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ASSESSING THE IMPACT OF IRRIGATION WITH AGRICULTURAL WASTEWATER ON AEROBIC RICE (*Oryza sativa* L.)

By

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Title: Assessing the impact of irrigation with agricultural wastewater on aerobic rice (*Oryza sativa* L.)

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1. BACKGROUND AND OBJECTIVES

The demand for high-quality food, coupled with a growing number of human population, is increasing pressure on agriculture around the world. To achieve this goal, freshwater resources and various chemicals (fertilisers, pesticides) are widely used. It is well known that agriculture is one of the largest areas that is responsible for a large amount of water consumption in the world. However, changing climatic conditions and economic costs do not always make them affordable. In the age of climate change and depletion of water resources, a new approach is needed to provide crops with sufficient water. It is especially important in climate vulnerable countries with arid and semi-arid areas, where growing plants suitable for these conditions is becoming an additional challenge for local farmers.

Rice (*Oryza sativa* L.) cultivation in many countries meets also water shortages and other environmental issues. Rice is considered the staple food that provides dozens of millions of people with essential nutrition. The main concerns of people involved in this area are associated with unstable weather conditions, lack of water and their cost, and fertilisers. Alternative sources of irrigation and methods of irrigation are seen as a way out to overcome existing problems. The continuous increase of wastewater as a result of urbanization and industrial development has become a major option for agricultural use nowadays. Besides water-saving technologies, alternative sources of irrigation water, such as wastewaters or effluent waters, are among the opportunities that can help to cope with water scarcity. Wastewater is one such alternative source in which plants can be irrigated without fertiliser application due to the nutrients present in them. In addition, the beneficial use of wastewater for irrigation can also reduce their potential environmental impact. Because, depending on the source of wastewater, it may contain hazardous elements that can be harmful to human health.

Although the use of agricultural wastewater is considered a solution to the problem of water scarcity and maintaining an ecological balance, from the point of view of food security, it is also necessary to study the impact on the quality parameters of rice.

This study covers a three-year experiment conducted in 32 lysimeters, in which changes in the qualitative characteristics and parameters of the mineral composition of 2 Hungarian rice varieties irrigated by effluent water from a fish farm are studied.

For better understanding of agricultural and plant physiological processes, it is necessary to study rice grown under aerobic conditions with agricultural waste water (AWW) irrigation and to evaluate its effect on the chemical composition of plants. The primary hypothesis was that the different macro nutrients in the accessible agricultural wastewater have different influences on the development and nutrient accumulation of the aerobic rice. Beside main nutrients, the focus was on the effects of high sodium content in the irrigation water, not only because of the predicted disadvantageous effects, but because of the possible bioremediation opportunities with the aerobic rice cultivation.

The purpose of the research is to answer the following questions:

- Whether is it suitable or not to use our specific agricultural wastewater for irrigation based on the complex evaluation of crop plant responses?
- How does agricultural wastewater affect the quality parameters of rice grown under the aerobic conditions?
- What is the role of agricultural wastewater used in the circulation and accumulation of minerals in aerobic rice varieties?

In this study, Hungarian rice varieties were irrigated with traditional and alternative irrigation water in a complex lysimeter study to unravel the effects of fish farm effluents on the mineral composition of aerobic rice plants. This can lead us to the better understanding of the advantages and disadvantages of effluent irrigation. Moreover, deeper analysis of different alternative water sources and the reutilization of agricultural effluents can reduce the impact of rice production and animal husbandry on the natural water bodies and lead to good quality food and feed production too.

2. MATERIALS AND METHODS

2.1. Experimental site and design

The experiment was conducted at the National Agricultural Research and Innovation Centre, Research Institute of Irrigation and Water Management (NAIK ÖVKI) Lysimeter Station in Szarvas, Hungary (46°51′48″ N, 20°31′39″ E) in the growing seasons of 2017, 2018, and 2019.

In the experiments, 32 non-weighing backfilled gravitation lysimeters with a volume of 1 m^3 each were used. Every lysimeter has a surface of 1x1 m and a depth of 1 m, placed in a square sector. The bottom 10 cm of the lysimeter is a layer of gravel to collect percolated water in case of heavy rain or high amount of irrigation, and the following 80 cm is a layer of soil. The type of soil in the lysimeter ponds was vertisol (expansive clay).

2.2. Treatment methods

Possible changes of effluent water from the intensive catfish farm on rice was explored during the experiment. Four types of treatments have been applied throughout the experiments: T_1 - raw effluent water; T_2 - effluent water supplemented with gypsum; T_3 - effluent water diluted with river water and supplemented with gypsum; T_C - control treatment, water from oxbow lake, which is a section of the Körös River in eastern Hungary (46°51′38.6″ N 20°31′28.0″ E, Szarvas). The distribution of irrigation treatments was done according to the following schematic diagram (Figure 1):

The treatments were applied by a micro sprinkler irrigation method and with four replications. The effluent water was obtained from an intensive fish farm near the experimental site. Here, a geothermal well from a confined aquifer was the main source of fish ponds. The main factor that is notable in effluent water (T_1) is its high total dissolved salt content. Because of that, given the potential harm to the soil and plants, supplementations were applied in T_2 and T_3.

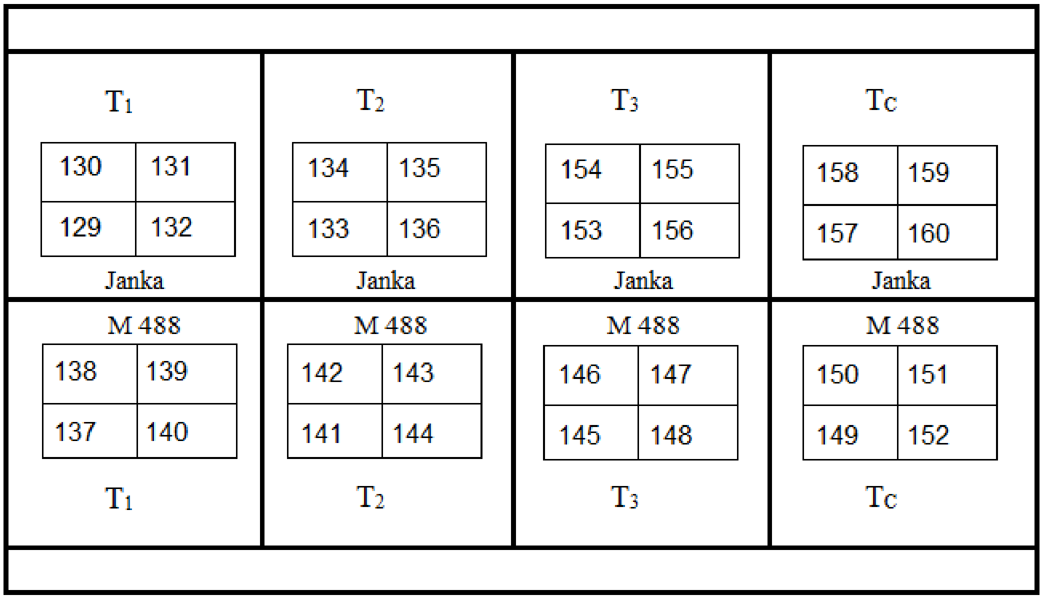

Figure 1. Schematic representation of the study. T_1 - effluent water; T_2 - effluent water supplemented with gypsum; T_3 - effluent water diluted with river water and supplemented with gypsum; T_C - river water (control). M 488 and Janka - Hungarian rice varieties

2.3. Experimental procedure

Growing season 2017: Seeds were sown manually on April 25. On June 13, 1 kg of fertiliser (NH_4NO_3 + $CaMg(CO_3)_2$) was applied (84.4 kg $N*ha^{-1}$). Rainfall during the growing season was 192.6 mm. The irrigation water amount was 360 mm. Plants were harvested on September 12.

Growing season 2018: Seeds were sown manually on April 25. Rainfall during the growing season was 143.8 mm. Due to technological issues this year, it was not possible to fully utilize effluent water for irrigation, and fertiliser was not applied. The amount of irrigation water was only 60 mm. However, the same irrigation scheme was applied for the rice crop of previous year that resulted especially the higher amount of sodium in the soil of effluent water lysimeters. Plants were harvested on August 22.

Growing season 2019: Seeds were sown manually on April 29. On July 4, 1 kg of fertiliser (NH_4NO_3 + $CaMg(CO_3)_2$) was applied (84.4 kg $N*ha^{-1}$). Rainfall during the growing season was 333.7 mm. The irrigation water amount was 160 mm. Harvesting was organized on September 24.

2.4. Monitoring and data analysis

Rice was harvested by hand. After the implementation of standard post-harvest operations (cleaning, drying, storing), the basic quality tests – Thousand Kernel Weight (TKW), Milling Quality Parameters (MQP), Mineral Content (MC), Gelatinization Temperature (GT), Grain Dimensions (GD) tests were analysed.

Mineral Content (MC) test involves determination of amount basic minerals (Ca, Mg, K, Na, and P) in rice grains and aboveground biomass. Based on standard methods, Ca, Mg, K and Na content were measured by Thermo Scientific Solaar M6 atomic absorption spectrophotometer. Determination of P was done with Thermo Scientific ICAP 6000 ICP-OES inductively coupled plasma atomic emission equipment, according to MSZ EN ISO 11885:2000 international and Hungarian standards.

2.5. Statistical analysis

Basic mathematical analyses were calculated using Microsoft Excel. The collected data were subjected to the analysis of variance (ANOVA) using IBM SPSS Statistics software (version 22.0) for Windows. The significant differences among mean values were determined with the Tukey test at the 0.1%, 1%, 5% levels of probability, respectively. In condition of violation of homogeneity of variances (Levene’s test, $p \leq 0.05$), Games-Howell Post hoc test was set under the terms of the Welch test ($p \leq 0.05$).

3. RESULTS AND DISCUSSIONS

3.1. Analyse of grain weight

The Thousand Kernel Weight (TKW) is an important economic feature that characterizes the quality of the seed. TKW is associated with the size and completeness of the seeds. Large, heavy seeds have a large supply of nutrients, and therefore well-developed plants give a high yield. So, determining TKW allows to evaluate the nutrient reserves in the seeds (Bhattacharya, 2011). Obviously, the larger the grain, the higher TKW. In many cases, the TKW of rice grains in cultivation under flooding conditions is greater than in aerobic rice systems, however, it may vary depending on the rice cultivar (Castaneda et al., 2003; Reddy et al., 2010).

In the first experimental year, the TKW of paddy seed was not effected significantly by treatments at the 0.05 level [$F(3, 12) = 0.80$, $p = 0.52$]. But the ANOVA test showed a statistically significant result in TKW of cargo seeds [$F(3, 12) = 7.69$, $p = 0.004$]. Post hoc comparisons using the Tukey HSD test found that the mean score T_1 irrigation ($M = 18.46$ g) was significantly different than control irrigation ($M = 20.04$ g, $p \leq 0.05$). Neither T_2 nor T_3 irrigations had a significant effect ($p \geq 0.05$) on TKW of cargo seeds. The mean value of T_1 was also significantly lower than T_3 ($M = 20.30$ g, $p \leq 0.05$).

In the second experimental year, after the treatments both the TKW of the paddy and cargo seeds of M 488 was not statistically significant ($p \geq 0.05$) from the values of the control irrigation.

In the third experimental year, as in the second year, significant differences between treatments and control irrigation were not observed ($p \geq 0.05$).

In 2018, the TKW test result of Janka variety was completely different compared to M 488. There was a significant effect on TKW of paddy seeds at the $p \leq 0.05$ level [$F(3, 12) = 8.19$, $p = 0.003$]. Post hoc comparisons test showed that the mean score T_1 ($M = 26.06$ g, $p \leq 0.01$), T_2 ($M = 26.84$ g, $p \leq 0.05$) and T_3 ($M = 26.34$ g, $p \leq 0.01$) was significantly different than T_C irrigation ($M = 28.58$ g).

A statistically significant effect was also noticed in TKW of cargo seeds of Janka, $F(3, 12) = 11.65$, $p = 0.001$. There was a statistically significant difference between control irrigation ($M = 23.07$ g) and T_1 ($M = 20.84$ g, $p \leq 0.01$), T_2 ($M = 20.53$ g, $p \leq 0.001$), T_3 ($M = 21.33$ g, $p \leq 0.05$).

In 2019, the ANOVA test showed a significant results [$F(3, 12) = 18.14$, $p < 0.001$] for TKW of paddy seeds of Janka. Apart from T_1 ($M = 25.98$ g), the effect of irrigation with T_2 ($M = 27.64$ g) and T_3 ($M = 27.51$ g) on the TKW of paddy seeds was statistically similar ($p \geq 0.05$) to the T_C ($M = 28.21$ g). There was a statistically significant difference between T_1 and T_C ($p \leq 0.001$), T_2 ($p \leq 0.05$), T_3 ($p \leq 0.05$).

The similar considerable effect was also noticed on the TKW of cargo seeds which was detected by the ANOVA test [$F(3, 12) = 9.73$, $p = 0.002$]. While there was no statistically significant difference ($p \geq 0.05$) between T_2 ($M = 22.42$ g), T_3 ($M = 22.26$ g) and T_C ($M = 22.72$ g); between T_1 ($M = 21.18$ g, $p \leq 0.01$) and T_C difference was statistically significant. The statistically significant difference was also noted between T_1 ($p \leq 0.05$) and T_2, T_3 irrigation.

Preliminary results indicate that both varieties reacted differently to irrigation treatments over the years. The similarity between the two varieties was that a significant effect led to a decrease in TKW. This situation is more pronounced in the case of Janka.

This kind of TKW loss in some cases indicates that the plants may have experienced stress. In an environment with optimal nutrition, like most plants, rice also responds positively by developing growth parameters (Jahan et al., 2017). According to some researchers, P and N fertilisers in different concentrations play a positive role in increasing TKW (Hasanuzzaman et al., 2012; Yosef Tabar, 2012). On the other hand, despite the rich mineral composition of the wastewater, Kaboosi and Esmailnezhad (2018) reported that they did not notice significant changes in the TKW in their experiment. The similar trend was also observed by Duy Pham et al. (2019) under continuous irrigation with treated wastewater. However, Rahman et al. (2017) have stated that the decline in the yield attributes of rice is the reason for the high percentage of Na that may be present in irrigation water. In our experiments, a decrease in these values can also be explained by the presence of Na in effluent water. Especially, under the conditions of using effluent water without any treatment and dilution had a more explicit effect. The similar outcome of the reduction in TKW also reported by Abdullah et al. (2002). Nevertheless, it should be noted that this decrease is typical particularly for salt-sensitive rice varieties (Chunthaburee et al., 2015). As noted in the experiments, the TKW loss was observed predominantly in Janka rice variety. These results suggest that the notable TKW loss in Janka may be due to its intolerance to saline conditions that occur during effluent water irrigation.

3.2. Head rice recovery

The importance of rice milling is mainly related to the percentage of whole white (polished) rice (Dhankhar et al., 2014). On the one hand, if the value of whole polished rice is connected with the tradition of consumption, on the other hand, it is closely connected with marketing goals (Dela Cruz and Khush, 2000; Kawamura et al., 2018; Zhou et al., 2019). Since the demand in the markets is mainly directed to whole polished rice. In addition, most consumers before buying a product, pay attention not only to the shape of the rice, but also to the colour and aroma of the rice (Rachmat et al., 2006).

In the current experiment, the data obtained at all stages of the rice milling fraction were subjected to statistical analysis. However, since the area of interest is the whole polished rice, the experiments here focused specifically on the percentage of the whole polished rice.

In the first experimental year, in M 488 rice variety treatments did not have a statistically significant effect on the percentage of cargo and polished rice. However, the One-Way ANOVA test found a statistically significant result on the percentage of whole polished rice [$F(3, 12) = 14.85$, $p < 0.001$]. While there was no significant ($p \geq 0.05$) difference between T_2 ($M = 62.00\%$), T_3 ($M = 63.75\%$) and T_C ($M = 61.55\%$), but the difference between T_1 ($M = 57.68\%$) and T_2 ($p \leq 0.05$), T_3 ($p \leq 0.05$), T_C ($p \leq 0.01$) was statistically significant (Table 1).

In the second experimental year (Table 1), all treatments did not make any statistical changes on the percentage of rice milling fraction ($p \geq 0.05$).

In the third experimental year (Table 1), according to the ANOVA test treatments did not cause a statistical change on the percentage of cargo rice [$F(3, 12) = 1.98$, $p = 0.16$] and on the percentage of whole rice [$F(3, 11) = 1.59$, $p = 0.23$], however there was a statistically significant effect on the percentage of whole polished rice [$F(3, 12) = 14.32$, $p < 0.001$]. We have observed a statistically significant difference between treatments and control irrigation, irrigation with T_1 ($M = 60.00\%$, $p \leq 0.05$), T_2 ($M = 61.10\%$, $p \leq 0.01$) and T_3 ($M = 59.12\%$, $p \leq 0.001$) caused a decrease in the average whole polished rice.

Table 1. The milling fraction (in %) of M 488 rice seeds developed with different quality of irrigation

Treatments		***2017***			***2018***			***2019***		
		Cargo	***Polished***	***Whole***	***Cargo***	***Polished***	***Whole***	***Cargo***	***Polished***	***Whole***
T_1	***M***	80.15a	70.00a	57.68a**	78.15a	67.15a	55.90a	79.20a	72.00a	60.00a*
	95% CI	[79.69; 80.61]	[69.41; 70.59]	[54.89; 60.45]	[76.49; 79.80]	[64.89; 69.41]	[52.77; 59.03]	[78.16; 80.24]	[71.12; 72.88]	[54.81; 65.19]
T_2	***M***	80.08a	70.65a	62.00b	79.30a	69.90a	56.95a	78.20a	71.10a	61.10a**
	95% CI	[79.88; 80.28]	[69.59; 71.70]	[60.46; 63.54]	[78.89; 79.71]	[66.76; 73.05]	[53.01; 60.89]	[77.65; 78.76]	[68.72; 73.48]	[58.14; 64.06
T_3	***M***	79.93a	70.05a	63.75b	78.90a	69.18a	57.00a	78.80a	72.80a	59.12a***
	95% CI	[79.77; 80.08]	[69.38; 70.72]	[62.19; 65.30]	[77.51; 80.29]	[65.78; 72.57]	[53.02; 60.98]	[78.19; 79.41]	[72.19; 73.41]	[57.93; 60.31]
T_C	***M***	79.95a	69.58a	61.55b	77.60a	68.70a	55.40a	78.80a	72.90a	68.50b
	95% CI	[79.67; 80.23]	[68.52; 70.63]	[59.22; 63.88]	[72.52; 82.68]	[66.03; 71.37]	[49.36; 61.44]	[77.86; 79.74]	[71.29; 74.51]	[66.92; 70.08]

M - mean. CI - confidence interval (lower and upper bound). The letters represent a significant difference between treatments, values followed by the same letter do not differ significantly from each other at the 0.05 level. *, **, *** *- the mean difference is significant from* T_C *at the 0.05, 0.01 and 0.001 levels, respectively*

In 2018, statistically significant results were detected in the percentage of cargo [$F(3, 12) = 17.75$, $p < 0.001$] and polished rice [$F(3, 12) = 14.21$, $p < 0.001$] of Janka, which indicates notable difference between control irrigation and treatments. There was a significant decrease in the percentage of cargo rice after T_1 ($M = 78.80\%$, $p \leq 0.01$), T_2 ($M = 78.40\%$, $p \leq 0.001$) and T_3 ($M = 79.20\%$, $p \leq 0.01$) irrigation (Table 2). Meanwhile, there was a statistically significant difference ($p \leq 0.05$) between T_2 and T_3. Similarly, except T_3 irrigation ($M = 68.00\%$, $p \geq 0.05$) the percentage of polished rice was also reduced significantly after T_1 ($M = 66.80\%$, $p \leq 0.01$) and T_2 ($M = 64.90\%$, $p \leq 0.001$) irrigation. The decrease under T_2 was statistically ($p \leq 0.05$) lower than T_3 too (Table 2). However, the most important milling parameter remained statistically unchanged and ANOVA result for whole polished rice was $F(3, 12) = 3.14$, $p = 0.07$.

Table 2. The milling fraction (in %) of Janka rice seeds developed with different quality of irrigation

Treatments		***2018***			***2019***		
		Cargo	***Polished***	***Whole***	***Cargo***	***Polished***	***Whole***
T_1	***M***	78.80ab**	66.80ab**	52.70a	77.92a	67.44a	52.08bc
	95% CI	[78.28; 79.32]	[65.86; 67.74]	[49.75; 55.65]	[76.63; 79.21]	[65.56; 69.32]	[46.95; 57.21]
T_2	***M***	78.40a***	64.90a***	53.80a	77.44a	67.20a	42.64a***
	95% CI	[77.50; 79.30]	[61.72; 68.08]	[49.19; 58.40]	[76.77; 78.11]	[66.85; 67.55]	[39.49; 45.79]
T_3	***M***	79.20b**	68.00bc	49.65a	78.64a	68.96a	47.12ab*
	95% CI	[78.75; 79.65]	[66.55; 69.45]	[48.63; 50.67]	[77.81; 79.47]	[67.62; 70.30]	[40.33; 53.91]
T_C	***M***	80.25c	70.60c	51.80a	78.64a	68.80a	56.08c
	95% CI	[79.85; 80.65]	[68.82; 72.38]	[48.79; 54.81]	[76.97; 80.31]	[66.72; 70.88]	[52.04; 60.12]

M - mean. CI - confidence interval (lower and upper bound). The letters represent a significant difference between treatments, values followed by the same letter do not differ significantly from each other at the 0.05 level. *, **, *** *- the mean difference is significant from* T_C *at the 0.05, 0.01 and 0.001 levels, respectively*

In 2019, the effect of irrigation treatments was not statistically significant for the percentage of cargo [$F(3, 12) = 1.91$, $p = 0.17$] and polished rice [$F(3, 12) = 2.60$, $p = 0.09$] of Janka variety. Only, based on statistical analysis, significant differences in whole polished rice percentage were determined [$F(3, 12) = 10.698$, $p < 0.001$]. Irrigation with T_2 and T_3 reduced the percentage of whole polished rice, and there was a statistically significant difference between the control ($M = 56.08$) and T_2 ($M = 42.64\%$, $p \leq 0.001$), T_3 ($M = 47.12\%$, $p \leq 0.05$), and although after T_1 ($M = 52.08\%$) irrigation whole polished rice percentage was lower, but between T_1 and T_C there was a statistically non-significant difference ($p \geq 0.05$) (Table 2). Moreover, between T_1 and T_2 irrigation a statistically significant ($p \leq 0.05$) difference was detected (Table 2).

From the source results, it is clear that both rice varieties reacted differently to the treatments. The main effect of treatments for both M 488 and Janka is related to the loss of whole polished rice percentage. Both varieties faced significant decline after the application of treatments, especially in the last experimental year. Even though the statistical analysis did not show significant changes after T_1 irrigation in Janka, the percentage reduction was evident. Here the decline is related to both severe weather conditions such as heat stress and the chemical composition of the irrigation source.

It should be noted, in general, rice plants cultivated under aerobic conditions is subject to abiotic stresses (Jabran et al., 2017). According to some studies, along with this sensitivity to abiotic factors, a decrease in a number of vital plant parameters is observed (Singh et al., 2012; Kato and Katsura, 2014). Moreover, the water of the intensive fish farm was distinguished by a high total dissolved salt. In itself, this is another disadvantageous situation for plants, because the high salt content in the water does not allow plants to absorb the essential elements they need (Ghosh et al. 2016). The biggest challenge starts with a rise in temperature, which ultimately leads to severe stress (Clermont-Dauphin et al., 2010; Mishra et al., 2015; Ali et al., 2019). The response to salinity of each rice genotype may be different, but an increase in the amount of salinity in irrigation water can drastically affect plants at all stages of growing (Castillo et al., 2007; Fraga et al., 2010; Chang et al. 2019). Thus, these factors led to a decrease in quality of rice seeds.

In particular, during the ripening stage, sudden changes in weather, temperature and precipitation fluctuations at a high level can lead to a decrease in the percentage of whole polished rice (Jin et al., 2005; Nokkoul and Wichitparp, 2014). For instance according to Counce et al. (2005) high temperatures at night above 24 °C can be one of the important reasons for decrease of the whole polished rice percentage. As Rao et al. (2013) reported earlier salinity is another reason for the increase of rice grain breakage. Because salinity also has a direct effect on the protein content of rice grains, where protein loss can increase the rice seed breakage (Leesawatwong et al., 2004; Balindong et al., 2018). Moreover, the decrease in protein content in salt-sensitive rice varieties is observed more distinctly (Billah et al., 2017).

3.3. The size of rice grains

For three years of research, seed size was also investigated. The parameters to consider here were the length, width and L/W ratio of the seeds.

Table 3. The size (mm) of paddy seeds of M 488 rice developed with different quality of irrigation

Treatments		***2017***		***2018***		***2019***	
		Length	***Width***	***Length***	***Width***	***Length***	***Width***
T_1	***M***	$7.95a^{***}$	3.17a	$8.01a^{***}$	3.11b	8.19b	$3.07a^{**}$
	95% CI	[7.90; 7.99]	[3.15; 3.19]	[7.97; 8.05]	[3.09; 3.13]	[8.15; 8.22]	[3.05; 3.09]
T_2	***M***	$7.92a^{***}$	3.16a	$8.02a^{***}$	3.12b	$8.04a^{***}$	3.12bc
	95% CI	[7.87; 7.96]	[3.14; 3.18]	[7.98; 8.06]	[3.09; 3.15]	[8.00; 8.08]	[3.09; 3.14]
T_3	***M***	$7.89a^{***}$	3.21b	8.13b	$3.09a^{**}$	8.19b	$3.08ab^{*}$
	95% CI	[7.85; 7.93]	[3.19; 3.23]	[8.09; 8.17]	[3.07; 3.11]	[8.16; 8.24]	[3.06; 3.11]
T_C	***M***	8.10b	3.19ab	8.15b	3.14b	8.15b	3.13c
	95% CI	[8.06; 8.14]	[3.17; 3.22]	[8.11; 8.19]	[3.12; 3.16]	[8.11; 8.19]	[3.10; 3.15]

M - mean. CI - confidence interval (lower and upper bound). The letters represent a significant difference between treatments, values followed by the same letter do not differ significantly from each other at the 0.05 level. *, **, *** *- the mean difference is significant from* T_C *at the 0.05, 0.01 and 0.001 levels, respectively*

In the first experimental year, there was a significant effect of treatments on length of M 488 rice paddy seeds which was detected by the One-Way ANOVA test [$F(3, 1585) = 18.73$, $p < 0.001$]. The significant reduction of seed length was observed (Table 3) after the irrigation with T_1 ($M = 7.95$ mm, $p \leq 0.001$), T_2 ($M = 7.92$ mm, $p \leq 0.001$) and T_3 ($M = 7.89$ mm, $p \leq 0.001$). In the case of rice width, irrigation treatments did not cause significant changes compared to the T_C irrigation. However, there was a statistically significant ($p \leq 0.05$) difference between T_3 ($M = 3.21$ mm) and T_1 ($M = 3.17$ mm), T_2 ($M = 3.16$ mm).

In the second experimental year, the ANOVA test yielded a significant effect of treatments on seed length of M 488 [$F(3, 1573) = 12.97$, $p < 0.001$]. The average length of seeds decreased after the irrigation with T_1, T_2. While the difference between T_C ($M = 8.15$ mm) and T_1 ($M = 8.01$ mm, $p \leq 0.001$), T_2 ($M = 8.02$ mm, $p \leq 0.001$) was statistically significant, but between T_C and T_3 ($M = 8.13$ mm, $p \geq 0.05$) there was not any statistically significant differences (Table 3). In addition, between T_3 and T_1, T_2 irrigation there was a statistically significant ($p \leq 0.05$) difference too (Table 3). A statistically significant difference was found when analysing the seed width [$F(3, 1557) = 3.62$, $p = 0.01$]. Only T_3 ($M = 3.09$ mm, $p \leq 0.01$) reduced significantly the width of seeds, other treatments (T_1, T_2) had a statistically similar result ($p \geq 0.05$) with the control irrigation ($M = 3.14$ mm), despite the fact that the width of seeds was also low (Table 3), moreover the mean value after T_3 was also statistically lower than T_1, T_2.

In the third experimental year, a statistically significant effect of ANOVA test for M 488 seed length was in the following order: $F(3, 1572) = 15.84$, $p < 0.001$. Unlike T_2 irrigation ($M = 8.04$ mm, $p \leq 0.001$), other treatments (Table 3) showed statistically similar ($p \geq 0.05$) result to T_C ($M = 8.15$ mm). The average length of seeds after T_2 was also statistically ($p \leq 0.05$) lower than T_1 ($M = 8.19$ mm) and T_3 ($M = 8.19$ mm). The ANOVA results of seed width was also significant [$F(3, 1541) = 15.84$, $p = 0.001$]. There was a statistically significant difference not only between T_1 ($M = 3.07$ mm, $p \leq 0.01$), T_3 ($M = 3.08$ mm, $p \leq 0.05$) and T_C ($M = 3.13$ mm), but also between T_1 and T_2 ($M = 3.12$, $p \leq 0.05$) (Table 3).

In 2018, based on statistical analysis significant results were obtained in length of Janka rice paddy seeds [$F(3, 1581) = 17.58$, $p < 0.001$]. The length of seeds (Table 4) significantly reduced in case of T_1 ($M = 9.27$ mm, $p \leq 0.001$) and T_3 ($M = 9.26$ mm, $p \leq 0.001$) irrigation, only the result of irrigation with T_2 ($M = 9.47$ mm, $p \geq 0.05$) was statistically similar to control method ($M = 9.46$ mm). However, under T_2 irrigation the average length was statistically higher than T_1 and T_3 (Table 4). Meanwhile, all treatments had a negative impact on width of seeds. The ANOVA test showed a statistically significant result in seed width [$F(3, 1573) = 27.39$, $p < 0.001$]. The average seed width was 2.85 mm ($p \leq 0.001$), 2.87 mm ($p \leq 0.001$), 2.87 mm ($p \leq 0.001$) and 2.99 mm for T_1, T_2, T_3 and T_C, respectively (Table 4).

Table 4. The size (mm) of paddy seeds of Janka rice developed with different quality of irrigation

Treatments		***2018***		***2019***	
		Length	***Width***	***Length***	***Width***
T_1	***M***	$9.27a^{***}$	$2.85a^{***}$	$9.49a^{***}$	$2.93ab^{*}$
	95% CI	[9.22; 9.33]	[2.83; 2.87]	[9.44; 9.54]	[2.91; 2.96]
T_2	***M***	9.47b	$2.87a^{***}$	$9.68b^{*}$	$2.89a^{***}$
	95% CI	[9.42; 9.53]	[2.84; 2.89]	[9.63; 9.73]	[2.87; 2.92]
T_3	***M***	$9.26a^{***}$	$2.87a^{***}$	$9.64b^{***}$	2.94bc
	95% CI	[9.19; 9.31]	[2.85; 2.89]	[9.59; 9.68]	[2.92; 2.96]
T_C	***M***	9.46b	2.99b	9.78c	2.99c
	95% CI	[9.41; 9.51]	[2.97; 3.01]	[9.74; 9.83]	[2.96; 3.01]

M - mean. CI - confidence interval (lower and upper bound). The letters represent a significant difference between treatments, values followed by the same letter do not differ significantly from each other at the 0.05 level. *, **, *** *- the mean difference is significant at the 0.05, 0.01 and 0.001 levels, respectively*

In 2019, analyses showed a significant reduction of length after the irrigation with treatments [$F(3, 1578) = 24.01$, $p < 0.001$]. Post hoc test (Table 4) indicated that the grain length was statistically lower after the irrigation with T_1 ($M = 9.49$ mm, $p \leq 0.001$), T_2 ($M = 9.68$ mm, $p \leq 0.05$) and T_3 ($M = 9.64$ mm, $p \leq 0.001$). The decrease after T_1 was statistically significant ($p \leq 0.05$) than T_2 and T_3. The One-Way ANOVA test displayed that grain width of Janka rice was also affected by irrigation [$F(3, 1586) = 8.38$, $p < 0.001$]. The average grain width after T_1 ($M = 2.93$ mm, $p \leq 0.05$) and T_2 ($M = 2.89$ mm, $p \leq 0.001$) irrigation was significantly lower compared to control irrigation ($M = 2.99$ mm). The effect of T_3 (M = 2.94 mm) irrigation on grain width was insignificant (p = 0.051). Meanwhile, the mean value of T_3 was statistically ($p \leq 0.05$) higher than T_2 irrigation.

Table 5 shows L/W ratio for M 488 and Janka paddy seeds. The role of treatments in the grain ratio was estimated based on the relationship between the average length and the average width of the grains, detected earlier in the course of statistical analysis. The ratio is calculated by simply dividing the mean length by the mean width, and was not subjected to statistical analysis.

In the first year of experiment, treatment showed a decreasing result in ratio. The L/W ratio of M 488 was 2.51, 2.51, 2.46 and 2.54 for T_1, T_2, T_3 and T_C, respectively (Table 5). In the second year of experiment, except T_3 (2.63) irrigation, under T_1 (2.58), T_2 (2.57) L/W ratio of M 488 was lower than T_C (2.60). Meanwhile, in the same year, the ratio of Janka under T_1 (3.25), T_2 (3.30), and T_3 (3.23) was greater than T_C (3.16). In the third year of experiment, the ratio of M 488 only after T_2 irrigation (2.58) was lower than control (2.60), but after T_1 (2.67) and T_3 (2.66) ratio was higher. This year, for Janka only under T_1 (3.24) the ratio was lower than control irrigation (3.27), under other treatments (T_2 = 3.35; T_3 = 3.28) was bigger.

Table 5. The paddy seed L/W ratio of M 488 and Janka rice developed with different quality of irrigation

Treatments	***M 488***			***Janka***	
	2017	***2018***	***2019***	***2018***	***2019***
T_1	2.51	2.58	2.67	3.25	3.24
T_2	2.51	2.57	2.58	3.30	3.35
T_3	2.46	2.63	2.66	3.23	3.28
T_C	2.54	2.60	2.60	3.16	3.27

In general, over the years of the experiment, different results of the ratio were obtained depending on the length and width. The above results show that significant changes in size parameters also affected seed ratio in both varieties. Especially, a significant decrease in width led to a change in L/W ratio. During the experiments, as a rule, both low and high seed ratio were observed. However, here, the high grain ratio is mainly associated with a significant decrease of grain width.

Once again it can also be verified that the composition of water plays an important role in this analysis. An interesting nuance was that all treatments did not affect either the length or width of the seeds at the same level. On the contrary, at least one of the factors investigated was adversely affected after irrigation with treatments. This case was observed in both M 488 and Janka varieties. Apparently, along with other parameters due to a stressful condition, the grain dimensions encountered to negative changes.

As Khatun et al. (1995) previously reported, salinization slows down the flowering phase of rice, having a major impact on seed formation. According to study of Fabre et al. (2005) the stressful condition created by high salinity one of the main reason of the reduced paddy seed size. Under stress, the plant faces difficulties during the growing season, which ultimately affects the seeds. Despite its nutrient content, the high total dissolved salt content of the effluent water was a critical factor affecting grain dimension. Saline conditions are dangerous even for salt tolerant rice genotypes (Rao et al., 2013).

3.4. Cooking quality of rice

In this experiment GT was measured with alkali spreading value method. Then the results were compared on the basis of a seven-point scale of the degree of spreading of grains (Little et al., 1958).

Within three experimental years, all samples of both rice varieties (M 488 and Janka) from every treatments gave similar result. The obtained results showed that grains from each rice variety irrigated by treatments and the control method were exposed to the solution. All results correspond to the third scale: grain swollen, collar incomplete and narrow. This result indicates a high intermediate temperature of rice gelatinization.

High intermediate GT is very common among rice genotypes (Székely et al., 2018). In this experiment, none of the irrigation treatments have been able to change this characteristic disposition for either M 488 or Janka, which shows there was not any difference between control and treatments. However, a distinctive feature of a high intermediate GT rice grain is that it takes a lot of time and water to prepare it (Pang et al., 2016).

3.5. Mineral uptake of rice

3.5.1. Mineral Content (MC) of aboveground biomass of rice

In the first experimental year, the ANOVA test showed significant result on Ca absorption of M 488 rice variety [$F(3, 12) = 5.33$, $p = 0.01$]. However, only between T_2 (M = 4967 mg*kg^{-1}, $p \leq 0.01$) and T_C (M = 3527 mg*kg^{-1}) we have observed a statistically significant difference (Table 6), the increase in T_1 (M = 4092 mg*kg^{-1}, $p \geq 0.05$) and T_3 (M = 4055 mg*kg^{-1}, $p \geq 0.05$) irrigation was not significant compared to T_C.

Table 6. Average (n = 4) MC (mg*kg^{-1}) in aboveground biomass of M 488 rice variety developed with different quality of irrigation, 2017

Treatments		***2017***				
		Ca	***Mg***	***P***	***K***	***Na***
T_1	***M***	4092ab	2902a	1575a*	10795a	1155c***
	95% CI	[3086; 5098]	[2393; 3411]	[1413; 1736]	[9504; 12085]	[1035; 1274]
T_2	***M***	4967b**	3035a	1445a**	10180a	1057c***
	95% CI	[4101; 5833]	[2822; 3247]	[1204; 1907]	[9044; 11315]	[1027; 1087]
T_3	***M***	4055ab	2770a	1675ab	10372a	685b**
	95% CI	[3318; 4791]	[2523; 3016]	[1442; 1907]	[9260; 11484]	[636; 735]
T_C	***M***	3527a	2635a	2027b	10900a	404a
	95% CI	[2894; 4160]	[2441; 2828]	[1603; 2451]	[9933; 11866]	[277; 530]

M - mean. CI - confidence interval (lower and upper bound). The letters represent a significant difference between treatments, values followed by the same letter do not differ significantly from each other at the 0.05 level. *, **, *** *- the mean difference is significant from* T_C *at the 0.05, 0.01 and 0.001 levels, respectively*

According to the statistical analysis neither the amount of Mg [*F*(3, 12) = 2.98, $p = 0.07$], nor K [*F*(3, 12) = 0.92, $p = 0.46$] in aboveground biomass of M 488 was statistically affected by treatments. However, a notable change was observed (Table 6) in case of Mg content after T_2 irrigation (M = 3035 mg*kg^{-1}, $p = 0.06$) compared to the control method. The ANOVA test showed a significant effect on P content of rice aboveground biomass [*F*(3, 12) = 7.94, $p = 0.003$]. Despite the high percentage of P in effluent water, the amount of P (Table 6) was statistically lower after the irrigation with T_1 (M = 1575 mg*kg^{-1}, $p \leq 0.05$) and T_2 (M = 1445 mg*kg^{-1}, $p \leq 0.01$).

Table 7. Average (n = 4) MC (mg*kg^{-1}) in aboveground biomass of M 488 rice variety developed with different quality of irrigation, 2018

Treatments		***2018***				
		Ca	***Mg***	***P***	***K***	***Na***
T_1	***M***	2455a	2180a	2242a	14057a	1006b**
	95% CI	[1816; 3093]	[1791; 2568]	[1595; 2889]	[9663; 18451]	[673; 1338]
T_2	***M***	2432a	1890a	2382a	11892a	885b**
	95% CI	[1726; 3139]	[1573; 2206]	[2026; 2738]	[9507; 14277]	[553; 1217]
T_3	***M***	2825a	2212a	2100a	13186a	982b**
	95% CI	[2164; 3486]	[1748; 2676]	[1829; 2370]	[10106; 16266]	[708; 1256]
T_C	***M***	2655a	2217a	2605a	11817a	344a
	95% CI	[1674; 3635]	[1857; 2577]	[1929; 3280]	[8510; 15124]	[256; 432]

M - mean. CI - confidence interval (lower and upper bound). The letters represent a significant difference between treatments, values followed by the same letter do not differ significantly from each other at the 0.05 level. *, **, *** *- the mean difference is significant from T_C at the 0.05, 0.01 and 0.001 levels, respectively*

The largest changes were recorded in the amount of Na. The result of the One-Way ANOVA test was in following order: *F*(3, 12) = 143.91, $p < 0.001$. After the irrigation with T_1 (M = 1155 mg*kg^{-1}, $p \leq 0.001$), T_2 (M = 1057 mg*kg^{-1}, $p \leq 0.001$) and T_3 (M = 685 mg*kg^{-1}, $p \leq 0.01$) amount of Na in aboveground biomass of M 488 has increased (Table 6). The increase under T_1, T_2 was also statistically ($p \leq 0.05$) higher than T_3.

In the second experimental year, compared to the previous year the amount of Ca [$F(3, 12) = 0.60$, $p = 0.63$], Mg [$F(3, 11) = 1.87$, $p = 0.19$], P [$F(3, 12) = 1.75$, $p = 0.21$] and K [$F(3, 11) = 1.11$, $p = 0.39$] has remained statistically unchanged. Despite the non-statistical difference, after all treatments a low level of P in the aboveground biomass of M 488 was noticed (Table 7). Moreover, as a result of T_1 ($M = 14057$ mg*kg^{-1}) and T_3 ($M = 13186$ mg*kg^{-1}), the amount of K (Table 7) was noticeably higher than T_C ($M = 11817$ mg*kg^{-1}).

Table 8. Average (n = 4) MC (mg*kg^{-1}) in aboveground biomass of M 488 rice variety developed with different quality of irrigation, 2019

Treatments		***2019***				
		Ca	***Mg***	***P***	***K***	***Na***
T_1	***M***	4872c***	2285a	1970b	7095c***	352c**
	95% CI	[4689; 5055]	[2084; 2485]	[1571; 2368]	[6784; 7405]	[187; 516]
T_2	***M***	3792a	2602b***	1797ab	7260c***	355c**
	95% CI	[3746; 3838]	[2301; 2903]	[1662; 1932];	[6949; 7570]	[232; 478]
T_3	***M***	4035b	2160a	1495a	5187b**	184b*
	95% CI	[3942; 4127]	[1974; 2345]	[1362; 1627]	[4799; 5575]	[162; 206]
T_C	***M***	3867ab	2067a	1785ab	3712a	131a
	95% CI	[3696; 4039]	[1993; 2141]	[1437; 2132]	[3173; 4251]	[108; 154]

M - mean. CI - confidence interval (lower and upper bound). The letters represent a significant difference between treatments, values followed by the same letter do not differ significantly from each other at the 0.05 level. *, **, *** *- the mean difference is significant from* T_C *at the 0.05, 0.01 and 0.001 levels, respectively*

Like last year the amount of Na in aboveground biomass is also increased, at which these indicators were statistically significant compared to the control method [$F(3, 12) = 12.92$, $p < 0.001$]. The average Na was 1006 mg*kg^{-1}, 885 mg*kg^{-1}, 982 mg*kg^{-1}, and 344 mg*kg^{-1} for T_1, T_2, T_3, and T_C irrigation, respectively (Table 7).

In the third experimental year, the outcome of ANOVA test for Ca content of aboveground biomass content of M 488 was in the following order: [$F(3, 12) = 136.68$, $p < 0.001$]. Only T_1 irrigation ($M = 4872$ mg*kg^{-1}, $p \leq 0.001$) had a statistically significant effect on Ca level (Table 8). Meanwhile, there was a statistically significant difference ($p \leq 0.05$) between T_1 and T_2; T_1 and T_3; T_2 and T_3. The analysis of Mg content also showed significant result [$F(3, 12) = 12.94$, $p < 0.001$]. Although, there was a statistical difference only between T_2 ($M = 2602$ mg*kg^{-1}, $p \leq 0.001$) and T_C ($M = 2067$ mg*kg^{-1}), but T_1 ($M = 2285$ mg*kg^{-1}) and T_3 ($M = 2160$ mg*kg^{-1}) also had visible changes on Mg content (Table 8). The outcome of statistical analysis also showed a significant difference between T_2 and T_1, T_3. The ANOVA test showed a statistical significance in P content analysis [$F(3, 12) = 4.98$, $p = 0.02$]. However, there was a statistically significant ($p \leq 0.05$) difference only between T_1 ($M = 1970$ mg*kg^{-1}) and T_3 ($M = 1495$ mg*kg^{-1}) irrigation (Table 8). This year, all treatment led to a considerable increase in the content of K [$F(3, 12) = 181.85$, $p < 0.001$] and Na [$F(3, 12) = 12.43$, $p = 0.001$] in the aboveground biomass of M 488. The average K (Table 8) was 7095 mg*kg^{-1}, 7260 mg*kg^{-1}, 5187 mg*kg^{-1}, and 3712 mg*kg^{-1} for T_1, T_2, T_3, and T_C irrigation, respectively. The average Na (Table 8) was 352 mg*kg^{-1}, 355 mg*kg^{-1}, 184 mg*kg^{-1}, and 131 mg*kg^{-1}for T_1, T_2, T_3, and T_C irrigation, respectively. In addition, both in K and Na content after T_1 and T_2 irrigation the difference was statistically significant ($p \leq 0.05$) than T_3 too (Table 8).

In the first experimental year (Table 9), after the T_1, T_2 and T_3 irrigation, visible changes in the amount of Ca [$F(3, 12) = 4.278$, $p = 0.003$], Mg [$F(3, 12) = 2.05$, $p = 0.16$], K [$F(3, 12) = 1.79$, $p = 0.20$] of aboveground biomass of Janka rice variety is also noted, but these changes were not statistically significant compared to the control irrigation. Only, in Ca content there was a statistically significant difference ($p \leq 0.05$) between T_2 and T_3 irrigation (Table 9). As with M 488, there was no increase in P [$F(3, 12) = 16.29$, $p < 0.001$] in aboveground biomass of Janka, although treatments contained high levels of P. The average P was 1500 mg*kg^{-1} and 2097 mg*kg^{-1} for T_1 ($p \leq 0.01$) and T_C irrigation, respectively (Table 9). Under the T_2 irrigation ($M = 1595$ mg*kg^{-1}), the P content in Janka was lower, but there was no statistical ($p = 0.07$) difference. Meanwhile, the average P after T_1 was also statistically ($p \leq 0.05$) lower than T_3 (Table 9). Na content was also influenced by irrigation treatments [$F(3, 12) = 30.255$, $p < 0.001$]. Here, the amount of Na in aboveground biomass of Janka increased as a result of irrigation with T_1 ($M = 1062$ mg*kg^{-1}, $p \leq 0.001$) and T_2 ($M = 967$ mg*kg^{-1}, $p \leq 0.05$), only the application of the T_3 ($M = 528$ mg*kg^{-1}, $p \geq 0.05$) irrigation gave a statistically similar result with T_C ($M = 361$ mg*kg^{-1}). But the effect of T_1 and T_2 irrigation was statistically higher than T_3 (Table 9).

Table 9. Average (n = 4) MC (mg*kg^{-1}) in aboveground biomass of Janka rice variety developed with different quality of irrigation, 2017

Treatments		***2017***				
		Ca ***mg/kg dry matter***	***Mg*** ***mg/kg dry matter***	***P*** ***mg/kg dry matter***	***K*** ***mg/kg dry matter***	***Na*** ***mg/kg dry matter***
T_1	***M***	3782ab	2940a	1500a**	10587a	1062b***
	95% CI	[3102; 4462]	[2655; 3224]	[1388; 1611]	[9427; 11747]	[944; 1130]
T_2	***M***	4335b	2852a	1595ab	10277a	967b*
	95% CI	[3616; 5043]	[2475; 3229]	[1186; 2003];	[9125; 11429]	[622; 1312]
T_3	***M***	3380a	2587a	2045b	11205a	528a
	95% CI	[2939; 3820]	[2456; 2718]	[1983; 2016]	[10547; 11862]	[370; 685]
T_C	***M***	3587ab	2652a	2097b	11802a	361a
	95% CI	[2927; 4247]	[2103; 3201]	[1875; 2319]	[9111; 14493]	[290; 432]

M - mean. CI - confidence interval (lower and upper bound). The letters represent a significant difference between treatments, values followed by the same letter do not differ significantly from each other at the 0.05 level. *, **, *** - the mean difference is significant from T_C at the 0.05, 0.01 and 0.001 levels, respectively

In the second experimental year, the amount of Ca [$F(3, 12) = 1.72$, $p = 0.22$], Mg [$F(3, 12) = 1.48$, $p = 0.27$], and P [$F(3, 12) = 1.45$, $p = 0.28$] did not change statistically after the irrigation with treatments (Table 10), their amount after the irrigation with T_1, T_2 and T_3 was statistically similar to control irrigation. Meanwhile, there was a statistical ANOVA result of K content [$F(3, 12) = 8.72$, $p = 0.002$]. An increase in the amount of K (Table 10) in aboveground biomass of Janka was noted after T$_1$ irrigation (M = 13392 mg*kg^{-1}), and this increase was not only significant than control irrigation ($p \leq 0.01$), but also than T$_3$. The absorption of Na by Janka like in M 488 was also higher after irrigation with T$_1$, T$_2$ and T$_3$ [$F(3, 12) = 31.52$, $p < 0.001$]. There was a statistically significant difference (Table 10) between control irrigation (M = 395 mg*kg^{-1}) and T$_1$ (M = 1051 mg*kg^{-1}, $p \leq 0.001$), T$_2$ (M = 884 mg*kg^{-1}, $p \leq 0.001$), T$_3$ (M = 776 mg*kg^{-1}, $p \leq 0.01$). Moreover, there was also a statistically significant ($p \leq 0.05$) difference between T$_1$ and T$_3$.

Table 10. Average (n = 4) MC (mg*kg^{-1}) in aboveground biomass of Janka rice variety developed with different quality of irrigation, 2018

Treatments		***2018***				
		Ca	***Mg***	***P***	***K***	***Na***
T$_1$	***M***	2297a	2437a	2472a	13392b**	1051c***
	95% CI	[1943; 2651]	[1926; 2948]	[2295; 2649]	[12443; 14341]	[918; 1184]
T$_2$	***M***	2727a	2362a	2187a	11535ab	884bc***
	95% CI	[2034; 3420]	2047; 2677]	[1772; 2602]	[9316; 13754]	[628; 1139]
T$_3$	***M***	2410a	2145a	2217a	10567a	776b**
	95% CI	[2101; 2718]	[1816; 2473]	[1774; 2660]	[9754; 11380]	[711; 840]
T$_C$	***M***	2715a	2135a	2277a	10002a	395a
	95% CI	[2072; 3357]	[1714; 2555]	[2032; 2522]	[8055; 11949]	[284; 506]

M - mean. CI - confidence interval (lower and upper bound). The letters represent a significant difference between treatments, values followed by the same letter do not differ significantly from each other at the 0.05 level. *, **, *** *- the mean difference is significant from T$_C$ at the 0.05, 0.01 and 0.001 levels, respectively*

In the third experimental year, there was a significant effect of treatments on Ca content of aboveground biomass of Janka [$F(3, 12) = 58.78$, $p < 0.001$]. Post hoc comparisons test showed (Table

11) that the mean score T_1 (M = 4512 mg*kg^{-1}, $p \leq 0.001$), T_2 (M = 4965 mg*kg^{-1}, $p \leq 0.001$) and T_3 (M = 4505 mg*kg^{-1}, $p \leq 0.01$) irrigation was significantly different than control irrigation (M = 4230 mg*kg^{-1}). The average Ca content after T_2 was also significantly ($p \leq 0.05$) higher than T_1 and T_3.

Table 11. Average (n = 4) MC (mg*kg^{-1}) in aboveground biomass of Janka rice variety developed with different quality of irrigation, 2019

Treatments		***2019***				
		Ca	***Mg***	***P***	***K***	***Na***
T_1	***M***	4512b**	2336a	1450b**	3652a***	249b**
	95% CI	[4407; 4617]	[1264; 3408]	[1296; 1603]	[3228; 4076]	[185; 313]
T_2	***M***	4965c***	2567a	1470b**	4907b***	197a
	95% CI	[4786; 5143]	[2309; 2825]	[1306; 1633];	[4028; 5786]	[168; 226]
T_3	***M***	4505b**	2590a	1925c***	4687b***	285b**
	95% CI	[4484; 4525]	[2517; 2662]	[1811; 2038]	[4576; 4798]	[259; 310]
T_C	***M***	4230a	2375a	1142a	6940c	165a
	95% CI	[4086; 4373]	[2327; 2422]	[1040; 1244]	[6260; 7619]	[152; 179]

M - mean. CI - confidence interval (lower and upper bound). The letters represent a significant difference between treatments, values followed by the same letter do not differ significantly from each other at the 0.05 level. *, **, *** *- the mean difference is significant from* T_C *at the 0.05, 0.01 and 0.001 levels, respectively*

Like Ca, P content of Janka aboveground biomass also increased significantly after treatments [$F(3, 12) = 57.09$, $p < 0.001$]. The average P content (Table 11) was 1450 mg*kg^{-1}, 1470 mg*kg^{-1}, 1925 mg*kg^{-1} and 1142 mg*kg^{-1} for T_1 ($p \leq 0.01$), T_2 ($p \leq 0.01$), T_3 ($p \leq 0.001$) and T_C irrigation. Moreover, the increase after T_3 was statistically ($p \leq 0.05$) higher than T_1 and T_2 too. The ANOVA test result for K content was in the following order: $F(3, 12) = 53.75$, $p < 0.001$. After the T_1 (M = 3652 mg*kg^{-1}, $p \leq 0.001$), T_2 (M = 4907 mg*kg^{-1}, $p \leq 0.001$) and T_3 (M = 4687 mg*kg^{-1}, $p \leq 0.001$) irrigation K content in the aboveground biomass of the Janka variety greatly reduced (Table 11). The mean value of K under T_1 was statistically ($p \leq 0.05$) lower than T_2 and T_3. The ANOVA test did not show significant result for Mg content [$F(3, 11) = 1.47$, $p = 0.28$], despite after the T_2 ($M = 2567$ mg*kg^{-1}) and T_3 ($M = 2590$ mg*kg^{-1}) irrigation the average Mg content (Table 11) was higher than control ($M = 2375$ mg*kg^{-1}). Another important result was recorded in the amount of Na [$F(3, 12) = 10.90$, $p = 0.001$]. While between control ($M = 165$ mg*kg^{-1}) and T_1 ($M = 249$ mg*kg^{-1}, $p \leq 0.01$), T_3 ($M = 285$ mg*kg^{-1}, $p \leq 0.01$) difference was statistically significant, but between T_2 ($M = 197$ mg*kg^{-1}, $p \geq 0.05$) statistically similar (Table 11). However, after T_2 irrigation the average Na content was much higher.

Although the levels of minerals in varieties differ depending on the amount of irrigation and environmental conditions in different experimental years, the main nuance that attracted attention was the increase in the amount of sodium in aboveground biomass. If one of the reasons for this is the high amount of Na in the treatments, then the other reason is that the mechanism for the supply of other elements in plants is very different from the supply mechanism of Na (Ochiai and Matoh, 2002; Goel et al., 2011; Tanoi et al., 2011; Yang et al., 2014; Sasaki et al., 2016; Kant et al., 2018). The plant protection system allows rice to avoid the accumulation of Na in the reproductive organs as much as possible, however, depending on the amount of this toxic element, it settles mainly in the vegetative organs (Marschner, 1995; Asch et al., 1999; Reddy et al., 2017). Moreover, according to some research given the stress levels caused by salinity, this can limit the absorption and uptake of other important minerals in the rice plant (Hussain et al., 2017; Razzaq et al., 2020), which has also been found in the current study. Apparently, in the current experiment the presence of sodium in the irrigation water created an imbalance in nutrition, which affected the disproportionate accumulation of other elements in the aboveground biomass of genotypes. The overall end result of three years of experience shows that irrigation treatments has affected the mineral composition of aboveground biomass of both genotypes.

3.5.2. Mineral Content (MC) of rice seeds

In 2018, based on statistical analysis, significant differences in Ca content in M 488 seeds were determined [$F(3, 12) = 19.57$, $p < 0.001$]. There was a statistically ($p \leq 0.05$) significant difference between T_1 ($M = 479$ mg*kg^{-1}), T_3 ($M = 521$ mg*kg^{-1}) and T_C ($M = 603$ mg*kg^{-1}); T_1, T_3 and T_2 (M

= 627 mg*kg^{-1}) irrigation (Table 12). The P content of seeds significantly declined [$F(3, 12) = 16.12$, $p < 0.001$]. The P content was 3867 mg*kg^{-1} ($p \leq 0.001$), 4102 mg*kg^{-1} ($p \leq 0.05$), 4120 mg*kg^{-1} ($p \leq 0.05$) and 4325 mg*kg^{-1} for T_1, T_2, T_3 and T_C, respectively (Table 12). After the T_1 the P content was significantly lower ($p \leq 0.05$) than T_2 and T_3 (Table 12).

Table 12. Average (n = 4) MC (mg*kg^{-1}) in seeds of M 488 rice variety developed with different quality of irrigation, 2018

Treatments		***2018***				
		Ca	***Mg***	***P***	***K***	***Na***
T_1	***M***	479a**	1572a**	3867a***	3300a*	146b***
	95% CI	[442; 515]	[1518; 1626]	[3681; 4053]	[3159; 3440]	[111; 180]
T_2	***M***	627b	1710b	4102b*	3472ab	128b**
	95% CI	[564; 690]	[1630; 1789]	[3984; 4220];	[3290; 3654]	[118; 139]
T_3	***M***	521a*	1652ab	4120b*	3227a**	125b*
	95% CI	[457; 586]	[1591; 1713]	[3972; 4267]	[3069; 3385]	[116; 134]
T_C	***M***	603b	1745b	4325c	3600b	92a
	95% CI	[580; 626]	[1656; 1833]	[4191; 4458]	[3329; 3870]	[82; 101]

M - mean. CI - confidence interval (lower and upper bound). The letters represent a significant difference between treatments, values followed by the same letter do not differ significantly from each other at the 0.05 level. *, **, *** *- the mean difference is significant from* T_C *at the 0.05, 0.01 and 0.001 levels, respectively*

The Mg content was also had a significant ANOVA result [$F(3, 12) = 11.06$, $p = 0.001$]. Although after the T_2 ($M = 1710$ mg*kg^{-1}, $p \geq 0.05$) and T_3 ($M = 1652$ mg*kg^{-1}, $p \geq 0.05$) irrigation the average Mg content (Table 12) in the M 488 rice seeds remains statistically unchanged, but a statistically significant decrease was noted after the T_1 ($M = 1572$ mg*kg^{-1}, $p \leq 0.01$) irrigation. Moreover, this result was also statistically ($p \leq 0.05$) lower than T_2. The ANOVA result of K content was in the following order: $F(3, 12) = 7.61$, $p = 0.004$. There was a statistically significant decline of K content

(Table 12) after T_1 (*M* = 3300 mg*kg^{-1}, $p \leq 0.05$) and T_3 (*M* = 3227 mg*kg^{-1}, $p \leq 0.01$). The result of K after T_3 (*M* = 3472 mg*kg^{-1}) was also low, but it was statistically similar to control irrigation (*M* = 3600 mg*kg^{-1}). The significant changes were also found in the content of Na [$F(3, 12) = 13.76$, $p < 0.001$]. The Na content (Table 12) of the M 488 rice seeds increased significantly after irrigation with the T_1 (*M* = 146 mg*kg^{-1}, $p \leq 0.001$), T_2 (*M* = 128 mg*kg^{-1}, $p \leq 0.01$) and T_3 (*M* = 125 mg*kg^{-1}, $p \leq 0.05$). It should be noted, all minerals faced some reduction, except Na, especially under T_1 irrigation.

Table 13. Average (n = 4) MC (mg*kg^{-1}) in seeds of M 488 rice variety developed with different quality of irrigation, 2019

Treatments		***2019***				
		Ca	***Mg***	***P***	***K***	***Na***
T_1	***M***	397a	1653b	4240b	3600b	200a
	95% CI	[307; 486]	[1573; 1732]	[3955; 4526]	[3328; 3872]	[165; 235]
T_2	***M***	413a	1718b	4490b	3808b	211a
	95% CI	[338; 487]	[1657; 1778]	[4267; 4713]	[3469; 4145]	[181; 242]
T_3	***M***	421a	1405a	3440a**	3005a**	227a
	95% CI	[362; 480]	[1365; 1445]	[3294; 3586]	[2808; 3202]	[208; 245]
T_C	***M***	428a	1650ab	4298b	3665b	201a
	95% CI	[369; 486]	[1419; 1881]	[3469; 5125]	[3218; 4112]	[183; 219]

M - mean. CI - confidence interval (lower and upper bound). The letters represent a significant difference between treatments, values followed by the same letter do not differ significantly from each other at the 0.05 level. ** *- the mean difference is significant from T_C at the 0.05 level*

In 2019, the ANOVA test did not show a statistical result in Ca [$F(3, 12) = 0.36$, $p = 0.78$] and Na [$F(3, 12) = 2.21$, $p = 0.14$] content. While the ANOVA test found statistically significant result in Mg [$F(3, 12) = 11.88$, $p = 0.001$] content, but none of the treatments was significantly different from control irrigation (Table 13). On the contrary, there was a statistically significant ($p \leq 0.05$) difference between T_3 and T_1 and T_2 (Table 13). The P content significantly reduced after T_3 irrigation [$F(3, 12) = 10.39$, $p = 0.001$]. There was a statistically significant difference (Table 13) between T_3 ($M = 3440$ mg*kg^{-1}) and T_1 ($M = 4240$ mg*kg^{-1}, $p \leq 0.05$), T_2 ($M = 4490$ mg*kg^{-1}, $p \leq 0.05$), T_C ($M = 4298$ mg*kg^{-1}, $p \leq 0.01$). The similar result was also observed in K content [$F(3, 12) = 11.87$, $p = 0.001$]. After T_3 ($M = 3005$ mg*kg^{-1}) irrigation K content in M 488 seeds decreased significantly (Table 13) compared to T_1 ($M = 3600$ mg*kg^{-1}), T_2 ($M = 3808$ mg*kg^{-1}) and T_C ($M = 3665$ mg*kg^{-1}).

Table 14. Average (n = 4) MC (mg*kg^{-1}) in seeds of Janka rice variety developed with different quality of irrigation, 2018

Treatments		***2018***				
		Ca	***Mg***	***P***	***K***	***Na***
T_1	***M***	546b	1653a	4210a	3200a**	162c***
	95% CI	[531; 561]	[1559; 1747]	[3974; 4445]	[3092; 3307]	[151; 173]
T_2	***M***	494a	1575a	4067a	3197a**	131b***
	95% CI	[466; 523]	[1500; 1649]	[3976; 4158];	[3124; 3270]	[117; 146]
T_3	***M***	497a	1570a	4087a	3210a**	128b***
	95% CI	[481; 513]	[1516; 1623]	[4024; 4150]	[3098; 3321]	[120; 136]
T_C	***M***	513ab	1575a	4165a	3382b	86a
	95% CI	[455; 570]	[1496; 1653]	[3892; 4437]	[3355; 3409]	[77; 95]

M - mean. CI - confidence interval (lower and upper bound). The letters represent a significant difference between treatments, values followed by the same letter do not differ significantly from each other at the 0.05 level. **, *** *- the mean difference is significant from* T_C *at the 0.01 and 0.001 levels, respectively*

In 2018, Mg [$F(3, 12) = 2.82$, $p = 0.09$] and P [$F(3, 12) = 1.26$, $p = 0.33$] content of Janka seeds remained statistically unchanged (Table 14). The Ca content (Table 14) after all treatments was statistically similar to T_C, despite significant ANOVA result, [$F(3, 12) = 4.89$, $p = 0.02$]. There was only a significant ($p \leq 0.05$) difference between T_1 (M = 546 mg*kg^{-1}) and T_2 (M = 494 mg*kg^{-1}), T_3 (M = 497 mg*kg^{-1}). All treatments had a significant effect on K content of Janka seeds [$F(3, 12) = 11.04$, $p = 0.001$]. After the T_1 (M = 3200 mg*kg^{-1}, $p \leq 0.01$), T_2 (M = 3197 mg*kg^{-1}, $p \leq 0.01$) and T_3 (M = 3210 mg*kg^{-1}, $p \leq 0.01$) K content (Table 14) significantly lower than T_C (M = 3382 mg*kg^{-1}). On the contrary, Na content increased significantly and Na content was 162 mg*kg^{-1} ($p \leq 0.01$), 131 mg*kg^{-1} ($p \leq 0.01$), 128 mg*kg^{-1} ($p \leq 0.01$) and 86 mg*kg^{-1} for T_1, T_2, T_3 and T_C irrigation, respectively (Table 14). The average value of T_1 irrigation was also statistically ($p \leq 0.05$) higher than T_2 and T_3.

Table 15. Average (n = 4) MC (mg*kg^{-1}) in seeds of Janka rice variety developed with different quality of irrigation, 2019

Treatments		***2019***				
		Ca	***Mg***	***P***	***K***	***Na***
T_1	***M***	399a	1390a	3365a	2743a	201a
	95% CI	[295; 504]	[1300; 1479]	[3109; 3620]	[2609; 2875]	[135; 266]
T_2	***M***	409a	1400a	3585ab	3065ab	229a
	95% CI	[339; 478]	[1282; 1517]	[3153; 4016]	[2674; 3455]	[137; 321]
T_3	***M***	435a	1470a	3810b	3190b	260a
	95% CI	[309; 561]	[1389; 1550]	[3457; 4162]	[2873; 3506]	[163; 355]
T_C	***M***	437a	1475a	3700ab	3025ab	237a
	95% CI	[389; 484]	[1429; 1520]	[3596; 3803]	[2829; 3220]	[206; 268]

M - mean. CI - confidence interval (lower and upper bound). The letters represent a significant difference between treatments, values followed by the same letter do not differ significantly from each other at the 0.05 level

In 2019, treatments did not have a statistically significant effect on Ca [$F(3, 12) = 0.42$, $p = 0.74$], Mg [$F(3, 12) = 2.71$, $p = 0.09$] and Na [$F(3, 12) = 1.04$, $p = 0.41$] content of seeds of Janka variety

(Table 15). Although, the ANOVA result of P [*F*(3, 12) = 3.79, *p* = 0.04] and K [*F*(3, 12) = 4.69, *p* = 0.02] was significant, Post hoc comparisons test showed statistically similar relationship between control irrigation and treatments (Table 15). However, after T_3 irrigation the mean value of P (*M* = 3810 mg*kg^{-1}) and K (*M* = 3190 mg*kg^{-1}) was statistically ($p \leq 0.05$) different than T_1 (Table 15).

In general, from a statistical point of view, treatments had remarkable impact on the seed mineral composition of both varieties only in 2018 experiment. The concentration of P, K, Mg minerals in our rice seeds was similar to the results obtained by Orasen (2018) in an experiment with 281 international rice varieties. Although, as Mir et al. (2017) pointed out, the distribution of indicators can vary significantly depending on the rice variety. Greatest changes was observed in 2018 experimental year. Although due to technical problems, only a small amount of irrigation was carried out in 2018, the reaction was visible from both rice plants. Nevertheless, it is necessary to note the role of properties that can change in the soil as a result of the experience of the previous year. In seeds of both genotypes composition of Na increased considerably. In 2018, direct application of effluent water had a significant impact on M 488 seeds. Under T_1 irrigation, while Na content increased markedly, the average amount of Ca, Mg, P and K decreased sharply compared to the control irrigation (T_C).

In the last experimental year, while after T_1, T_2 irrigation, the MC of M 488 rice seeds did not statistically change, but only after T_3 irrigation, the average content of P and K decreased. This is most likely due to the concentration of T_3 irrigation or due to the lack of access of plants to the mineral in the field. Meanwhile, non-significant changes in the MC of Janka seeds indicate a similar response of plants to treatments. Also, this stable result can be the reason for the successful protection of plant from stress factors, avoiding the transport of Na to the reproductive organs.

These results again show that the MC of plants is closely related to water quality, and excessive salt in water can reduce the absorption of minerals from the soil (El-Sharkawi et al., 2004). Na^+ has a profound effect on the absorption of a number of ions (Akter and Oue, 2018). A decrease in the absorption of certain minerals by rice is characteristic of both salt sensitive and salt tolerant rice varieties. As Saleethong et al. (2013) have already mentioned, a salt tolerant rice such as Pokkali and a salt sensitive rice such as KDML105 may experience a decrease in mineral accumulation under saline conditions.

4. NEW SCIENTIFIC RESULTS

1. In general, the thousand kernel weight (TKW) of the M 488 variety has remained constant throughout study years after these treatments used here. But in case of Janka variety, regardless of treatment type (T_1, T_2 and T_3), the TKW remarkably decreased.

2. The direct application of effluent water from intensive catfish farm (T_1) significantly reduced the percentage of whole polished grains of M 488 variety.

3. Regardless of the type of irrigation treatment, namely after the direct application of effluent water from intensive catfish farm (T_1), the use of effluent water with the addition of gypsum (T_2) and the use of effluent water diluted with river water and supplemented with gypsum (T_3), significantly reduced the seed size of both rice varieties.

4. None of the treatments had a significant impact on gelatinization temperature (GT). After the direct application of effluent water from intensive catfish farm (T_1), the use of effluent water with the addition of gypsum (T_2) and the use of effluent water diluted with river water and supplemented with gypsum (T_3), the GT did not change, and the result was similar to the control irrigation (T_C) result.

5. The study found that under the direct application of effluent water from intensive catfish farm (T_1) Ca, Mg, P and K content of M 488 rice seeds significantly decreased, and Na significantly increased.

6. During the experimental years, the mineral content of both rice varieties in the aboveground biomass was also influenced by treatments (T_1, T_2 and T_3). Both M 488 and Janka are particularly good at storing large amounts of Na in the aboveground biomass. Planting these varieties for bioremediation purposes to reduce soil salinization can give positive results.

7. The conducted experiments proved that under the stress of Na, accumulation of other minerals are reduced.

5. CONCLUSIONS

One of our main goals was the evaluation of different water types as irrigation water. Since different agricultural effluents have different quality parameters (e.g. salinity, nutrients, microbiological properties, etc.) that can significantly affect their suitability for irrigation, I have implemented a three-year lysimeter research with aerobic rice to determine the applicability of our specific fish farm effluent. Based on the primary water quality parameters (see Table 1), I have calculated the total amount of applied macronutrients and sodium per seasons (Table 16).

Table 16. Average amount of macronutrients and sodium in the irrigation water treatments applied in three consecutive growing seasons (2017-2019)

Treatments	*Year*	*Amount of irrigation (mm aka. L)*	*Total N/m^2 (g)*	*Total P/m^2 (g)*	*Total K/m^2 (g)*	*Na/m^2 (g)*	*Total N/ha (kg)*	*Total P/ha (kg)*	*Total K/ha (kg)*	*Na/ha (kg)*
T_1	2017	360	9.47	0.78	2.19	89.6	94.7	7.8	21.9	896.4
T_2		360	10.28	0.96	2.38	96.0	102.8	9.6	23.8	960.3
T_3		360	4.72	0.55	1.95	47.3	47.2	5.5	19.5	472.5
T_C		360	0.43	0.05	1.34	10.4	4.3	0.5	13.4	104.0
T_1	2018	60	1.58	0.13	0.36	14.9	15.8	1.3	3.6	149.4
T_2		60	1.71	0.16	0.40	16.0	17.1	1.6	4.0	160.1
T_3		60	0.79	0.09	0.33	7.9	7.9	0.9	3.3	78.8
T_C		60	0.07	0.01	0.22	1.7	0.7	0.1	2.2	17.3
T_1	2019	160	4.21	0.35	0.97	39.8	42.1	3.5	9.7	398.4
T_2		160	4.57	0.43	1.06	42.7	45.7	4.3	10.6	426.8
T_3		160	2.10	0.24	0.87	21.0	21.0	2.4	8.7	210.0
T_C		160	0.19	0.02	0.59	4.6	1.9	0.2	5.9	46.2

The most characteristic property of the fish farm effluent is the high sodium content what was detected in T_1 and T_2 treatments. Even under low-doses of irrigation, more than 14.9 $g*m^{-2}$ and 16.0 $g*m^{-2}$ of sodium was applied in 2018. This parameter made the chosen effluent water potentially harmful for the rice plants. Positive effect of macronutrients was predicted based on the higher Nitrogen and Potassium content of the effluent water. With higher irrigation regimes in 2017, Nitrogen application in the T_1, T_2 and T_3 were significant as 9.47 $g*m^{-2}$, 10.28 $g*m^{-2}$ and 4.72 $g*m^{-2}$, respectively.

Overall, the effect of the treatments varied between genotypes. The current study has shown that direct use of effluent water from intensive catfish farm in aerobic rice production has a high impact in terms of Na accumulation. Long-term irrigation with this effluent increased Na accumulation in the soil. The accumulation of Na, especially in the root zone, presents a potential risk to crops that can cause stress and ultimately affect plant health. Although Na uptake and accumulation was also observed with all irrigation treatments, but it was the lowest under T_3 irrigation (effluent water diluted with river water and supplemented with gypsum). It can be assumed that further development of this treatment (T_3) can give the desired effective result.

I have followed the effects of different irrigation treatments on the aerobic rice plants in three consecutive years. Different milling quality parameters and the nutrient uptake of rice plants were measured and statistically analysed. Based on the previous detailed analyses, the complex comparison of agricultural usability of the different irrigation treatments was done and it is shown in Table 17.

Table 17. The comparison of three irrigation (T_1, T_2 and T_3) water on the examined parameters in case of two rice varieties

Treatments	***Variety***	***TKW***	***GT***	***MQP***	***Minerals***
T_1	M 488	ns. (3 years)	ns. (3 years)	-cargo and polished are ns. (3 years); -whole grain is sig. **decline** (2 years)	High Na (3 years)
	Janka	sig. **decline** (2 years)	ns. (2 years)	-cargo and polished are sig. **decline** (1 year) -whole grain is ns. (2 years)	High Na (2 years)
T_2	M 488	ns. (3 years)	ns. (3 years)	-cargo and polished are ns. (3 years); -whole grain is sig. **decline** (1 year)	-Lower Na (2 years) -Highest Ca (1 year)
	Janka	sig. **decline** (1 year)	ns. (2 years)	-cargo, polished and whole are sig. **decline** (1 year)	-Lower Na content (3 years) -Ca increase (2 years)
T_3	M 488	ns. (3 years)	ns. (3 years)	-cargo and polished are ns. (3years); -whole grain is sig. **decline** (1 year)	Lowest Na content (2 years)
	Janka	sig. **decline** (1 year)	ns. (2 years)	-cargo and whole grain are sig. **decline** (1 year)	Lowest Na content (1 year)

ns. - non significant effect; sig. - significant effect. Its reliability is indicated in brackets.

We have found that the two Hungarian rice varieties showed different tolerance levels to the salinity in the irrigation water under aerobic conditions. Long-term experience has shown that during irrigation with treatments, the TKW of rice tends to stable in M 488 and reduction in case of Janka, both in paddy and cargo seeds. Similar situation was also noticed in MQP of both varieties. M488 was more resistant to irrigation water quality than Janka. In general, over the years of the experiment, different results of the ratio were obtained depending on the changes of grain length and width. Our results show that significant changes in size parameters also affected seed ratio in both varieties. Especially, a significant decrease in width led to a change in L/W ratio. Gelatinization temperature of the rice varieties was found stable and after the irrigation with the treatments, the GT did not change significantly compared to the control irrigation. The treatments did not change the composition of starch properties of seeds.

The highest detected impact on both rice varieties was the higher level of Na uptake in the aboveground biomass and seed too (based on T_1 and T_2 treatment). However, the negative effect of Na and the higher accumulation by the plants were effectively reduced by the application of the diluted effluent (T_3). This was found one of the most important factors affecting the accumulation of other minerals and led to nutrient imbalance, especially Ca content. The added gypsum (T_2 and T_3) improved the nutrient balance, but there were no noticeable effects on the concentration of the other elements in the aboveground biomass. Therefore, the gypsum supplementation of the wastewater was found a good practise to change Ca content of biomass.

The irrigation water quality does not affect significantly the magnesium content of biomass and seed. The future studies will be focused on to proof this kind of usability.

The correlation among the minerals shows that the amount of different elements has different correlations. The most remarkable interaction was visible between the sodium and the other measured minerals. The correlation between them was significantly negative. On the other hand we found significant strong correlation between Mg-P relations.

6. LIST OF PUBLICATIONS

Peer-reviewed articles with impact factor

- Ibadzade, M., Kun, Á., Székely, Á., Szalóki, T., Penksza, K., Jancsó, M. (2020). The influence of irrigation with intensive fish farm water on the quality indicators of aerobic rice (*Oryza sativa* L.). Applied Ecology and Environmental Research, 18(5): 7077-7088. http://dx.doi.org/10.15666/aeer/1805_70777088

- Ibadzade, M., Kun, Á., Székely, Á., Szalóki, T., Penksza, K., Jancsó, M. (2020). The role of effluent water irrigation in the mineral absorption of aerobic rice varieties (*Oryza sativa* L.). Cereal Research Communications, 1-9. https://doi.org/10.1007/s42976-020-00117-x

- Székely, Á., Szalóki, T., Ibadzade, M., Pauk, J., Lantos, Cs., Jancsó, M. (2021). Germination dynamics of European rice varieties under salinity stress. Pakistan Journal of Agricultural Sciences, Vol. 58(1), 1-5. DOI: 10.21162/PAKJAS/21.464.

Peer-reviewed articles (in English)

- Ibadzade, M., Székely, Á., Penksza, K., Jancsó, M. (2018). Effects of water quality on the milling characteristics of aerobic rice. Alkalmazkodó vízgazdálkodás: lehetőségek és kockázatok, 267-272.

- Ibadzade, M., Székely, Á., Szalóki, T., Penksza, K., Jancsó, M. (under review) Reuse of wastewater from fish farm for irrigation in aerobic rice (Oryza sativa L.) cultivation.

Conference abstracts (in English)

- Ibadzade, M., Székely, Á., Szalóki, T., Penksza, K., Jancsó, M. (2019). Quality changes of rice under different irrigations in lysimeters. 18th Alps-Adria Scientific Workshop, april 1-6. Cattolica, Italy.

- Jancsó, M., Kun, Á., Székely, Á., Szalóki, T., Ibadzade, M., Bozán, Cs. (2019). New developments at the Lysimeter Station in Szarvas. Lysimeter - a perfect tool for quantifying fluxes of water, nutrients and pollutants, 18. Gumpensteiner Lysimetertagung, 155-156. ISBN: 978-3-902849-64-9

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