Reclaimed water reuse in agriculture: a review on potentials and drawbacks

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Abstract Water has always been the limiting factor of agricultural production in the Mediterranean basin, with its continuously increasing demand driven by climate-induced factors. In the Mediterranean the agricultural sector is the prime water consumer as it requires more than 70% of the total water demand. Reclaimed water may represent a viable solution to face the problem of water scarcity, increasing the availability of fresh water sources, while supporting local economies. Reclaimed water needs to be of adequate microbiological and chemical quality in order to be safely reused. Based on a literature review presented in this article, the use of reclaimed water does not affect the quality of the agricultural products. However, more research should be conducted to thoroughly evaluate whether the quality of reclaimed water can undermine the quality of crops particularly with respect to emerging contaminants. A major challenge that needs to be overcome is public acceptance by the end users and particularly the farmers.

Keywords: agriculture, water scarcity, circular economy, water management, pollution

1. Introduction

A major issue of concern specifically in the Mediterranean (MED) basin is water scarcity. The water needs are increasing in the Mediterranean basin due to climate change, urbanization and growing population. The Mediterranean climate (Lulla 1987), although highly variable and unpredictable, has three main characteristics: summer droughts, generally mild winters and precipitation occurring mostly in the winter. Taking also into account the uneven distribution of water resources, significant water infrastructure works are required to provide local communities with high quality water and higher levels of wastewater treatment (Angelakis 1999). Likewise, the Mediterranean basin is characterized by unequal distribution of water demand (UNEP/MAP, 2016). In many countries the water reserves are less than 500 m3/capita/year, ('structural shortage') (GWP, 2012). This water shortage may be attributed to a number of factors ranging from climate change to industrialization and intensification of agricultural activities (Scoullos & Feggarina, 2010). Agriculture, in specific, is considered as the most water intensive activity since it consumes 72% of the total freshwater in the MED region (Masia et al., 2018). This problem is drawing more attention lately as several drought incidents raise more voices of concern and public awareness. It is the purpose of this article to investigate the possibilities provided for the reuse of treated wastewater for agricultural irrigation.

2. Reclaimed water as a resource

In cities that depend on groundwater the phenomenon of intensive extraction is usual and can lead to saline intrusion into the aquifer. A study conducted by Angelakis et al. (1998) showed that back in 1998 even though the high potential for wastewater reclamation and reuse in the Mediterranean countries was recognized, not many of these countries exploited systematically this resource. High quality water should be primarily used for drinking water, whereas reclaimed water can represent an alternative water source for other applications. However, this successful practice is governed by serious misunderstandings and lack of knowledge (Ait-Mouhec et al., 2018). The primary misunderstanding of this practice lies on the suspicion of potential human health and environmental risks, depending on its previous treatments. On the other hand, the scientists believe that taking into account the water shortage this may represent a resource under a circular economy rationale.

To battle the problem of water shortage, the cities usually seek solutions like desalination of seawater, water transportation from other areas and wastewater reuse after appropriate treatment. The utilization of treated wastewater for irrigation and aquifer recharge presents several economic, environmental and technical advantages (Elizondo and Mendoza-Espinosa, 2020). Abdulhameed et al (2021) used water evaluation and planning (WEAP) to evaluate water amounts and reused wastewater in the current and future years. Their results indicated that domestic wastewater discharges for 2021 to Euphrates River could cover about 22% of the irrigation requirements of the area. They also estimate a substantial increase, both in wastewater and grey water generation, up to the year 2040 (Abdulhameed et al 2021).

Wastewater and grey water have several applications and can be a promising resource in agriculture for the production of food, for animal feed and for the construction/restoration of protective green areas in cities. In water scarce regions the pressure on groundwater resources and pumping energy requirements keeps growing to cover the needs of the agricultural activity. In many arid and semi-arid zones raw, partially and treated wastewater is used in agriculture to tackle the problem of water scarcity and it is also recognized for its nutrient value. Despite that, irrigation with wastewater without the proper treatment could be hiding potential risks to public health and the environment mainly due to microbial contamination (Elgallal 2016).

According to Ramirez et al. (2021) an efficient way to relieve the groundwater stress is to use treated wastewater in agricultural irrigation a practice that can lead to a 49% stress reduction and a 15% reduction of the total energy requirement. However, other measures like improvement of water pricing, creation of management strategies to improve water productivity and examination of a more efficient irrigation scheme, should be taken (Ramirez et al., 2021). A circular and sustainable food system contains nutrient reuse and recycling and differs in different areas and agricultural systems. According to Papangelou and Mathijs (2021) nutrient soil balances depend on the type of agricultural system, as areas with intense livestock production accumulate high concentration of N, P and K in their soil annually, while areas with mostly arable production have low N and K surpluses and P deficits. Furthermore, in areas characterized by lower livestock densities and a partial reuse of sewage sludge, the total inputs, P use efficiency, share of reused to total input, recycling rate, and losses seem to benefit. Angin et al. (2005) found that the long-term irrigation with raw wastewater increased the salinity, by 557%, and decreased the pH, and at the same time it increased the organic matter, the N and the concentrations of major cations and heavy metals of the soil. On the other hand, the long-term irrigation with treated wastewater affected the plant nutrient contents as it increased N, P, Fe, Mn, Zn, Cu, B, Mo and Cd contents of cabbage (*Brassica olerecea* var. Capitate cv. Yalova-1) and potato (*Solanum tuberosum*) (Angin et al. 2005). However, the authors do not mention if there were any statistical differences between the values of irrigated and non-irrigated treatment, nor which are the accepted limits of these nutrients for human consumption. Similarly, Kiziloglu and his partners conclude that, primary effluent increased yield and N, P, K, Fe, Mn, Zn, Cu, B, and Mo contents of cabbage plants (Kiziloglu et al 2007) or cauliflower and red cabbage (Kiziloglu et al 2008), without any undesirable side effects observed in the plants such as excessive heavy metal accumulation, from the application of wastewater to soil. The same authors found that the irrigation with raw and primary effluent even if it increased the yield, it also increased significantly the content of heavy metals. It should be noted that the heavy metal values were within the acceptable limits by WHO and also that some plant species are Zn accumulators; the extent of the accumulation varies with soil properties, plant organ and tissue age (WHO, 2021) A similar research on the impact of long-term irrigation with municipal reclaimed water on the uptake and degradation of organic contaminants in lettuce and leek pinpoint a *de minimis* human health risk related to the consumption of raw leafy green vegetable irrigated with domestic treated wastewater (TWW) containing organic contaminants residues (Manasfi et al 2021). Similar results are reported for tomato fruit (Al-Lahham et al. 2003).

On Mallorca Island the utilization of secondary-treated municipal wastewater in irrigation is a wide known practice for more than 20 years. According to Adrover et al. (2010) this long-term irrigation with secondary-treated wastewater on arable soils resulted in the increase of the soil water-soluble organic carbon, soil microbial biomass and b-glucosidase and alkaline phosphatase activities. Also, mainly soil organic matter affected the biological activity. The investigators consider that this increase is not only due to the treated wastewater irrigation, but also a result of the typical crop management of alfalfa, and other forage crops associated with.

According to Cifuentes-Torres et al. (2021) aquaponics could eliminate dissolved N and P through their absorption from the roots and at the same time offer economic (plant production) and environmental advantages.

Irrigation using treated wastewater may affect soil by altering its physicochemical and microbiological properties and/or introduce and contribute to the accumulation of chemical and biological contaminants. The first case may affect its productivity and fertility, while the second one may pose serious risks to environmental and human health. A sustainable treated wastewater reuse in agriculture should prevent both types of effects under a holistic and integrated risk assessment and management. There is an ongoing discussion in the academic community and among water practitioners on whether to introduce limits on the levels of organic micropollutants and particularly emerging contaminants of reclaimed water. These compounds include pharmaceuticals, personal care products, oestrogens, pesticides and others. Introducing limits to these substances would then require the addition of advanced oxidation processes as extra treatment step to remove these compounds, thus increasing significantly the total treatment cost. In the recent Water Reuse Regulation (2018/0169), limits are not given for these compounds. Rather a risk management approach is taken

The long-term reclaimed water irrigation may affect the physical and chemical properties of the soils even though it is unclear how it can affect nutrient cycling in soils. According to Chen et al. (2008) soil enzyme activities varied widely between five sampling sites of long-term reclaimed water irrigation and the cycling of C, N, P, and S was enhanced. Also, they propose that the soil microbial functional diversity could be evaluated based on activities of catalase, alkaline phosphatase, acid phosphatase, dehydrogenase, and urease.

In a research realized by Al Nasir and Batarseh (2008) soil, treated wastewater, groundwater and plant parts (roots, leaves and fruits) of various plant types were investigated to determine the residues of polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), chlorinated benzenes (CBs) and phenols. According to the results, groundwater and wastewater had similar distribution profiles of PAHs and PCBs, while the concentrations of PAHs, PCBs and phenols in the soil had a wide range and the CBs were detected at low concentrations. For the plants it was determined that even though they have different uptake and translocation behaviour, which makes the evaluation difficult, roots were found to be the most contaminated by the previously mentioned compounds and fruits the least contaminated.

Farhadkhani et al. (2018), evaluated the impact of irrigation with secondary treated wastewater (STWW), which was ultimately chlorinated, on soil properties as well as the safety of various types of crops as compared with tap water (TW) irrigation through a furrow system, by monitoring total and faecal coliforms and Escherichia coli as indicator bacteria in STWW, irrigated soil and harvested crops. Based on their results, no microbial contamination in terms of E. coli was found on harvested maize and onion, while E. coli contamination of lettuce and spring onion was found for both irrigation schemes. It is interesting that no STWW, soil or crop, samples were found positive for pathogenic bacteria and it was concluded that the climate conditions of an arid or semi-arid region could inactivate microorganisms in the soil and on the crop surface. Friedel et al (2000) evaluated this effect on a long-term experiment of untreated wastewater irrigation (80-years) in Mexico. Soil type (Vertisols vs Leptosols) in combination to the water quantity applied, influenced the total organic carbon (TOC). It is presumed that the larger application of organic matter increased soil microbial biomass C and activities. Based on the same authors, changes in soil microbial communities occurred, since denitrification capacities increased greatly and adenylate energy charge ratios were reduced after long-term irrigation. These changes were attributed to the addition of surfactants (effect on denitrification capacity) and the addition of sodium and salts (effect on adenylate energy charge) through untreated wastewater irrigation. According to an experiment conducted by Al-Nakshabandi et al. (1997), the irrigation of eggplant (aubergine) with treated effluent by the process of stabilization ponds, resulted in reclaimed water, with a relatively low range of faecal coliform and free from nematode eggs. The coliform count on the fruit skins was very low, while it was zero on the crop leaves. Concerning the eggplant tissue, they did not find any abnormal concentration of nutrients and heavy metals. According to the same investigators, the yield doubled with the treated effluent irrigation in comparison to the utilization of fresh water and conventional fertilizers. The presence of algae in the effluent was also noted. At the same time, the soil at the effluent irrigation spot contained faecal coliform the concentration of which decreased by the depth. After the eggplant harvest an increase in heavy metals and salt was noted at the periphery of the wet zone. Last but not least, a minimum clogging of the irrigation system was noted without any prior filtration of the treated effluent.

Heavy metals contained in the sewage are in low concentrations and do not appear to be affecting soil processes, due to their low availability. Similarly, Li and Wu (2021) in their work, tested the hypothesis that long-term use of treated sewage to irrigate farmland will increase the content of heavy metals in the soil and cause soil pollution while restricting the sustainable development of local agriculture and negatively impacting the environment. Based on their results, the content of heavy metals Pb, Cu, Zn and Cd at the tested reclaimed water irrigation areas do not exceed the national standard limit; also the heavy metal pollution grade in the soil belongs to the safety grade, indicating that the content of heavy metals in the soil has not reached the alert level. The same authors conclude that, although the content of the heavy metals in the soil is safe, the potential ecological risk of Cd is quite high. In an experiment conducted by Batarseh et al. (2010), soil, olive leaves, and fruits were sampled both from olive grove irrigated with treated municipal wastewater (TMWW) and olive grove irrigated with fresh water. It was shown that in leaves and fruits, essential elements accumulated, while heavy metals accumulated in significantly lower quantities, independently of the TMWW heavy metal concentration, proving a selective uptake of the metals by the olive plants. The transfer of heavy metal from the soil to olive fruits and leaves, followed the same course, proof of a consistent transfer.

When the construction of a centralized wastewater treatment plant is not a viable solution, land treatment or decentralized constructed wetlands is a good alternative especially for small communities. The type of the land treatment can be defined by the capacity of the plants used in this treatment to absorb and purify water. The slow rate systems seem to be a good choice to accomplice the above but according to Paranychianakis et al. there is still knowledge and experience on this practice to be obtained to minimize potential environmental and health risks (Paranychianakis 2006).

4. Conclusions

Based on the presently available literature, reclaimed water represent a safe, efficient and sufficient resource that could contribute to agricultural production without an adverse impact on human and animal health. However, research should continue and focus on the investigation of the possible accumulation in the soil of bioavailable forms of heavy metals, of organic matter and other residues such as salts, of microbial contamination, of possible accumulation of contaminants into the plants posing serious health problems to humans and fauna. Last but not least, since research is up scaling lately, contributing to our knowledge in water reuse, it is equally important to involve consumers and the public in general to a change-of-mind effort on the adoptability of such practices.

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