located (Keraita et al., 2007; Campos C., 2008). Under favorable conditions, viruses can survive for several months in the soil and around 2-3 weeks in agricultural crops. Pathogenic protozoa are particularly sensitive to high temperatures and are less persistent in the environment, and their survival for more than 2 weeks is unusual. Fecal bacteria generally have a limited hope of survival in water, but can persist for months in most organic soils.

CONCLUSIONS

Wastewater is a valuable resource of water throughout the year, and its recovery in irrigated agriculture becomes an essential practice in the current conditions.

The categories of physico-chemical and microbiological pollutants in wastewater, as well as their degree of danger to agricultural soil, crops and human health are factors that must be taken into account for the safe recovery of wastewater in agriculture.

BIBLIOGRAPHY

1. Becerra-Castro, C., Lopes, A.R., Vaz-Moreira, I., Silva, E.F., Manaia, C.M., Nunes, O.C., 2015 - *Wastewater reuse in irrigation: a*

microbiological perspective on implications in soil fertility and human and environmental health, Environment International, vol. 75, pp. 117–135.
2. Bedbabis, S., Ben Rouina, B., Boukhris, M., Ferrara, G., 2014 - *Effect of irrigation with treated wastewater on soil chemical properties and infiltration rate*, Journal of Environmental Management, vol. 133, pp. 45–50.
3. Campos, C., 2008 - New perspectives on microbiological water control for wastewater reuse, Desalination, vol. 218, pp. 34–42.
4. Chaoua, S., Boussaa, S., El Gharmali, A., Boumezzough, A., 2019 - *Impact of irrigation with wastewater on accumulation of heavy metals in soil and crops in the region of Marrakech in Morocco*, Journal of the Saudi Society of Agricultural Sciences, vol. 18, pp. 429–436.
5. Chojnacka, K., Witek-Krowiak, A., Moustakas, K., Skrzypczak, D., Mikula, K., Loizidou, M., 2020 - *A transition from conventional irrigation to fertigation with reclaimed wastewater: prospects and challenges*, Renewable and Sustainable Energy Reviews, vol. 130, 109959.
6. Christou, A., Karaolia, P., Hapeshi, E., Michael, C., Fatta-Kassinos, D., 2017 - *Long-term wastewater irrigation of vegetables in real agricultural systems: concentration of pharmaceuticals in soil, uptake and bioaccumulation in tomato fruits and human health risk assessment*, Water Research, vol. 109, pp. 24–34.
7. Cossio, C., Perez-Mercado, L.F., Norrman, J., Dalahmeh, S., Vinnerås, B., Mercado, A., McConville, J., 2019 - *Impact of treatment plant management on human health and ecological risks from wastewater irrigation in developing countries – case studies from Cochabamba, Bolivia*, International Journal of Environmental Health Research, pp.1–19.
8. De Fraiture, C., Wichelns, D., 2010 - *Satisfying future water demands for agriculture*, Agriculture Water Management, vol. 97, pp. 502–511.
9. De Santiago-Martin, A. Meffe, R., Teijon, G., Martinez-Hernandez, V., López-Heras, I., Alonso-Alonso, C., Arenas, M., De Bustamante, I., 2020 - *Pharmaceuticals and trace metals in the surface water used for crop irrigation: risk to health or natural attenuation?* Science of the Total Environment, vol. 705, 135825.
10. Elgallal, M., Fletcher, L., Evans, B., 2016 - Assessment of potential risks associated with chemicals in wastewater used for

irrigation in arid and semiarid zones: a review, Agricultural Water Management, vol. 177, pp. 419–431.

11. Ganjegunte, G., Ulery, A., Niu, G., Wu, Y., 2018 - *Organic carbon, nutrient, and salt dynamics in saline soil and switchgrass (Panicum virgatum L.) irrigated with treated municipal wastewater,* Land Degradation & Development, vol. 29 (1), pp. 80–90.

12. Gharaibeh, M.A., Ghezzehei, T.A., Albalasmeh, A.A., Ma'in, Z.A., 2016 - Alteration of physical and chemical characteristics of clayey soils by irrigation with treated wastewater, Geoderma, vol. 276, pp. 33–40.

13. Gurjar, O.P., Meena, R., Latare, A.M., Rai, S., Kant, S., Kumar, A., Sheshama, M.K., 2017 - *Effects of sewage wastewater irrigation compare to ground water irrigation on soil physico-chemical properties*, International Journal of Chemical Studies, vol. 5 (6), pp. 265–267.

14. Hussain, M.I., Muscolo, A., Farooq, M., Ahmad, W., 2019 - *Sustainable use and management of no conventional water resources for rehabilitation of marginal lands in arid and semiarid environments*, Agricultural Water Management, vol. 221, pp. 462–476.

15.Jaramillo, M.F., Restrepo, I., 2017 - *Wastewater reuse in agriculture: a review about its limitations and benefits*, Sustainability, vol. 9, 1734.

16. Jasim, S.Y., Saththasivam, J., Loganathan, K., Ogunbiyi, O.O., Sarp, S., 2016 - *Reuse of treated sewage effluent (TSE) in Qatar*, Journal of Water Process Engineering**,** vol. 11, pp. 174–182.

17. Khai, N.M., Tuan, P.T., Vinh, N.C., Oborn, I., 2016 - *Effects of using wastewater as nutrient sources on soil chemical properties in peri-urban agricultural systems*, VNU Journal of Science: Earth and Environmental Sciences, vol. 24, pp. 87–95.

18. Khalid, S., Shahid, M., Irshad Bibi, N., Sarwar, T., Shah, A.H., Niazi, N.K., 2018 - *A review of environmental contamination and health risk assessment of wastewater use for crop irrigation with a focus on low and high-income countries*, International Journal of Environmental Research and Public Health, vol. 15, pp. 895–921.

19. Li, Q., Tang, J., Wang, T., Wu, D., Jiao, R., Ren, X., 2017 - *Impacts of sewage irrigation on soil properties of farmlands in China: a review*, Yellow River, vol. 4, no. 5.

20. Mahmood, A., Malik, R.N., 2014 - *Human health risk assessment of heavy metals via consumption of contaminated vegetables*

collected from different irrigation sources in Lahore, Pakistan, Arabian Journal of Chemistry, vol. 7, pp. 91–99.

21. Minhas, P.S., Ramos, T.B., Ben-Gal, A., Pereira, L.S., 2020 - *Coping with salinity in irrigated agriculture: crop evapotranspiration and water management issues*, Agricultural Water Management, vol. 227, 105832.
22. Muyen, Z., Moore, G.A., Wrigley, R.J., 2011 - *Soil salinity and sodicity effects of wastewater irrigation in South East Australia*, Agricultural Water Management, vol. 99, pp. 33–41.
23. Perez-Lopez, M., Hermoso de Mendoza, M., Lopez Beceiro, A., Soler Rodriguez, F., 2008 - Heavy metal (Cd, Pb, Zn) and metalloid (As) content in raptor species from Galicia (NW Spain), *Ecotoxicology* and *Environmental* Safety, vol. 70, pp. 154–162.
24. Qadir, M., Wichelns, D., Raschid-Sally, L., McCornick, P.G., Drechsel, P., 2010 - *The challenges of wastewater irrigation in developing countries,* Agricultural Water Management, vol. 97, pp. 561–568.
25. Pedrero, F., Kalavrouziotis, I., Alarcóna, J.J., Koukoulakis, P., Asano, T., 2010 - *Use of treated municipal wastewater in irrigated agriculture - review of some practices in Spain and Greece*, Agricultural Water Management, vol. 97, pp. 1233–1241.
26. Springer, N.P., Duchin, F., 2014 - *Feeding nine billion people sustainably: conserving land and water through shifting diets and changes in technologies*, Environmental Science and Technology, vol. 48, pp. 4444–4451.
27. Ungureanu, N., Vlăduț, V., Voicu Gh., 2020 - *Water scarcity and wastewater reuse in crop irrigation*, Sustainability, vol. 12, no. 21, 9055.
28. Zhang, Y., Chen, Y., 2017) - *Wastewater irrigation: past, present, and future*, Wiley Interdisciplinary Reviews: Water, e1234, Wiley Periodicals Inc.
29. Warrington, D.N, Goldstein, D., Levy, G.J., 2007 - *Clay translocation within the soil profile as affected by intensive irrigation with treated wastewater*, Soil Science, vol. 172 (9), pp. 692–700.