Fertigation with treated wastewater - a solution to drought in a moderate climate

K. Chojnacka[1], A. Witek-Krowiak[2], D. Skrzypczak[2]

[1]Department of Advanced Material Technologies, Faculty of Chemistry, Wrocław University of Science and Technology, Smoluchowskiego 25, 50-372 Wrocław, Poland
[2]Department of Chemical Engineering, Faculty of Chemistry, Wroclaw University of Science and Technology, Norwida 4/6, 50-373 Wroclaw, Poland

Abstract:
Purpose: The consequence of climate change is hydrological drought that makes it necessary to look for new irrigation water sources for agricultural purposes. The aim of the work was to explore the potential of fertigation with treated wastewater as a source of water and nutrients.
Methods: The treated sewage is rich in fertilizer nutrients, in particular nitrogen and phosphorus (as biogenic compounds) and can be directly used after disinfection as a fertigation medium for watering arable crops.
Results: The use of treated wastewater as a source of nutrients and water can reduce the necessary amount of fertilizers applied in agriculture by almost half.
Conclusions: The use of fertigation significantly reduces the need for fertilizers and water. It contributes to a more efficient absorption of nutrients by plants what results in significant water and fertilizer savings. Management of treated wastewater for this purpose is in line with the concept of the circular economy.

Keywords: hydrological drought, agriculture, fertigation, wastewater, nutrients

1. Introduction

Water is essential for agricultural. The scarcity of water is the part of abiotic tress that has a substantial impact on plant growth. In particular this concerns moderate climate, whereby the plants cultivated have acclimated to abundant water conditions. Due to the recent climatic changes, now agricultural plantations in moderate climate suffer for water scarcity caused by drought. The solution would be to either modify the plants cultivation profile or to provide additional water by e.g. fertigation.

Human activity affects the warming of the climate, which directly results in the acceleration of the hydrological cycle not only regionally but also on a global scale. In this situation, the main hydrological components, such as the amount of rainfall, may change. In many parts of the world numerous weather anomalies, including decreasing trend in precipitation was observed [1].

Drought is considered one of the most dangerous natural hazards. It is the direct cause of serious environmental problems and their economic consequences, as well [2]. In recent years droughts have focused the attention of the public mainly due to the economic consequences. The search for solutions enabling the use of other water sources for social purposes in the period of reduced rainfall is continuing. One of the proposals is to use the potential of treated wastewater for irrigation of agricultural areas as a source of water and nutrients for plants.

Many moderate climate countries suffer from water scarcity, which has become severe recently due to change of climate. Consequently, periods of drought appeared mainly during the summer. At present, 50% of Europe suffers for water stress. Treated wastewater could be considered as a valuable resource, instead of a waste, although wastewater reuse may cause both health and environmental hazards. Irrigation with treated sewage is already practiced in France, Italy, Spain, Cyprus, Malta, Israel, Jordan or the USA [3]. In the countries with moderate climate (e.g. Poland, Germany) has not been implemented yet.

Treated municipal wastewater – secondary effluents can become alternative source of water, as well as nutrients to meet the needs of cultivated crops. In tertiary treatment, also called biogenic compounds (N, P) removal, nitrification, denitrification and defosfatation processes are employed to reduce the load of N and P compounds, that are on the other hand fertilizer nutrients. Tertiary biogenic treatment will not be necessary if water is to be used for fertigation/irrigation purposes. This will call for effluents sanitation and building water distribution system that could transport it from the treatment plant to the agricultural fields. Irrigation with treated wastewater has positive and negative environmental impact. There are many risks related with agricultural wastewater re-use: microbial pathogens, higher salinity of the soil [4].

Recently, wastewater recycling in agriculture has become a significant part of water supply in agriculture in countries of Mediterranean climate [5]. The additional benefit is the preservation of drinking water resources and lower environmental impact related with the discharge of waste water into the surface waters. The presence of N, P, K and organic matter in treated effluents additionally maintains fertility and productivity of soil, improving crop yield and reducing fertilizers application rates.

On the other hand, wastewater can be also a source of pathogenic organisms (intestinal bacteria and viruses) and potentially toxic substances (salts, heavy metals and surfactants). These contaminants can accumulate in soil, causing adverse effects on yield and on ecological aspects of soil. This is a challenge to elaborate a safe way of the agricultural re-use of treated wastewater. For instance, treated wastewater reuse in agriculture is regulated by law: microbial contamination (eg *Escherichia coli* <10 CFU 100 ml-1 in 80% of samples), which may become a standard for international guidelines. However it has been found that the safe contamination of irrigation water does is 1000 CFU ml-1 [6].

2. Drought and its consequences

The hydrological drought is the result of atmospheric drought, the period during which flows in rivers fall below the long-term average values. In the case of prolonged drought, there is a significant reduction in surface water and groundwater resources supplying the rivers in the period without rainfall. Drought can also be exacerbated by human activity [7].

To track the phenomenon of drought, various techniques can be used, including Palmer drought severity index (PDSI), standardized precipitation index (SPI), drought condition index (SDCI) and others. All methods include observing characteristic hydroclimatic parameters that change over time and space [8]. Satellite images enable precipitation monitoring, soil moisture and plant health, as an early warning system against drought. The integration of various hydroclimatic variables or indicators, i.e. precipitation, soil moisture, evapotranspiration, and vegetation, from different areas enables effective monitoring of drought. Drought tracking combines *in situ* observations, the use of remote sensing products, simulations of land surface models and climate predictions [9].

Changes in the climate of a given region are caused by both natural changes and human activities. Weather disturbances can cause local and global changes, contributing to many negative effects, such as lower yield quality and consequent socio-economic changes [10]. The area of land covered by drought is growing from year to year, it is estimated that it will increase from 1% to 30% in the 21st century [11]. Over the past 30 years, drought has caused losses of over 100 billion euros in EU and has covered almost 40% of Europe's area [12].

Drought is a regional phenomenon and means continuous limited availability of water, below the average value in natural conditions [13]. Drought covers all disadvantageous phenomena related to water scarcity for a given region. The main sectors that are affected by drought are agriculture, energy and industry as well as water quality [12]. Low water levels during hydrological drought increase the residence time of water in the reservoirs, reducing their rinsing, also affecting water quality [14]. The drought occurrence may consequently cause soil drying, reduction or complete destruction of plant crops. Agricultural drought is a direct consequence of hydrological drought, during this time the plants do not receive proper hydration and thus all components necessary for plant growth (i.e. macro- and micronutrients). Other negative effects include not only crop losses, also increased risk of fires, soil degradation and social changes caused by increased competition for resources [11].

3. Irrigation

Many semi-arid and arid areas are struggling with water shortages, this phenomenon is starting to appear more and more often in other areas, which so far have not had such problems. So far, based solely on irrigation in the form of rainfall agriculture must also take into account other forms of water supply to plants.

In areas susceptible to drought, the growth of plants with the forecasted climate changes, including the prediction of drought, should be synchronized. As an example, the development of early maturing varieties can be given [15].

Negative effects of drought on plant vegetation can be combated by artificial irrigation. The need for irrigation of crops significantly increases investment costs and may influence crop prices. It is estimated that agriculture uses up to 70% of global water consumption. In many regions of the world, irrigation is carried out in a non-economic way, using a significant excess of water. Such a large use of precious water forces farmers to use it efficiently. Irrigation should be carried out in accordance with procedures, including constant measurements of evapotranspiration and soil water tension [15]. To ensure that the plants have enough water to grow, and at the same time not cause wastage, special irrigation protocols are introduced and special technologies are applied. The use of drip irrigation with low pressure saves up to 40% of water without affecting the quality of the yield [15].

Also the concept of regulated deficit irrigation (RDI), which determines irrigation carried out using less water than the plant needs, is introduced. A small water scarcity may to some extent have a positive effect on plant growth and at the same time allow water savings [16]. The response to stress caused by RDI varies with the growth stages of the plant. In addition, this reaction is influenced by additional factors such as weather conditions or plant species [16].

The use of rainwater for supplemental irrigation can contribute to sustainable agriculture, allowing to overcome not only drought but also soil erosion . Storage of rainwater at the time of conditions requiring additional irrigation enhances the interaction of environmental resources (rainwater) and the needs of the environment (the plant needs water).

Incorrect irrigation can also lead to disastrous consequences. Water used in agriculture is often rich in salts that remain in the soil as a result of water evaporation. Increased concentration of salt may lead to soil salinity, causing its degradation.

Climate models predict a significant drop in rainfall and extended periods of drought in many areas, including the Mediterranean. At the same time, a significant increase in agricultural production is expected due to the rapid population growth [17]. In areas with a dry climate, field irrigation requires up to 85% of the water resources in this region . In this situation, the effective use of water is necessary. Reduced access to surface or groundwater requires the use of other sources.

4. Fertigation

Global fertilizer demand is predicted to increase significantly reaching 202 million Mg in 2020. Demand for basic nutrients (nitrogen, phosphorus and potassium) will increase on average by 1.5, 2.2, and 2.4 per cent from 2015 to 2020 annually (FAO).

Improper fertilizer management causes environmental and economic problems. When used in inappropriate amounts, proportions or terms, may cause disturbances in the proper functioning of the soil. Over-fertilization is typical for highly developed countries using intensive farming. The use of nutrients in doses exceeding the nutritional requirements of plants, may lead to changes in the ionic balance of the soil solution and cause the migration of fertilizer nutrients into groundwater. If fertilizers are used inadequately, they may cause irreversible changes in the soil structure, including acidification, heavy metal accumulation or soil microflora disorder. Minerals introduced into the soil in the form of fertilizers are not fully utilized during the vegetation of plants. Increasing the level of fertilization may lead to uneven use of minerals and serious environmental impacts.

The only way to counteract unfavorable phenomena is to change the management of fertilizers [18]. A practical solution is the direct introduction of fertilizer components into the water stream used for crops irrigation, called fertigation.

Fertigation is the application of a fertilizer solution with drip irrigation. This form facilitates the supply of water and nutrients directly to the root zone. Fertigation is a method that allows increased nutrient transport to the plant by precise supply of the nutrients near the plant root system. The nutrients should be delivered in a controlled manner, depending on the weather situation. The advantages of fertigation are precision and uniformity of fertilization, small doses of ingredients can be easily supplied to large areas [19]. The fertilizer doses are also considerably reduced due to the possibility of multiple applications in smaller quantities. The possibility of precise selection of fertilizer doses allows for quick response to the changing needs of plants, which makes this method also very economical. The nutrients are delivered in doses that can be used immediately by the plants, there is a reduced migration of nutrients into deeper layers of soil and to groundwater [20]. The nutrients are delivered directly to the root zone, which greatly reduces nutrient losses to the environment. This solution fits the scope of precision agriculture.

The use of fertigation reduces the need for fertilizer and water (up to 25%), contributes to more efficient absorption of components by plants resulting in better productivity [21]. This saves water, nutrients and prevents leaching of nutrients from the soil into groundwater.

5. Fertigation with treated wastewater

The use of treated wastewater in agriculture is a way to use nutrients, in particular biogenic compounds of nitrogen and phosphorus (**Fig. 1**.). The presence of NPK in the secondary effluent serves as a fertilizer - rich in major macronutrients (such as nitrogen, phosphorus, and potassium) necessary for plant growth [22].

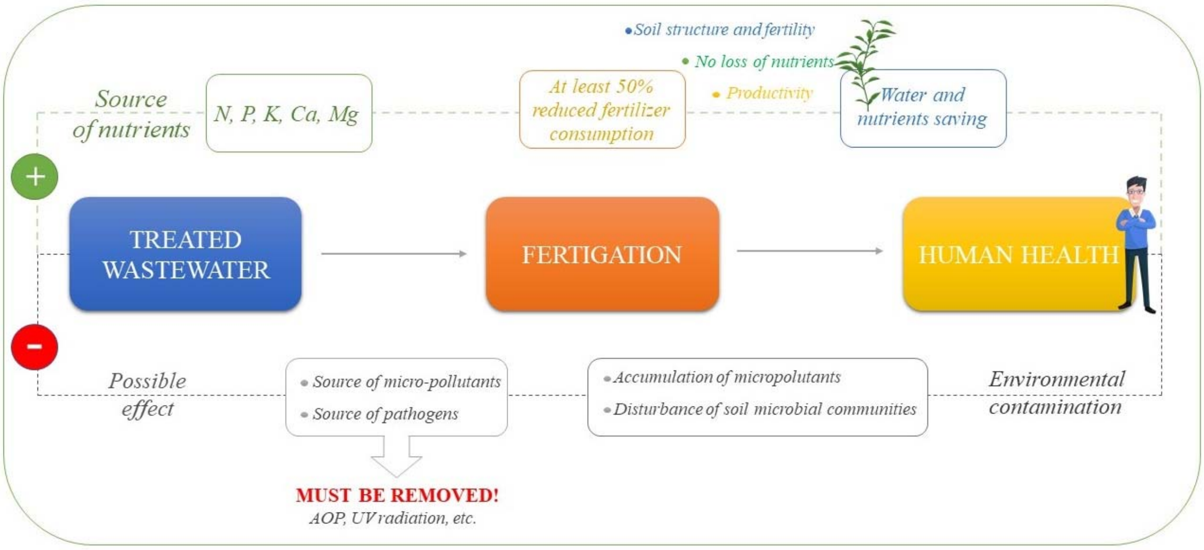

Fig. 1. Fertigation scheme – possible benefits and drawbacks

Biological processes are the main methods used to remove nitrogen and phosphorus from sewage in these processes allow the removal of most nutrients, however, secondary effluents from municipal wastewater treatment plants contain nitrogen and phosphorus, domestic secondary effluents contain 5–30 mg L^{-1} of total nitrogen and 0.2–3 mg L^{-1} of total phosphorus [23]. Assuming an application rate of 5000 m^3/ha.year (Pescod, 1992) it is possible to use from the wastewater 25-150 kg/ha.year and 1-15 kg/ha.year of nitrogen and phosphorus, respectively. The use of treated wastewater as a source of nutrients and water can reduce the fertilizers application rates by ca. 50 %. The use of secondary effluent for irrigation of agricultural fields reduces the amount of nutrients discharged into surface waters, thus reducing the environmental load. The use of wastewater for plants nutrition and watering improves physical, chemical and soil fertility conditions. In addition, it allows the natural circulation of nutrients without the need for additional fertilizer sources [3]. Therefore, there will be a decrease in the risk of eutrophication, nutrients will not be squandered, while the expenditure on the purchase of fertilizers by farmers will be reduced [24].

The main disadvantages of using treated wastewater are the presence of pathogenic microorganisms and micropollutants. Pathogenic bacteria may pose a direct threat to human health, hence it is necessary to ensure that they do not endanger consumers. Pretreatment (i.e. using advanced oxidation processes, AOP) allows the removal of unwanted compounds (i.e. phenolic, [25]), as well as fecal microorganisms from the wastewater. No significant restrictions have been set on the use of secondary effluent as a source of fertigation [26]. It was noted that wastewater can be mixed with water to dilute undesirable components (eg micropollutants, high salinity).

The plants irrigated with secondary sewage effluent had significantly higher content of selected nutrients in particular plant parts, moreover had higher vegetative growth (height and leaf numbers) and water content in the tissues. Tomatoes under fertigation with treated wastewater produced more fruit and achieved significantly higher yields than plants watered with tap water [27].

The use of treated wastewater as a source of water and nutrients for plants is common in water-stressed countries, among them Mediterranean countries (especially in Spain and Greece, Koukoulakis et al., 2010). Due to the growing problem of hydrological drought in other countries, the use of treated wastewater as a fertigation medium may be an interesting solution.

6. Conclusions

The important aspects of wastewater reuse are growing global water scarcity, insufficient treatment and disposal of wastewater, as well as increasing costs of fertilizers. Wastewater is a source of plant nutrients and organic matter, but chemicals and pathogens, which can lead to secondary environmental pollution, also contaminate it.

Exploiting the potential of fertigation treated wastewater is quite difficult and requires many changes. Important is careful planning and management. First of all, it is necessary to change the system of managing water and nutrients from wastewater. Treated wastewater is a wealth of valuable nutrients for plants and its use for crop irrigation is part of the circular economy concept. However, further research and socio-economic work is needed to be able to take full advantage of existing opportunities.

7. Acknowledgments

This project is financed in the framework of grant entitled “Crop plants and natural products as a source of biologically active substances for the manufacture of cosmetics, pharmaceuticals and dietary supplements” (BIOSTRATEG2/298205/9/NCBR/2016) attributed by The National Centre for Research and Development in Poland.

8. References

[1] Q. Zhang, X. Gu, V. P. Singh, D. Kong, and X. Chen, “Spatiotemporal behavior of floods and droughts and their impacts on agriculture in China,” *Glob. Planet. Change*, vol. 131, pp. 63–72, 2015.

[2] H. Zhang *et al.*, “Three dimensional printed polylactic acid-hydroxyapatite composite scaffolds for prefabricating vascularized tissue engineered bone: An in vivo bioreactor model,” *Sci. Rep.*, vol. 7, no. 1, pp. 1–13, 2017.

[3] E. F. Silva, I. Vaz-Moreira, C. M. Manaia, C. Becerra-Castro, A. R. Lopes, and O. C. Nunes, “Wastewater reuse in irrigation: A microbiological perspective on implications in soil fertility and human and environmental health,” *Environ. Int.*, vol. 75, pp. 117–135, 2014.

[4] E. Shakir, Z. Zahraw, and A. H. M. J. Al-Obaidy, “Environmental and health risks associated with reuse of wastewater for irrigation,” *Egypt. J. Pet.*, vol. 26, no. 1, pp. 95–102, 2017.

[5] A. Gagliardi *et al.*, “Agro-industrial wastewater reuse for irrigation of a vegetable crop succession under Mediterranean conditions,” *Agric. Water Manag.*, vol. 196, pp. 1–14, 2017.

[6] G. Gatta *et al.*, “Treated agro-industrial wastewater irrigation of tomato crop: Effects on qualitative/quantitative characteristics of production and microbiological properties of the soil,” *Agric. Water Manag.*, vol. 149, pp. 33–43, 2014.

[7] Y. Wada, L. P. H. Van Beek, N. Wanders, and M. F. P. Bierkens, “Human water consumption intensifies hydrological drought worldwide,” *Environ. Res. Lett.*, vol. 8, no. 3, 2013.

[8] J. Lessel, A. Sweeney, and P. Ceccato, “An agricultural drought severity index using quasi-climatological anomalies of remotely sensed data,” *Int. J. Remote Sens.*, vol. 37, no. 4, pp. 913–925, 2016.

[9] Z. Hao, X. Yuan, Y. Xia, F. Hao, and V. P. Singh, “An overview of drought monitoring and prediction systems at regional and global scales,” *Bull. Am. Meteorol. Soc.*, vol. 98, no. 9, pp. 1879–1896, 2017.

[10] Z. T. Zambreski, X. Lin, R. M. Aiken, G. J. Kluitenberg, and R. A. Pielke, “Identification of hydroclimate subregions for seasonal drought monitoring in the U.S. Great Plains,” *J. Hydrol.*, vol. 567, no. September, pp. 370–381, 2018.

[11] Y. Wang, M. Liu, B. Ni, and L. Xie, “j -Carrageenan À Sodium Alginate Beads and Superabsorbent Coated

Nitrogen Fertilizer with Slow-Release , Water-Retention , and Anticompaction Properties," pp. 1413–1422, 2012.

[12] V. Blauhut, L. Gudmundsson, and K. Stahl, "Towards pan-European drought risk maps: Quantifying the link between drought indices and reported drought impacts," *Environ. Res. Lett.*, vol. 10, no. 1, 2015.

[13] T. Tokarczyk, "Classification of low flow and hydrological drought for a river basin," *Acta Geophys.*, vol. 61, no. 2, pp. 404–421, 2013.

[14] L. M. Mosley, "Drought impacts on the water quality of freshwater systems; review and integration," *Earth-Science Rev.*, vol. 140, pp. 203–214, 2015.

[15] D. Levy, W. K. Coleman, and R. E. Veilleux, "Adaptation of Potato to Water Shortage: Irrigation Management and Enhancement of Tolerance to Drought and Salinity," *Am. J. Potato Res.*, vol. 90, no. 2, pp. 186–206, 2013.

[16] Q. Chai *et al.*, "Regulated deficit irrigation for crop production under drought stress. A review," *Agron. Sustain. Dev.*, vol. 36, no. 1, 2015.

[17] S. Masia, J. Sušnik, S. Marras, S. Mereu, D. Spano, and A. Trabucco, "Assessment of irrigated agriculture vulnerability under climate change in Southern Italy," *Water (Switzerland)*, vol. 10, no. 2, pp. 1–19, 2018.

[18] H. Ebrahimian, M. R. Keshavarz, and E. Playán, "Surface fertigation: A review, gaps and needs," *Spanish J. Agric. Res.*, vol. 12, no. 3, pp. 820–837, 2014.

[19] H. Lv *et al.*, "Drip fertigation significantly reduces nitrogen leaching in solar greenhouse vegetable production system," *Environ. Pollut.*, vol. 245, pp. 694–701, 2019.

[20] L. Incrocci, D. Massa, and A. Pardossi, "New Trends in the Fertigation Management of Irrigated Vegetable Crops," *Horticulturae*, vol. 3, no. 2, p. 37, 2017.

[21] S. García-Morales *et al.*, "Fertigation: Nutrition, Stimulation and Bioprotection of the Root in High Performance," *Plants*, vol. 7, no. 4, p. 88, 2018.

[22] G. D. S. Jos eacute, J. eacute de C. Joaquim, M. R. da L. Jos eacute, and E. C. da S. Jos eacute, "Fertigation with domestic wastewater: Uses and implications," *African J. Biotechnol.*, vol. 15, no. 20, pp. 806–815, 2016.

[23] J. H. Wang, T. Y. Zhang, G. H. Dao, X. Q. Xu, X. X. Wang, and H. Y. Hu, "Microalgae-based advanced municipal wastewater treatment for reuse in water bodies," *Appl. Microbiol. Biotechnol.*, vol. 101, no. 7, pp. 2659–2675, 2017.

[24] M. F. Jaramillo and I. Restrepo, "Wastewater reuse in agriculture: A review about its limitations and benefits," *Sustain.*, vol. 9, no. 10, 2017.

[25] S. Mseddi, L. Chaari, C. Belaid, I. Chakchouk, and M. Kallel, "Valorization of treated olive mill wastewater in fertigation practice," *Environ. Sci. Pollut. Res.*, vol. 23, no. 16, pp. 15792–15800, 2016.

[26] M. Buxton, R. Carey, and K. Phelan, *Balanced Urban Development: Options and Strategies for Liveable Cities*, vol. 72. 2016.

[27] S. Emongor, V.E. Macheng, B.J. Kefilwe, "Effects of secondary sewage effluent on the growth, development, fruit yield and quality of tomatoes (Lycopersicon lycopersicum (L.) Karten)," *Food Chem.*, 2012.

[28] P. Koukoulakis, F. Pedrero, I. Kalavrouziotis, T. Asano, and J. J. Alarcón, "Use of treated municipal wastewater in irrigated agriculture—Review of some practices in Spain and Greece," *Agric. Water Manag.*, vol. 97, no. 9, pp. 1233–1241, 2010.