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Macro-, mesoelement and sodium content of plant parts of energy willows irrigated with effluent water of agricultural origin

Ildikó KOLOZSVÁRI[1,2] – Ágnes KUN[1] – Mihály JANCSÓ[1] – Csaba BOZÁN[1] – Csaba GYURICZA[2]

1: Research Center for Irrigation and Water Management, Institute of Environmental Sciences, Hungarian University of Agriculture and Life Sciences, H-5540 Szarvas, Anna-liget Str. 35., Hungary, e-mail: Kolozsvari.Ildiko@uni-mate.hu
2: Institute of Agronomy, Hungarian University of Agriculture and Life Sciences, H-2100 Gödöllő, Páter Károly Str. 1., Hungary

Abstract: Irrigation with recycled water can be considered as an element of integrated water management, in which the nutrients in the water are used and decomposed by natural processes, while water retention is realized at the local level. The objective of the study was to monitor the changes in nitrogen, phosphorus, potassium, calcium, magnesium and sodium content of the plant parts (leaves, stems, roots) of the energy willow in response to effluent water irrigation of the fish farm. In our study, we used the effluent of an intensive African catfish farm for irrigation. The farm uses thermal water for fish farming, which is characterized by a high sodium content. At the same time, the effluent is rich in organic matter and minerals. The planting of the willow plants in the study area, which is close to 3 ha, took place in the spring of 2014 with a variety candidate 'Naperti'. During the experiment, seven treatments were set up, of which one was non-irrigated, three were irrigated with the water of the Körös oxbow lake and three were irrigated with the effluent water. Three doses of irrigation water (15, 30, 60 mm) were applied to the one-week irrigation intervals with a microspray irrigation system. At the end of the growing season, samples of the plant parts were collected, during which mineral element analysis was performed with special regard to N, P, K, Ca, Mg and Na levels. The results of the study showed a significant difference in macroelements only for nitrogen for all plant parts. However, there was no significant difference in case of the mesoelements. In the case of sodium, compared to the leaf and stem plant samples, the root part accumulated a significant amount of salt, especially in the samples irrigated with 30 mm effluent water, where the Na content reached 521 mg kg^{-1}.

Keywords: effluent water, irrigation, energy willow, mineral content

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Introduction

The growing demand for biomass and renewable energy sources in the European Union can be met in the long term by setting energy efficiency targets in the European Energy Union's strategy and increasing the European share of renewable energy sources (European Environment Agency, 2006). The use of renewable energy sources is becoming less and less avoidable. Nowadays, the production and utilization of bioenergy from biomass has become a strategic issue. Both Europe and the world are facing energy shortages, and energy-based systems are declining, while energy demand is on the rise (depending on social and economic development) worldwide (European Environment Agency, 2013; Popp et al., 2014).

The willows are one of the plants which can be used to produce biomass for energy purposes. Woody stem crops grown

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for energy can generally withstand extreme weather conditions. Mostly 500–600 mm of rainfall are needed for the balanced development of these crops, but they can reach high biomass masses in years with 300–400 mm of rainfall. However, a balanced water supply is particularly important in the year of planting, as the plants are more sensitive to periods of drought during their initial development (Liberacki et al., 2022). Dimitriou and Aronsson (2011) described in their study that the wastewater applied had no negative effect on plant growth. Hangs et al. (2011) noted that moderately saline (ECe $\leq$ 5.0 dS m^{-1}) conditions were still tolerated by energy willows.

Water scarcity and climate change are among the most pressing global challenges of our time. Due to declining freshwater supplies, the use of alternative water sources in agricultural cultivation has become necessary (Gabr et al., 2020). In the integration of aquaculture and crop production, effluent water has been successfully used in irrigation or hydroponic systems in many crops (Castro et al., 2006; McMurtry et al., 1993; Naegel, 1977). The effluents from intensive fish production have a high content of organic matter and macronutrients. They provide an excellent opportunity for nutrient replenishment during crop production (Omeir et al., 2019; Kolozsvári, Kun, Jancsó, Bakti, et al., 2021; Valencia et al., 2001). Several promising studies have been conducted in the field of crop and vegetable productions by using higher salinity effluent water from fish and shrimp farms for irrigation during cultivation (Castro et al., 2006; Guimarães et al., 2016; Simões et al., 2016).

The aim of our thesis was to determine the effect of irrigation with the effluent of intensive fish farming on the macro- and,-mesoelement and sodium contents of the plant parts of the short-rotation energy willows.

Materials and Methods

The experimental area was set up in the field (46°51′06.9″N 20°31′25.0″E Szarvas, Hungary) of the Hungarian University of Agriculture and Life Sciences, Institute of environmental Sciences, Research Center for Irrigation and Water Management in spring of 2014, with an area of 2.7 hectares. The short rotation energy willow (*Salix alba* L.) coppice of Forest Research Institute 'Naperti' candidate variety was used for the experiment. The cuttings were planted in the spring of 2014. Sampling of plant parts (leaf, stem and root) took place in 2014 at the end of the growing season (october). During the examination we applied a non-irrigated treatment (C) and combinations of two different water types and three different irrigation doses for the irrigation of the energy willow clones. The area of a treated plot was 20 × 50 meter (width × length). We used water from the Körös River oxbow lake (K15, K30, K60) and untreated effluent water (E15, E30, E60) from a local intensive African catfish (*Clarias gariepinus*) farm. Irrigation water was sampled three times during the irrigation cycle and the average chemical parameters are presented in Table 1. The effluent water was directly collected from the outflow of fish rearing tanks. The quality of the effluent is characterized by a higher sodium content, as thermal water is used for the production of African catfish (Table 1.). In addition, it is characterized by higher organic matter and nutrient content (Table 1.). The irrigation interval was one week with the doses of 15 mm (K15, E15), 30 mm (K30, E30), and 60 mm (K60, E60). We used microspray irrigation system (in three replications). The plantation was irrigated six time during one irrigation period (June, July, August), with natural rainfall (326 mm).

The mineral content of the plant parts was analyzed at the end of the growing season. All samples were assayed by the Hungar-

Table 1: Mean of plant height and stem diameter for lettuce under two cultivation systems during three phenophases

	EC μS/cm	NH_4-N mg/dm^3	P mg/dm^3	Ca mg/dm^3	K mg/dm^3	Mg mg/dm^3	Na mg/dm^3
Körös River water	399	0.161	0.093	41.2	4.97	9.93	31.9
Effluent water	1 330	21	3.47	20.5	6.8	9.35	273

ian and ISO standard methods according to Kolozsvári, Kun, Jancsó, Bakti, et al. (2021):

Macroelements and sodium:

Kjeldahl-Nitrogen MSZ EN ISO 5983-2:2005: Animal feeding stuffs. Determination of nitrogen content and calculation of crude protein content. Part 2: Block digestion and steam distillation method (ISO 5983-2:2005).

Phosphorus MSZ-08-1783-28:1985: Use of high capacity equipment in plant analyses. Quantitative determination of phosphorus of plant materials by ICP method.

Potassium and Sodium MSZ-08-1783-5:1985: Use of high capacity equipment in plant analyses. Quantitative determination of potassium and sodium contents of plant materials.

Mesoelements:

Calcium MSZ-08-1783-26:1985: Use of high capacity equipment in plant analyses. Quantitative determination of calcium of plant materials by ICP method.

Magnesium MSZ-08-1783-26:1985: Use of high capacity equipment in plant analyses. Quantitative determination of magnesium of plant materials by ICP method.

The statistical analyses were implemented by IBM SPSS Statistics 25.0 software. One-way analysis of variance (ANOVA) was applied. The differences were determined significant, where the Tukey's post hoc test were considered significant at $p \leq 0.1$.

Results

Nitrogen

In the case of nitrogen (Figure 1) it can be stated that the leaf part had the highest N level. In the case of K30 treatment it was 4.47 m/m%, while the lowest value was measured in case of C treatment (0.37 m/m%). Lower levels were observed in the stem and root parts. The N level was between 1.41–0.08 m/m% and 0.88–0.5 m/m% in the stem and the root parts, respectively. Furthermore, it can be considered that the N content of the C and 30 and 60 mm effluent water irrigated plant samples differed from the values measured in the other treatments. In a one-way analysis of variance, we found a significant difference between treatments for all three plant parts. In the case of the leaf part, the K30 treatment ($p = 0.028$) had a significantly higher N level than the other treatments. In the case of the stem and root parts, in both cases the plant samples of the K15 treatment ($p \leq 0.001$) contained significantly more nitrogen compared to the lowest C treatments.

Phosphorus

In the case of phosphorus (Figure 2), it can also be observed that the leaf had the highest P content (2935 mg kg^{-1}). The values for stem and root parts were in the same range (1655–950 mg kg^{-1}). No significant difference was detected in any of the plant parts during the statistical evaluation. However, it can be observed that the P levels of C treatments are in the lower range for the stem and

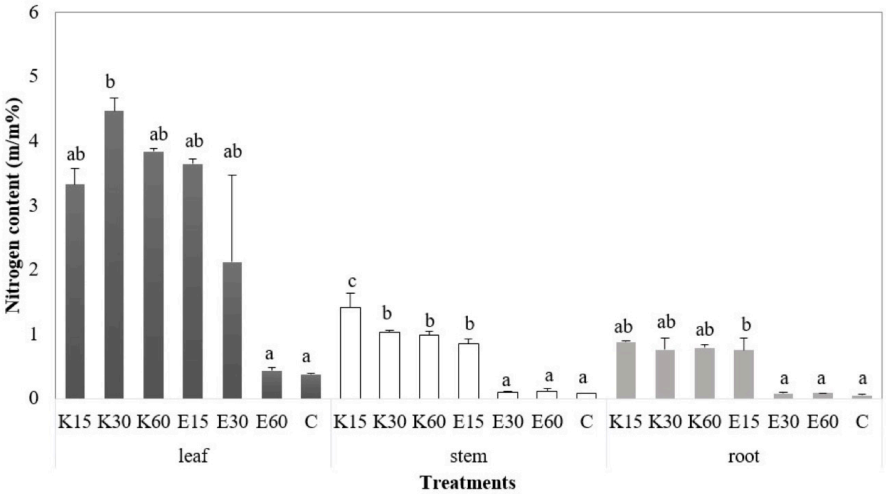

Figure 1: The nitrogen content of the plant parts (leaf, stem and root) at the end of the growing season. The different letters show a significant difference between treatments during the study period, according to the Tukey's test was used at $p \leq 0.1$ level.

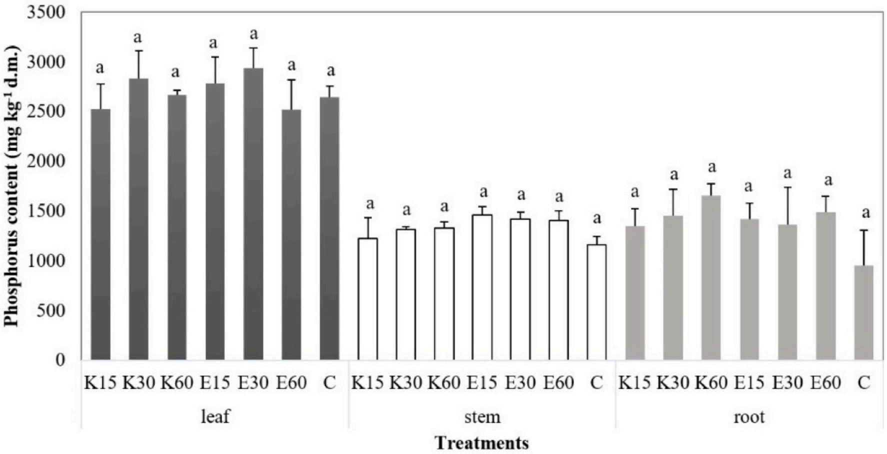

Figure 2: The phosphorus content of the plant parts (leaf, stem and root) at the end of the growing season. The different letters show a significant difference between treatments during the study period, where the Tukey's test was used at $p \leq 0.1$ level.

root plant part.

Potassium

For potassium (Figure 3), the same trend as for phosphorus can be observed, with a higher range of K levels in leaf parts (13630–9505 mg kg^{-1} d.m.). This is followed by the potassium content of the root samples, where K15 treatment (8265 mg kg^{-1} d.m.) produced the lowest and K30 treatment (9390 mg kg^{-1} d.m.) the highest values. The stem parts had the lowest potassium levels. Here, we measured the lowest values for the K15 samples (3655 mg kg^{-1} d.m.) and the highest element levels for the E15 treatment (5180 mg kg^{-1} d.m.). In the one-way analysis of variance, no significant difference was detected between treatments for the root samples. However, in leaf samples, C treatment ($p = 0.096$) had a significantly higher K content compared to K15 and E60 treatments. In

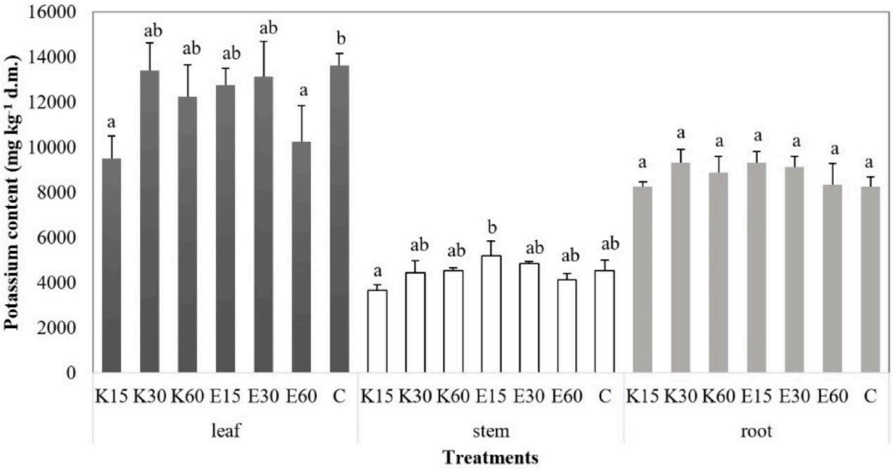

Figure 3: The potassium content of the plant parts (leaf, stem and root) at the end of the growing season. The different letters show a significant difference between treatments during the study period, where the Tukey's test was used at $p \leq 0.1$ level.

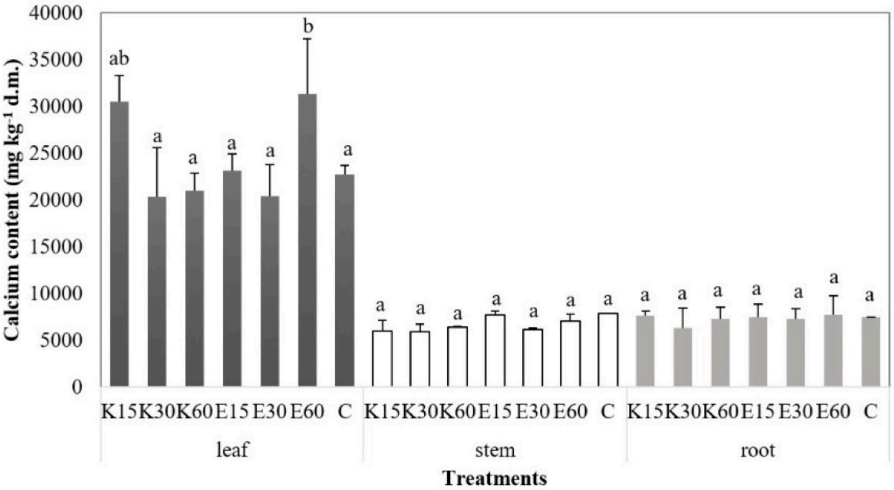

Figure 4: The calcium content of the plant parts (leaf, stem and root) at the end of the growing season. The different letters show a significant difference between treatments during the study period, where the Tukey's test was used at $p \leq 0.1$ level.

the case of stem samples, E15 treatment ($p = 0.061$) had a significantly higher K level.

Calcium

It was also observed that leaf samples contained calcium in the highest proportion (Figure 4). Where the lowest value was measured in the K30 treatment (20310 mg kg^{-1} d.m.) and the highest to E60 samples (31345 mg kg^{-1} d.m.). The stem and root samples moved in the same range. For stem parts, the K30 treatment (5885 mg kg^{-1} d.m.) had the lowest Ca content, while the E15 samples (7730 mg kg^{-1} d.m.) had the highest, but no significant difference between treatments was observed. The calcium content of the root parts ranged from 6295 to 7630 mg kg^{-1} dm. The statistical evaluation showed significant differences only in leaf parts, where E60 treatment samples ($p = 0.047$) had significantly the highest Ca values.

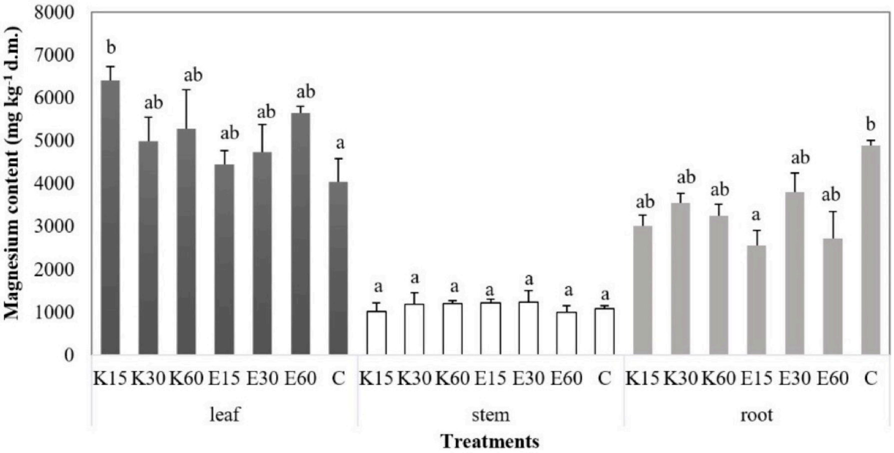

Figure 5: The magnesium content of the plant parts (leaf, stem and root) at the end of the growing season. The different letters show a significant difference between treatments during the study period, where the Tukey's test was used at $p \leq 0.1$ level.

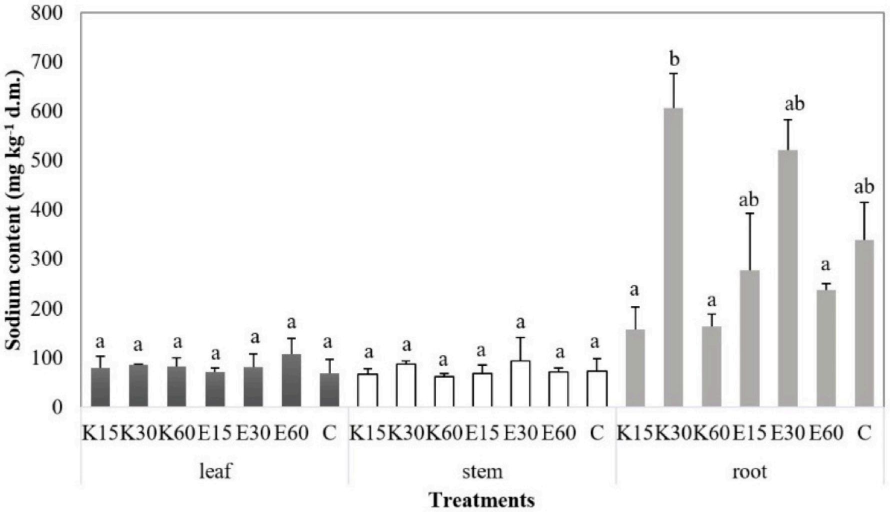

Figure 6: The sodium content of the plant parts (leaf, stem and root) at the end of the growing season. The different letters show a significant difference between treatments during the study period, where the Tukey's test was used at $p \leq 0.1$ level.

Magnesium

In the case of magnesium, the leaf parts also contained the highest concentration (Figure 5). This was followed by the Mg element content of the root parts and then the stem parts. For leaf samples, treatment C (4045 mg kg^{-1} d.m.) had the lowest value, while treatment K15 (6410 mg kg^{-1} d.m.) had the highest value. In the case of the stem part, the Mg content was between 999 and1225 mg kg^{-1} d.m. The lowest element content was measured for the root samples in the E15 treatment (2555 mg kg^{-1} d.m.) and the highest in the C samples (4895 mg kg^{-1} d.m.). According to the one-way analysis of variance, compared to the C treatment the K15 sample ($p = 0.075$) had significantly higher Mg levels in the case of the leaf samples. Furthermore, compared to the E15 treatment the C sample ($p = 0.081$) detected significantly higher values in the root part. No significant difference was observed between stem treatments.

Sodium

The sodium content of the plant parts developed differently from the mineral elements presented above (Figure 6). In this case, the willow leaf and stem parts stored significantly less Na in the tissues. This value ranged from 62 to 108 mg kg^{-1} d.m. In contrast, in the case of root samples, the K15 treatment (157 mg kg^{-1} d.m.) with the lowest value also had higher Na levels. The Na content of the root samples of the highest K30 treatment reached 606 mg kg^{-1} d.m. During the statistical evaluation, there was a significant difference between the treatments for the root samples between K30 ($p = 0.003$) and K15, K60, E60.

Discussion

The effect of effluent from an intensive African catfish farm on the mineral content of plant part was investigated in a short rotation coppice plantation in 2014. In the case of nitrogen, it can be observed for all parts of the examined plants that the C treatments and the samples irrigated with 30 and 60 mm effluent water had significantly lower N content. For treatment C, this decrease was caused by water deficit, and for the samples irrigated at 30 and 60 mm, it could be due to irrigation of effluent water with higher EC. Similarly, as nitrogen, phosphorus is an essential macronutrient for all plants. In addition, it is a component of many cellular compounds that are essential for energetic and photosynthetic metabolism (Maathuis & Diatloff, 2012). During the measurement the leaf samples had the highest phosphorus value. Potassium is the most abundant cation in plants and its amount decreases as the growing season progresses (Gierth & Mäser, 2007). The highest concentration was measured for leaf samples.

Mg^{2+} and Ca^{2+} are essential for plant growth because magnesium is a structural component of chlorophyll and calcium is a component of the cell wall and a receptor for environmental stimuli (Ranty et al., 2016). According with the study of Akter and Oue (2018) measured magnesium levels in root samples irrigated with high salinity irrigation water were lower than in non-irrigated C treatments. In the case of calcium, leaf samples irrigated with 60 mm of effluent had the highest concentration.

High salinity can induce nutrient deficiencies in plants. In addition to altering the ionic balance of cells, salt stress can also generate oxidative stress in plant cells and tissues. In halophytic plants (which are well adapted to the saline environment), they increase the presence of compounds with high antioxidant activity, such as the production of polyphenols (Mansour et al., 2018). Under the study, there was a significant difference between the treatments for the root samples. During which the highest Na concentration reached 606 mg kg^{-1} d.m. The same result as in our previous study was obtained during effluent water irrigation of silage sorghum (Kolozsvári, Kun, Jancsó, Bíróné Oncsik, et al., 2021).

In summary, in areas where irrigation water is not available or we have poorer quality soil, the effluent of the intensive fish farm we studied can be a suitable alternative. At the same time, it is necessary to monitor the irrigated area, in particular to monitor changes in soil parameters.

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