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Evaluation of the agricultural utilization of a wastewater originated from an intensive fish farm in energy willow experiment

Theses of dissertation

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Introduction and aims

Current demand of the agriculture for the world's freshwater supply is unsustainable. In one day, crop production uses 7.4 trillion litres of water for irrigation. By 2025, an estimated 1.8 billion people will be living in regions with absolute water scarcity, and two-thirds of the world population could be living under water stressed conditions (FAO 2014).

Sustainable soil and water management and use of alternative water resources for agricultural production are one of the key elements of the fight against the continuous increase in global population and effects of climate change (Singh 2015). The new water resources play determining role because of the water scarcity in addition to water and energy saving irrigation methods (Francés et al. 2017).

Because of the more and more common extreme water related phenomena, adaptation to changing environmental conditions requires the modification of the formal national agricultural practices. The climate change also affects our country due to the basin character, the unfavourable distribution of rainfall is the consequence of the change of the regional climate patterns. Other example is the decreasing surface water quantity at summer time thereby there is a growing number of water bodies with water scarcity and regions with water stress. This water scarcity is occurred at summer time when the irrigation water demand is the highest (Hungarian River Basin Management Plan 2015). *Alternative water resources utilization should take priority over the conventional irrigation water resources (surface and subsurface waters) in the future in Hungary as well, similarly to the global trends because of the global warming and water scarcity, also in Hungary.*

Hungary has significant potential for agricultural wastewater discharge, total of 112 million m^3/year wastewater generated from processing plans, food processing plans, distilleries and from fish ponds. The energy plantation may provide prosperous opportunity for the wastewater reuse in the future through irrigation (Vermes 2017). Energy willow and poplar have many advantages compared to other plants: long growing season, high evapotranspiration rate, ability to take up nutrients and toxic elements with minimum leaching potential.

However, major challenges of the country is that significant portion (48 million m^3) of the total wastewater are thermal water based hence the properties (high salt content and sodium content) of the wastewater can endanger the soil resilience by causing salinization. The human induced salinization endangered our most important natural sources, the soil hence the farmers and researchers are responsible for development soil management practices and irrigation principles. Soil degradation (salinization) can be avoided and natural soil processes can be improved through the adaptaion by farmers of these new, sustainable technologies.

The purpose of my research was to explore the wastewater irrigation prosperous and harmful effects on the soil. The wastewater was originated from an intensive catfish farm with high nutrients, salt and sodium content what was used for irrigation in experiment with energy plants (willow, poplar). The research was founded by the Ministry of Agriculture, so called "Irrigation of wastewater from agricultural sources". The project was carried out by two institutions of the National Agricultural and Innovation Centre (NAIK): Research Department of Irrigation and Water Management (ÖVKI) and Forest Research Institute (ERTI). *Hypotheses was that the wastewater is suitable for irrigation because the nutrients can be utilised by the energy trees and water retention can be implemented* instead of driving it to surface water so the wastewater can contribute for the water supply of the local soil-water-plant system.

The aim of my research was to evaluate the applicability of this wastewater for irrigation, mainly:

- to determine two irrigation water quality originated by different sources, to evaluate the water main chemical parameters of applied waters and classifies the waters according to Hungarian and international (USDA, FAO) irrigation qualification systems;
- to determine the wastewater impacts of the soil properties and willow yield, to evaluate the soil main parameters, fertility, salinity and sodicity for the sustainability;
- to determine the environmental risks of wastewater irrigations, mainly nitrate leaching and salinization;
- to make a feedback on the Hungarian actual irrigation classification according to my results in order to develop an advanced system.

Material and Methods

Description of the wastewater experiment

The experiment was conducted on two sites: first one experiment was at the Lysimeter Research Station of NAIK ÖVKI with willow clones and the second one was on a field experiment with willow and poplar. Research was based on the results of the experiment between 2015 and 2017.

In this experiment four different irrigation waters were used in two sites. The first one is the untreated wastewater which directly originated from a catfish farm in Szarvas and it was used on the lysimeter experiment. The second one originated from the first pond (so called compensation pond without any aquatic plants) of constructed wetlands which was established to decrease the nutrient content of wastewater as a bioreactor. The third type of irrigation water originated from the oxbow lake of Körös. The fourth one was the treated wastewater, which was diluted (1:3) with Körös water than gypsum was added to it according to the following equation:

$$x = Sz_e * E$$

where the x means the gypsum quantity (mg/l or g/cm^3), Sze= residual sodium carbonate index (RSC), E= equivalent weight of gypsum (86,1).

Experiment sites and plants

Before the lysimeter experiment each vessel (1m^3) was fulled with disturbed topsoil of solonetz meadow soil in 80 cm depth without soil genetic layers in 2014. In one vessel there were two willow clones (named "Naperti") and around the vessel willows were in 1.25 and 0.75 m zones in order to ignore the site effects. In the experiment there were 8 irrigation treatment: wastewater with 15 mm (H15), 30 mm (H30) and 60 mm (H60) per 2 weeks, Körös water with 15 mm (K15), 30 mm (K30), 60 mm (K60) per two weeks, treated wastewater with 60 mm (HG60) per 2 weeks and a non-irrigated (control) treatment. Microirrigation method was used. The applied irrigation water amount depended on the weather conditions.

The area of the field experiment was 0.3 ha. The plantation with willow and poplar clones was installed in 2013 in block design. All plots had the same size (136.5 m^2) with 8 rows. The space between the rows was 2.5 m and between the plants was 0.5 m. The clones were provided by NAIK ERTI. The irrigation started in 2013 with sprinkler irrigation then drip irrigation system was installed in 2015. Three treatments were applied H60, H30 and K30. The wastewater originated from the first pond of the wetland system.

Description of the sampling methods and the analyses

During the two vegetation period(2015, 2016) 33 irrigation water samples were analyzed. The values of the pH, specific electrical conductivity (EC), alkalinity, bicarbonate and the main cations (Ca^{2+}, K^{+}, Mg^{2+}, Na^{+}) concentrations were used to determine the irrigation water quality, mainly to evaluate the salinity risk of the water. The values of the chloride and sulphate parameters were used to determine the impact of the water in the irrigation equipment. Different forms of the nitrogen, potassium and phosphorus content of the irrigation waters were used to determine the nutrient content of the waters. (All water, soil and plant analyses were made by the related Hungarian standards.)

The aims of the leachate water (originated form lysimeters) analyses were in particular to determine the risk of the nitrate leaching and to assess the sodium accumulation rate in the different wastewater irrigation treatments. The leachate water amounts were measured 33 times between 03.07.2015. and 21.04.2017. for 22 months in 64 lysimeter vessels. The leachate sampling occurred in summer and winter time as well. In winter time the leachate samling occurred in January and February (2015, 2016) and in summer time in July and August (2015, 2016, 2017). The analyzed parameters were the same like in case of the irrigation waters. Based on the results of the leachate analyses nitrogen and sodium budget was calculated. For the calculation the input quantities were: the nitrogen fertilizers, the nitrogen content of the irrigation waters and the rain and the output quantities were the nitrogen amount that was accumulated in the willow stems and the nitrogen losses by leaching. The sodium budget calculation was the same but without the fertilizers.

The soil sampling was carried out in each year (2015, 2016) before and after the irrigation season, the last sampling time was in spring of 2017. Disturbed soil samples were collected in 3 replications from 3 depth (in the lysimeter vessels 0-20 cm, 20-40 cm, 40-60 cm and 0-30 cm, 30-60 cm, 60-90 cm in the field experiment). The examined parameters of soil samples can be classified into three main groups. To assess the soil main properties and conditions, the basic parameters (pH, soil texture, salt and lime content and organic matter content) were evaluated. In order to determine the nutrient supply of the soil, the nitrogen, potassium and phosphorous content of soil ($KCl\text{-}NO_2^{-}+NO_3^{-}$ -N, $AL\text{-}P_2O_5$, $AL\text{-}K_2O$) were measured. From the result of the exchangeable cations and the ammonium-soluble sodium contents the environmental risks of the irrigation, like salinization were concluded.

The plant sampling was carried out in the lysimeter experiment after the irrigation seasons. The results of the plant sampling from 2015 were used. The calcium, sodium and dry matter content parameters of the plant tissues were determined in 3 replications (4 replications in case of dry matter). The biomass production was measured two times: in December of 2015 and January of 2016. The average yield of the different treatments was calculated from the mean willow yields of 4 replications.

Methods of the salt budget calculation

The salt budget calculation was made for the period between spring of 2015 and 2017 according to Darab (1961, 1969). To determine the salt supply at the beginning and at the end of the observation time soil salt content, bulk density and the soil depth parameters were measured and used. The difference of the salt supply at the beginning and at the end of the observation time means the alteration of the salt supply during the observation time, and then the salt content of the irrigation water was subtracted.

Statistical methods

For the statistical analyses the IBM SPSS 22.0 software and the MS Office Excel were used. Independent sample T-Test was used to determine the difference between the values (soil, water, leachate parameters as well) at different sampling time. If the conditions of the T-test was not satisfied (normality, homogeneous variance) non-parametric test was used (Manny-Whitney). One way ANOVA was used to determine the differences between the different irrigation treatments. If the condition of the homogeneous variance was satisfied, Tukey's HSD Test was used but the condition was not satisfied, Dunett T'3 test was used instead. If the conditions of the ANOVA was not fulfilled, non-parametric Kurskal-Wallis Test was used. Principal Component Analyses was used in case of analyses of the leachate water to explore the connection between the parameters and to reduce the variables.

Results

Summary of the new scientific results:

1. *According to the result of the salt budget, irrigation waters with 800 mg/l concentration total soluble salt content can be suitable for irrigation as opposed to the Hungarian recommendation (500 mg/l in case of soil with high clay content), if the sodium content of the irrigation water is low. The leaching effect of wastewater irrigation is stronger than the impact of the wastewater on the salt content of the soil.*

   Between 2015 and 2017 salt accumulation did not occur in the root zone according to the salt content of the soils irrigated with wastewaters. Despite of the salt content of the wastewater the salt budget was negative in the treatment with 30 mm (-0.7 t/ha) and 60 mm (-2.89 t/ha) water amount per two weeks. Positive salt budget occurred only in case of 15 mm irrigation water amount per two weeks (+0,08 t/ha). In the root zone, in case of wastewater irrigation the salt budget decrease was higher in the treatments with higher irrigation water doses than smaller ones.

2. *The untreated wastewater, which is unsuitable or suitable only just with restrictions for irrigation because of its high salt content, according to the Hungarian water classification can be made applicable for irrigation purposes with special treatments. According to our results the treated wastewater can be suitable for irrigation after dilution and added gypsum, even though the Hungarian classification does not suggest the use of it only in case of salt affected soils.*

   There were no significant differences regarding the exchangeable sodium cation concentration in the soil between the treated wastewater (2015: 181 mg/kg, 2016: 201 mg/kg) and the fresh water irrigation (2015: 208 mg/kg, 2016: 124 mg/kg) treatments after neither of the examined years. Also there were no significant differences in sodium budget in the soil between the treated wastewater and the fresh water treatments after neither of the years, although in case of treatment with treated wastewater in both years higher sodium accumulation was measured (2015:579 kg/ha , 2016: 337 kg/ha) than in case of freshwater treatment. According to the results it is suggested denser monitoring of the exchangeable sodium content of the soils in parallel with irrigations.

3. *The wastewaters originated from fish farms with high nitrogen content (~30 mg/l) may have nitrogen replenishment effect on the soils without nitrate leaching. Also the treated wastewater has nitrogen replenishment effect on the soils.*

   The nitrate concentration of the soils irrigated with wastewaters was higher (12.7 mg/kg) than in the soils irrigated with freshwater (5.5 mg/kg) after both irrigation seasons. Between 2015 and 2017, in the field experiment in case of treatments with wastewater in depth of 0-60 cm the nitrate concentration increased (0-30 cm: H30: +5%, W60:+30% and 30-60 cm: W30: +21%, W60: +51%), while in case of fresh water the concentration decreased (0-30 cm: -7%, 30-60 cm: -21%). The irrigation with wastewater did not cause the nitrate pollution of the groundwater because the concentration of the leachate water was below the limit of the Hungarian regulation (50 mg/l).

   At every soil sampling, the nitrate concentration was higher in case of treated wastewater than in the *freshwater*, but it was not significant and the nitrogen budget was also more prosperous in case of wastewater. In the first year the nitrogen budget was positive (+20.1 kg/ha), while in case of freshwater there was big nitrogen loss (-44.5 kg/ha). In the second year in each treatments negative budget was calculated, but in case of treated and the raw wastewater the budget was almost in balance (-6.5 kg/ha and -9.1 kg/ha) as opposed to big nitrogen losses of irrigation with freshwater (-33.4 kg/ha).

4. *The most important limiting factor for the biomass production in the Hungarian climatic conditions is the water supply. Based on the results, the salt content was not a growth inhibitory factor and the yield did not increase significantly caused by the nitrate content of the irrigation water but the lack of water in the area limits the maximum yields available.*

   My experiments have shown that there is a strong, positive linear relationship between the amount of biomass and the absolute amount of irrigation water (R2=0.944) in dry year (2015). (In the rainy years, this correlation is weaker.) The detrimental characteristics of the wastewater on the soil did not cause losses in the bio-production of willow but the nutrients in the wastewater did not increase it. However, we could achieve yield of 24-28 t/ha at 15 mm irrigation norm in 2015 and yield of 44-46 t/ha at 60 mm irrigation norm in any treatment independently of water quality.

5. *During the irrigation planning, the effect of leaching processes in the soil in winter can be considered when selecting the irrigation water quality. As a result of the winter runoff, the amount of salt accumulated in the root zone during the irrigation season can be even completely removed during the non-irrigated periods.*

   In both experimental areas, the soil's water-soluble salt content decreased to such an extent that during the two-year experimental period there was no significant change in the salt content of the soil or a decrease could be demonstrated. In the outdoor experimental field, the salt content of the soil decreased in depth between 0 and 60 cm in all treatments between 2015 and 2017. The salt supply and soil salt concentration changes confirmed that irrigation water with ~ 800 mg/l of all dissolved salt content concentrations did not cause salt accumulation in the soil over two years.

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