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Journal of Agricultural and Environmental Sciences

Reuse of wastewater from fish farm for irrigation in aerobic rice (*Oryza sativa* L.) cultivation

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Abstract: The utilization of wastewater in irrigated agriculture is becoming vital in those regions where access to freshwater is low. Wastewater in rice cultivation as an alternative water source can also play significant role in the future. This experiment was conducted in Szarvas, Hungary to evaluate the performance of a Hungarian rice variety (‘Janka’) irrigated with a saline effluent water from an intensive fish farm. Irrigation was carried out both in the form of direct use (I1) of the wastewater and with two additional treatments: I2 - gypsum supplementation, I3 - wastewater dilution with oxbow lake water and gypsum supplementation. Water from the local oxbow lake was set as irrigation control. During the experiment, the quality parameters, grain size and mineral composition (Na, K, Mg, Ca, and P) of rice seeds were measured. The study showed that the application of wastewater and treated wastewater decreased many of these parameters. I1 significantly reduced the thousand grain weight of paddy and cargo seeds. Meanwhile, I2 and I3 had a significant negative effect on the head rice percentage. Grain length, width and ratio were also decreased significantly compared to the control irrigation. Only the mineral content of the grains remained statistically unchanged. The current study showed that the selected rice variety generally reacted negatively to the wastewater and also to the treated wastewater.

Keywords: Rice; quality parameters, grain dimensions; mineral content; aquaculture effluent

Received 24 November 2020, Revised 18 September 2021, Accepted 29 October 2021

Introduction

Rice (*Oryza sativa* L.) is one of the most important food crops that is widely grown all over the world like wheat and maize (Maclean et al. 2013). The rice plant is commonly referred as the queen of cereals because of its mineral wealth (Anjum et al. 2007). Rice is rich in several important proteins and minerals (Verma 2011), however, mono diet can cause many health issues too (e.g. Vitamin A deficiency). Beside breeding approaches, production conditions (soil, irrigation water, weather, technology) have a significant effect on the nutrient uptake of rice plants (Gurusamy et al. 2007).

Rice goes through several production stages before reaching the consumers’ table. After harvest, mechanical drying and cleaning is usually used before storage. To obtain cargo (or brown) rice, indigestible husk must be removed. During the final milling steps, bran from brown rice is polished and white rice is received (IRRI 2013). As these steps are implemented, rice undergoes not only changes in weight and shape, but also loss of minerals (Juliano 1993). Although brown rice has higher mineral content, white rice is much more popular in most countries because of the easier storage and cooking ability (Danquah and Egyir 2014).

DOI: 10.18380/SZIE.COLUM.2021.8.2.17

Like other crops, rice also depends on the proper supply of nutrients to ensure a high and healthy harvest (Sasaki et al. 2016; Che et al. 2018). The absorption of nutrients by the rice plant is a complex process that involves the relationship between soil, water and air. The minerals, taken from the roots of the rice, are transmitted to the above-ground parts, circulate during the growing season and provide plant growth. The use of different treatments plays an essential role in improving the yield-attributing parameters of rice (Pati et al. 2016). For instance, the application of potassium in the manner proposed by Hu and Wang (2004) can lead to an increase in the nutrient uptake and nutrient use efficiency of rice. Many factors can affect the mineral content of plants, one of that is the amount of available water (Martínez-Ballesta et al. 2010).

Plants need water to maintain normal development and enzymatic activities. Moreover, water dissolves nutrients in the soil and ensures their availability for absorption by plants (Fipps 2003). Nowadays, water is a main limiting factor for agriculture in many regions and one of the biggest challenges for farmers to maintain appropriate water supply. Because of this, alternative water resources are becoming more and more important to meet the water demand for irrigation (Birol et al. 2010). Wastewater or effluent water irrigation is one of the leading alternatives among these methods (Zhang et al. 2010). Among other parameters, quality and quantity of different irrigation water types from conventional and alternative sources have a significant role on the productive parameters and chemical composition of crop plants (Eid and Hoballah 2014).

Water scarcity, competition for water resources, high cost of water and fertilisers have made the wastewater application attractive. Wastewater, in addition to the elements that plants need, can also contain heavy metals, pathogens that can damage them. From this point of view, Soothar et al. (2018) did not suggest the direct application of wastewater in rice cultivation. Mukherjee et al. (2013) noted that the presence of lead and mercury in wastewater affected the rice plant and caused economic damage to farmers. On the other hand, during the use of wastewater, farmers have direct contact with them, which raises concerns about health issues (Pham and Watanabe 2017). However, most researchers believe that positive results can be obtained by choosing a tolerant rice variety and proper wastewater treatment. The use of reclaimed wastewater, especially in arid and semi-arid zones, where the salinity of fresh water is higher, gives more effective results (Kaboosi and Esmailnezhad 2018). For example, with suitable dilution in accordance with special standards, rice performance immediately increases from the initial stage (Kang et al. 2004; Dash 2012; Gassama et al. 2015; Akhtar et al. 2018). According to some studies, reclaimed wastewater does not have a side effect on human health (Papadopoulos et al. 2009; Jang et al. 2013). Moreover, in some cases, during irrigation with wastewater, rice yield may be higher than with conventional sources of water (Yoon et al. 2001; Kang et al. 2007).

The current study involves investigation of the effect of fish farm effluent water on aerobic rice as a follow-up experiment of previously published studies (Ibadzade et al. 2020). The main focus was on plant performance by measuring quality parameters, grain dimensions and grain mineral composition.

Materials and Methods

Experimental area and design

The research area is located in the Lysimeter Station (46°51′48″N, 20°31′39″E) of the Hungarian University of Agriculture and Life Sciences, Institute of Environmental Sciences, Research Centre of Irrigation and

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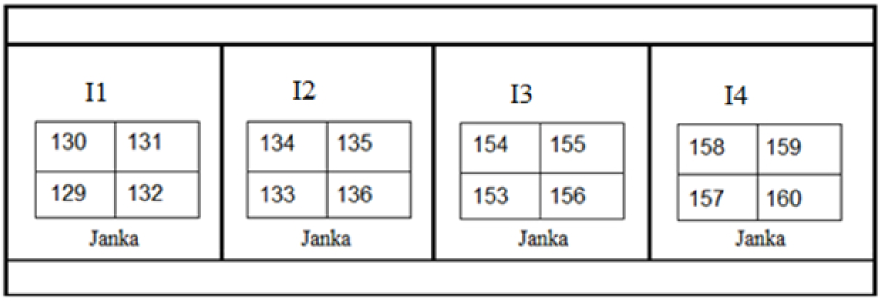

Figure 1: Schematic representation of experimental design. I1: wastewater, I2: gypsum supplemented wastewater, I3: wastewater diluted with surface water and supplemented with gypsum, I4: oxbow lake water (control). Number in cells: lysimeter ID number. Janka: Hungarian rice.

Table 1: The chemical characteristics of irrigation water used in the experiment. I1: wastewater, I2: gypsum supplemented wastewater, I3: wastewater diluted with oxbow lake water and supplemented with gypsum, I4: oxbow lake water (control). M: mean. SD: standard deviation.

Parameters	I1 M ± SD	I2 M ± SD	I3 M ± SD	I4 M ± SD
pH	7.77±0.12	7.71±0.12	7.70±0.15	7.55±0.04
EC (µS cm^{-1})	1180.00±125.30	1905.00±125.30	1033.75±208.33	371.86±20.14
TN (mg L^{-})	26.30±3.04	28.55±3.04	13.10±2.53	1.19±0.09
TP (mg L^{-})	2.18±0.13	2.67±0.13	1.53±0.68	0.15±0.04
$SO_4{}^{2}$- (mg L^{-})	32.65±2.19	448.75±2.19	164.18±103.00	34.58±3.20
Ca (mg L^{-})	23.23±1.35	187.50±1.35	90.83±31.11	39.04±0.73
Mg (mg L^{-})	10.08±0.86	11.02±0.86	10.69±1.05	9.80±0.56
Na (mg L^{-})	249.00±47.16	266.75±47.16	131.25±12.84	28.90±4.01
K (mg L^{-})	6.08±0.75	6.61±0.75	5.43±0.35	3.71±0.70

Water Management (MATE IES ÖVKI) in Szarvas, Hungary. The experiment was carried out in 16 non-weighing lysimeters with a volume of 1 m^3 in 4 repetitions (Figure 1). The soil used in these gravitational lysimeters is classified as Vertisol (expansive clay).

Untreated wastewater from a local intensive African catfish farm was used and directly collected from the outflow of the fish rearing tanks. The flow-through system of the fish tanks is supported by a geothermal well from a confined aquifer. Because of the geothermal origin, the effluent water also carrying high content of total salinity including high amount of sodium (Table 1).

The use of wastewater for irrigation was performed as: direct use of wastewater – I1; gypsum supplemented wastewater – I2; wastewater diluted with oxbow lake water and supplemented with gypsum – I3. For control treatment, the water of the nearby oxbow lake (I4) was applied (Szarvas-Békésszentandrási Holt-Körös, Szarvas).

Crop management, irrigation and weather

In our experiment, a Hungarian rice variety ‘Janka’ (temperate japonica) was used. The cultivation of the plants was carried out un-

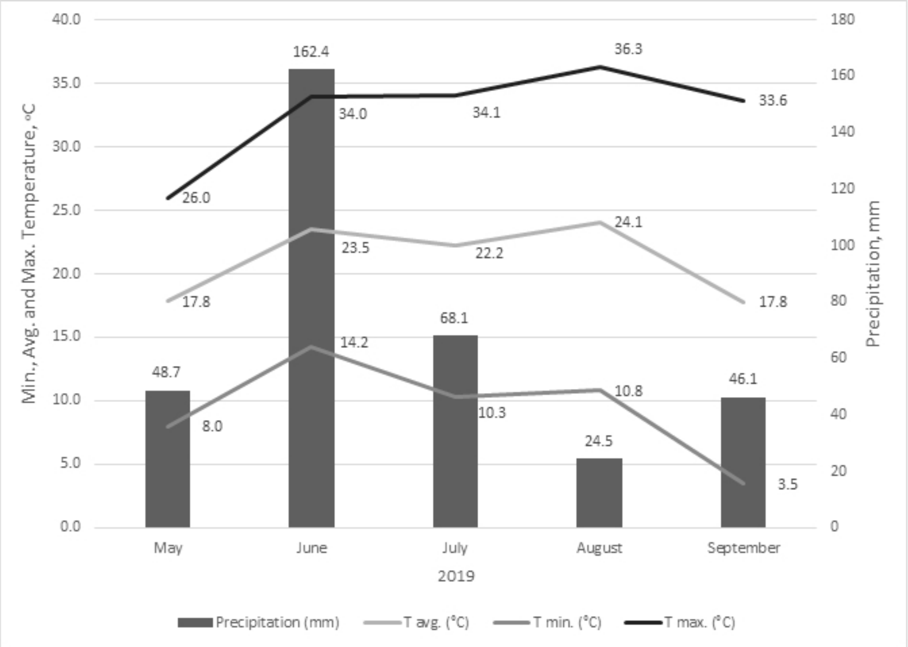

Figure 2: Monthly precipitation; Average, Minimum and Maximum temperature.

der aerobic conditions in large non-weighing lysimeters.

Rice seeds were sown manually on the 22nd of May, 2019 and 0.5 kg of fertiliser (NH_4NO_3 + $CaMg(CO_3)_2$) was applied (84.4 kg Nha^{-1}) only once during the growing season. Irrigation of plants was carried out in all the treatments with a commercially available micro-sprinkler irrigation system. At the beginning of the experiment, 20 mm of river water was applied twice on all of the lysimeters to achieve uniform emergence. After that, irrigation schedule was planned as a weekly dose of 20 mm, which was modified according to the meteorological conditions. During the growing season (May-August), the amount of irrigation water for all the treatments was as total 160 mm. Dates of irrigations were 14th of June, 2nd, 4th, 12th, 18th, and 26th of July, 12th and 22nd of August, respectively. The crop was harvested manually on the 24th September, 2019.

All primary meteorological data for the experiment were received from an automatic weather station (Agromet-Solar, Boreas Ltd., Hungary) which were set next to the experimental site (Figure 2).

Measurements

Determination of 1000 Grain Weight (TGW)

A sample of 100 seeds was weighed to measure paddy seeds, then the husks were removed with a Satake THU Laboratory Husker equipment and the cargo rice was weighed on analytical balance (Sartorius BP221S), and then the result was multiplied by ten. The test was repeated four times for the whole sample, and the average thousand grain weight of paddy (TGWp) and cargo (TGWc) rice was calculated.

Determination of Head Rice Percentage (HRP)

A husk layer of 100 g of seeds from each sample was removed and weighed. Later, brown grain was polished with Satake TM05 Test Mill laboratory equipment from these samples, and the result was weighed. The whole polished rice (white grain) was separated and weighed in four repetitions.

Grain Dimensions (GD)

In order to measure grain size and shape, 100 seeds from every sample were scanned using a flatbed scanner (HP ScanJet Pro 3500 f1) and Readiris Pro 14.1 software into "tiff" format. The scanned pictures were transferred to "jpg" format and were analysed using SmartGrain 1.2 software. These steps were repeated four times for the samples and the mean length (mm), width (mm) and L/W ratio were calculated.

Mineral composition (MC)

Based on MSZ EN ISO 11885:2000 international and Hungarian standards, in this experiment we analysed the mineral composition in rice grains, i.e. the content of Na, K, Mg, Ca and P. Na, K, Mg and Ca were measured with a Thermo Scientific Solaar M6 Atomic Absorption Spectrophotometer, and P was determined using Thermo Scientific ICAP 6000 Inductively Coupled Plasma Atomic Emissions at the MATE ÖVKI Laboratory for Environmental Analytics (Szarvas, Hungary).

Statistical analysis

The data were analysed by using of IBM SPSS software (version 22). To compare the effect of every irrigation treatments, data were tested through one-way analysis of variance (ANOVA). Differences between means were compared ($p < 0.05$) by Tukey's test.

Results and discussion

Quality parameters

The results of thousand grain weight tests of paddy (TGWp) and cargo (TGWc) seed of the Janka rice variety are illustrated in Table 2. There was a significant effect of treatments on TGWp at the $p < 0.05$ level [$F(3,12) = 14.6, p = 0.001$]. Post hoc comparisions using the Tukey HSD test showed that the mean TGWp in I1 irrigation (24.59 ± 0.56) was significantly lower than the I4 ($26.45 \pm 0.56, p < 0.001$), I2 ($26.08 \pm 0.29, p < 0.01$) and I3 ($25.86 \pm 0.46, p < 0.01$) irrigations. But there was no significant difference beetween I2 and I3 irrigations ($p > 0.05$) on TGWp.

An analogous result was also observed in TGWc [$F(3,12) = 7.66, p = 0.004$] (Table 2). While there was no statistically significant difference between I2, I3 and I4 ($p > 0.05$); but between I1 (20.05 ± 0.43) and I2 ($21.16 \pm 0.37, p < 0.05$), I3 ($20.93 \pm 0.42, p < 0.05$), I4 ($26.45 \pm 0.33, p < 0.01$) the difference was statistically significant.

During the milling stage (Table 3), the effect of irrigation with different water sources was not statistically significant for the percentage of brown and white grain of 'Janka' ($p > 0.05$). However, significant differences in HRP (Table 3) were determined [$F(3,16) = 10.69, p = 0.001$]. Irrigation with I2 and I3 reduced the HRP, and there was a statistically significant difference between the control (56.08 ± 3.26) and I2 ($42.64 \pm 2.54, p < 0.001$), I3 ($47.12 \pm 5.47, p < 0.05$). Only between I1 and I4 was found a non-significant difference ($p > 0.05$).

Typically, rice plants respond positively to the environment with an optimal level of nutrition (Jahan et al. 2017). For instance, different levels of P and N fertilisers can increase thousand grain weights at an important degree (Hasanuzzaman et al. 2012; Yosef Tabar 2012). However, regardless of the rich mineral composition of wastewater, Kaboosi and Esmailnezhad (2018) in their experiment did not notice significant changes in the weight of thousand grains. Duy Pham et al. (2019) also identified this trend under continuous irrigation with treated wastewater. In irrigation water with a high percentage of sodium, the yield attributes of rice may drop drastically (Rahman et al. 2017). In the current experiment, the TGW decrease was more evident with the application of I1 irrigation. Basically, a decrease in these values can also be explained by the presence of sodium in wastewater. Similar result was noted by Abdullah et al. (2002) as well.

Table 2: TGW of paddy and cargo seeds of rice developed with different irrigation water. I1: wastewater, I2: gypsum supplemented wastewater, I3: wastewater diluted with oxbow lake water and supplemented with gypsum, I4: oxbow lake water (control). M: mean. SD: standard deviation. Values followed by the same letter do not differ significantly from each other at 0.05 level according Tukey's honestly significant difference (HSD) post hoc test.

Irrigation treatments		TGWp (g)	TGWc (g)
I1	M	24.59^{a}	20.05^{a}
	SD	0.56	0.43
I2	M	26.08^{b}	21.16^{b}
	SD	0.29	0.37
I3	M	25.86^{b}	20.93^{b}
	SD	0.46	0.42
I4	M	26.45^{b}	21.3^{b}
	SD	0.33	0.40

Table 3: Milling fraction of rice grain developed with different irrigation water. I1: wastewater, I2: gypsum supplemented wastewater, I3: wastewater diluted with oxbow lake water and supplemented with gypsum, I4: oxbow lake water (control). M: mean. SD: standard deviation. Values followed by the same letter do not differ significantly from each other at 0.05 level according Tukey's honestly significant difference (HSD) post hoc test.

Irrigation treatments		Brown grain (%)	White grain (%)	Head rice (%)
I1	M	77.92^{a}	67.44^{a}	52.08^{bc}
	SD	1.04	1.51	4.13
I2	M	77.44^{a}	67.20^{a}	42.64^{a}
	SD	0.54	0.28	2.54
I3	M	78.64^{a}	68.96^{a}	47.12^{ab}
	SD	0.67	1.08	5.47
I4	M	78.64^{a}	68.80^{a}	56.08^{c}
	SD	1.35	1.67	3.26

Moreover, according to Chunthaburee et al. (2015), salt-sensitive rice varieties are more likely to have this type of low result.

On the other hand, during I2 and I3 irrigation the HRP significantly decreased. Although the effect of treatments did not manifest itself in the TGW, it caused the loss of the HRP. Stress factors caused by sodium always led to negative changes in yield parameters (Alam et al. 2004), which in our case, despite an attempt to reduce the influence of sodium in wastewater, encountered a decrease in HRP.

Grain dimensions

Statistical analysis revealed that the treatments have resulted considerable changes in grain dimensions. There was a significant ef-

Table 4: Milling fraction of rice grain developed with different irrigation water. I1: wastewater, I2: gypsum supplemented wastewater, I3: wastewater diluted with oxbow lake water and supplemented with gypsum, I4: oxbow lake water (control). M: mean. SD: standard deviation. Values followed by the same letter do not differ significantly from each other at 0.05 level according Tukey's honestly significant difference (HSD) post hoc test.

Irrigation treatments		Length (mm)	Width (mm)	L/W Ratio (mm)
I1	M	9.49^{a}	2.93^{ab}	3.23^{a}
	SD	0.49	0.27	0.31
I2	M	9.68^{b}	2.89^{a}	3.29^{a}
	SD	0.53	0.25	0.27
I3	M	9.64^{b}	2.94^{bc}	3.24^{a}
	SD	0.48	0.22	0.29
I4	M	9.78^{c}	2.99^{c}	3.38^{b}
	SD	0.46	0.27	0.30

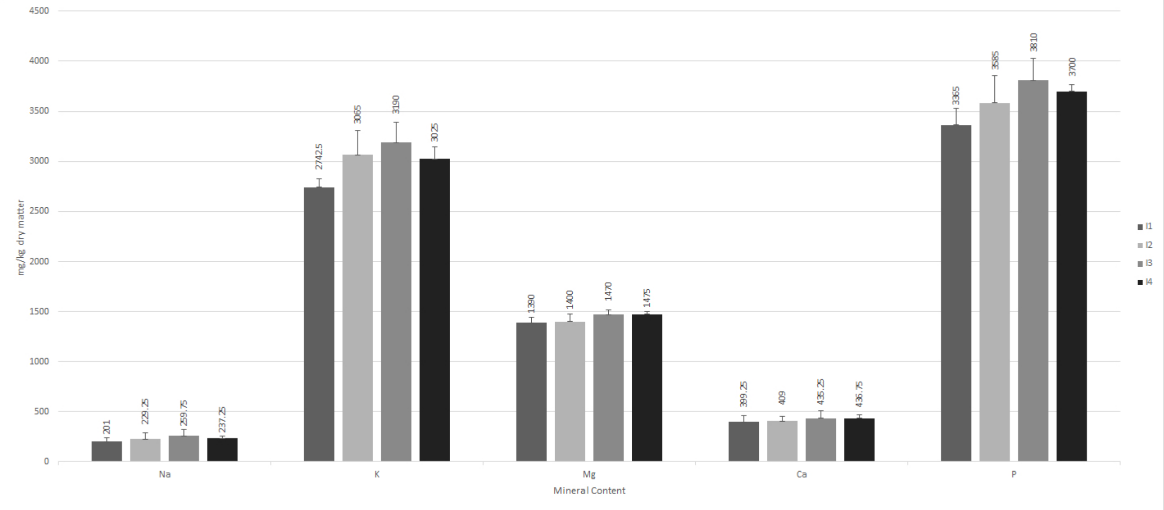

Figure 3: The mineral content in Janka rice grains developed with different irrigation water. I1: wastewater, I2: gypsum supplemented wastewater, I3: wastewater diluted with surface water and supplemented with gypsum, I4: oxbow lake water (control).

fect of treatments (Table 4) on grain length of Janka rice variety $[F(3,1578) = 24.01, p = 0.0001]$. Post hoc test indicated that the grain length was statistically lower after the irrigation with I1 $(9.49 \pm 0.49, p < 0.001)$, I2 $(9.68 \pm 0.53, p < 0.05)$ and I3 $(9.64 \pm 0.48, p < 0.001)$. The average length of grain after the I1 irrigation was statistically lower even after I2 $(p < 0.001)$ and I3 $(p < 0.001)$ irrigations.

Grain width of rice (Table 4) was also affected by irrigation $[F(3,1586) = 8.38, p = 0.0001]$. The average grain width after I1 $(2.93 \pm 0.27, p < 0.05)$ and I2 $(2.89 \pm 0.25, p < 0.001)$ irrigations was significantly lower compared to the control irrigation

(2.99 ± 0.27). The effect of I3 irrigation on grain width was non-significant ($p = 0.051$). Irrigation with I1, I2, and I3 significantly reduced the average L/W ratio of Janka rice grains [$F(3,1561) = 21.27, p = 0.0001$]. The average L/W ratio of grains was $3.23 \pm 0.31, 3.29 \pm 0.27, 3.24 \pm 0.29$ and 3.38 ± 0.30 for I1, I2, I3 and I4 irrigation, respectively (Table 4).

As with drought conditions (Haider et al. 2015), salinity protection is also important for seed formation. Especially in the flowering stage, it is more necessary to avoid these undesirable factors (Yang et al. 2019). Altogether, in our experiment rice grain dimensions were negatively affected regardless of the irrigation treatments. Apparently, along with other parameters due to a stressful environment, the size of paddy seeds also changed. As Fabre et al. (2004) previously reported, the decrease in grain size is associated with stress conditions caused by salinity. According to Rao et al. (2013) while this varies depending on the level of stress tolerance, as the stress level increases, a decrease in grain dimensions is inevitable.

Mineral Composition

Among the studied parameters, the mineral composition of grains was the least variable during irrigation treatments (Figure 3). Although some changes were recorded in the Na, K, Mg, Ca and P content of grains, but this was not reflected in the statistical analysis. The effect of irrigation treatments as determined by one-way ANOVA was statistically similar to each other ($p > 0.05$).

Nutrient distribution is a complex function that encompasses all plant cells (Wang et al. 2011). Usually, mineral accumulation can be impaired in salty environments (Huang et al. 2017). According to some studies, the sodium content increases considerably in different parts of the plant (Cha-um et al. 2007; García Morales et al. 2012). However, in this experiment, we did not see any change in the mineral composition of the Janka rice grains after the treatments. Despite their rich nutrient content and high Na, the treatments could not influence the mineral composition of the grains, and the studied rice plant could maintain the grain mineral composition even in a moderate saline environment.

Conclusions

The current study showed that the selected rice variety generally reacted negatively to the wastewater and also to the treated wastewater. Taking into account the individual parameters of 'Janka', it was found that the thousand grain weight of paddy and cargo seeds decreased significantly after the I1, and the head rice percentage after the I2 and I3 irrigations, respectively. Moreover, all treatments have significantly reduced grain dimensions compared to the control. Although, the sodium in the wastewater played a decisive role in the development of plants and seeds. However, the wastewater treatments were higher in mineral concentration; they did not affect significantly the mineral composition of the grains. In this regard, the improvement of wastewater treatments and the cultivation of more salt tolerant rice varieties could promote reutilization and bioremediation approaches of wastewater irrigation in the coming years.

Acknowledgements

The experiments were financially supported by the Hungarian Ministry of Agriculture (AM O15500, OD001). The research infrastructure was improved by the GINOP-2.3.3-15-2016-00042 project. Marks Ibadzade was a scholarship holder of Stipendium Hungaricum.

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