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ORIGINAL PAPER

The role of effluent water irrigation in the mineral absorption of aerobic rice varieties (*Oryza sativa* L.)

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Abstract

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. Appropriate alternative water sources and the reutilization of agricultural effluents can reduce the impact of rice production and animal husbandry on the natural water bodies. In the present study, influence of four different types of irrigation water was analyzed on the nutrient uptake (P, K, Ca, Mg, Na) of aerobic rice (*Oryza sativa* L.) in a complex lysimeter experiment in two consecutive years. Early maturing Hungarian rice varieties (M 488 and Janka) were irrigated with traditional river water (RW) and different alternative irrigation sources to evaluate the feasibility of a sodium containing intensive fish farm effluent with (EWG) or without (EW) gypsum supplementation and with the addition of natural river water (EWGR). Significant effects on the mineral content of the aboveground biomass were measured. P uptake by M 488 and Janka decreased after the irrigation with EW in 2017. In case of EW, EWG and EWGR, the Na content increased significantly ($p \leq 0.05$) in both varieties; however, pre-treatment of salt containing effluent waters can moderate the stress level. As a consequence, the ability of both rice varieties to absorb Na suggests that rice production could be conditionally part of bioremediation of salt-affected soils and water bodies.

Keywords Aerobic rice · Effluent water · Mineral content · Wastewater irrigation

Introduction

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 (Bortolini et al. 2018). 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 (Tabatabaei et al. 2020).

The continuous increase of wastewater as a result of urbanization and industrial development has become a major option for agricultural use nowadays (Zakir et al. 2016). Moreover, agriculture itself also plays an indisputable role in freshwater pollution (Özerol et al. 2012; Hatfield 2015). Basically, large agricultural wastewater (AWW) discharges what come from poultry and livestock farming. Only for processing one bird with 2.3 kg on average 26.5 l of water is required (Avula et al. 2009). According to Ran et al. (2016), livestock farming alone uses one-third of global agricultural water sources. In the end, usually AWW is discharged into soil or water bodies without treatment. Reuse of wastewater is becoming more and more important from the view of environmental protection, and on the other hand, it can also provide plants with the necessary macro- and microelements (Rahman et al. 2018). The biggest risk factor is that AWW often contains microbes and pathogens, chemicals, antibiotic residues and other substances that threaten the health of living organisms and nature (Yordanov 2010; Bustillo-Lecompte et al. 2016). However, nutrient-rich AWW, if properly treated in irrigated agriculture, can offer great benefits too (Domashenko and Vasilyev 2018; Villamar

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et al. 2018). Mekki et al. (2006) noted that wastewater from olive mills after pre-treatment positively affects soil structure and growth of several plants, such as tomato, wheat and beans. Singh et al. (2012) reported that application of wastewater containing high amount of nutrients greatly increased yield of different crops. Aquaculture is one of the main water-dependent sectors in agriculture, especially intensive aquaculture where large water volume and high protein content in feed are used. This results in a significant amount of nutrient-rich effluents (Kerepeczki et al. 2011). Management of the discharged wastewater from such systems still needs developments to lower the negative effects on natural water bodies (Csorbai and Urbányi 2019; Tóth et al. 2020.). There are traditional and improved methods for quality treatment that significantly determine the reutilization possibilities of output nutrients (Edwards 2015; Ribeiro and Naval 2019). However, aquaculture effluents that can be characterized by high sodium content need special pre-treatments before conditionally reuse them in agricultural irrigation (Kun et al. 2018).

Rice (*Oryza sativa L.*) cultivation in many countries meets also water shortages and other environmental issues (He et al. 2016). This is really important because rice is a staple food for more than half of the world's population (Rejesus et al. 2012). According to the forecast of Seck et al. (2012), an additionally 116 million tons of rice production will be needed in order to provide the increasing demand by 2035. Rice is not only a food crop, but also an important foundation for the economies of several developing countries (Van Dis et al. 2015). In India, according to Jena and Grote (2012), the total rice export in 2010–2011 was about 2.5 billion US dollars. Unfortunately, rice is one of the most water-intensive cereal crops among agricultural plants. Getting high yields is usually associated with many difficulties (water shortage, low temperature, diseases, etc.) due to its specific production technology (Stoop et al. 2009). Limited water resources and low farm income were reported as major limiting factors for rice farming (Nguyen and Ferrero 2006).

The aerobic rice system is one of the novel ways of intensive rice cultivation, where water consumption is many times reduced compared to the conventional paddy method (Bouman et al. 2002, 2005; Peng et al. 2006). Aerobic rice is grown mainly on non-saturated soils, while several irrigation techniques (e.g., alternative wetting, sprinkler irrigation, drip irrigation) can be applied. Thus, compared to the conventional paddy cultivation, it is easier to avoid water loss, but drought stress can occur more often. Moreover, other environmental stresses such as low temperature can also cause more serious damage in unfavorable seasons (Gombos and Simon-Kiss 2005). Under these circumstances, sufficient varieties and nutrient supply are required to maintain plant health and yield quality. In Hungary, new rice varieties with good abiotic stress tolerance such as Janka and Ábel were released via doubled haploid production (Pauk et al. 2009). These varieties were specially developed for the colder aerobic conditions of the temperate climate (Jancsó et al. 2017). The presence of various nutrients in AWW can even simplify the technology. For better understanding of agricultural and plant physiological processes, it is necessary to study rice grown under aerobic conditions with AWW irrigation and to evaluate its effect on the chemical composition of plants.

In the present 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 better quality food and feed production too.

Materials and methods

Experimental site and meteorological data

The experiments were carried out in two consecutive years, 2017 and 2018, at the Lysimeter Station (Szarvas, Hungary) of the National Agricultural Research and Innovation Centre, Research Institute of Irrigation and Water Management (NAIK ÖVKI) (46°51′48″ N, 20°31′39″ E). Two widespread Hungarian rice varieties "M 488" and "Janka" (both *temperate japonicas*) were chosen to test the effect of different irrigation water types on the mineral composition of aboveground biomass in aerobic rice.

Measurement of meteorological data was taken using meteorological equipment (Agromet-Solar automatic weather station, Boreas Ltd., Hungary) installed in the experimental field. Table 1 presents the monthly precipitation and temperature (average, minimum and maximum) over the years of the experiment.

Experimental design and treatments

Rice varieties were sown into 32 non-weighing backfilled gravitational lysimeters (1 m^3) in 4 repetitions (Fig. 1). The bottom 10 cm of the lysimeters is a layer of fine gravel, and the upper 80 cm is a layer of soil; the soil type was vertisol (expansive clay). Gravitational lysimeters were chosen for the experiment mainly because of the isolation of the plants and soil from the horizontal and vertical environmental influences. Outflow of percolation water was not detected during the experiment.

Table 1 Monthly precipitation and temperature (min., max., avg.) during growing seasons in 2017 and 2018

Year	Month	Precipitation (mm)	Temperature (°C)		
			Minimum	Maximum	Average
2017	April	49.7	0.0	25.0	11.0
	May	40.9	4.2	30.5	17.2
	June	69.3	10.5	33.3	22.1
	July	31.8	11.0	36.4	22.8
	August	33.3	8.2	39.2	23.7
	September	74.2	5.4	34.3	16.6
2018	April	11.2	4.9	29.7	16.4
	May	37.4	10.0	31.2	20.1
	June	31.0	8.0	32.8	21.4
	July	69.8	8.3	33.3	22.8
	August	43.9	13.6	35.2	24.4
	September	14.5	2.5	33.2	18.4

Table 2 The chemical parameters of irrigation water types used in the experiment

	EW	EWG	EWGR	RW
pH	7.77	7.71	7.70	7.55
Ammonium-N (mg/dm^3)	24.4	24.4	10.8	0.526
Total phosphorus (mg/dm^3)	2.16	1.82	0.918	0.139
Potassium (mg/dm^3)	6.25	6.34	5.40	3.93
Calcium (mg/dm^3)	20.9	187.5	90.9	39.2
Magnesium (mg/dm^3)	9.9	11.0	10.7	9.8
Sodium (mg/dm^3)	276.3	266.8	131.3	35.3

EW effluent water, *EWG* effluent water supplemented with gypsum, *EWGR* effluent water diluted with river water and supplemented with gypsum, *RW* river water

In the course of the experiment, effect of four irrigation water types was investigated: raw effluent water (EW) from an intensive fish farm, effluent water supplemented with gypsum (312 mg/L calcium sulfate) (EWG), effluent water diluted four times (1:3) with river water and supplemented with gypsum (EWGR) and natural river water (RW) as a control. The source of RW was a local oxbow lake of Körös River (46°51′38.6″ N 20°31′28.0″ E, Szarvas, Hungary). Considering this, gypsum was addedto the EW according to the method proposed by Kun et al. (2018) in the EWG and EWGR irrigation. Thus, gypsum was applied in the EWG and EWGR to reduce the potential harmful effects of EW on the soil and plant development. Key indicators of water quality are listed in Table 2.

Microplots in the lysimeters were treated according to standard aerobic rice production technology. After direct dry sowing, pre-emergent herbicide (pendimethalin) was applied to suppress weed development. Later, during the growing season only mechanical weeding was used. Other plant protection interventions were not necessary. Commercially available micro-sprinkler irrigation system (Rivulis Rondo) with precision water meters was set up to the experimental site. Irrigation frequency and thus the gross irrigation amount per season were adjusted for weather conditions.

In the first year of the experiment, rice seeds were manually sowed on April 25, 2017. On June 13, 1 kg of fertilizer ($NH_4NO_3 + CaMg(CO_3)_2$) was applied (84.4 kg N*ha^{-1}). The irrigation water amount was 360 mm. Plants were harvested on September 12, 2017.

In the second year of the experiment, rice seeds were manually sowed on April 25, 2018. Due to technological issues this year, it was not possible to fully utilize effluent water for irrigation, and fertilizer was not applied. The amount of irrigation water was only 60 mm. However, the

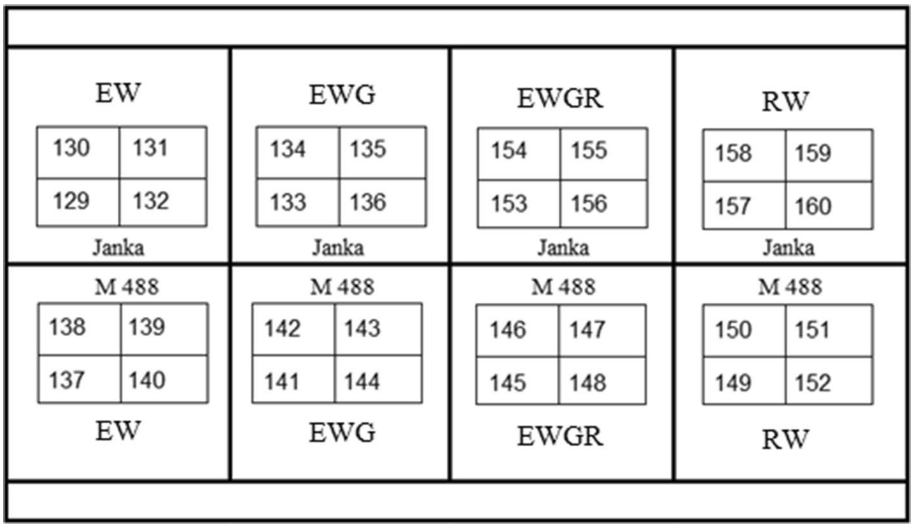

Fig. 1 Experimental design in the lysimeter study. *EW* effluent water, *EWG* effluent water supplemented with gypsum, *EWGR* effluent water diluted with river water and supplemented with gypsum, *RW* river water (control). The numbers in the cells represent the identification number of the gravitational lysimeters. M 488, Janka—Hungarian rice varieties

same irrigation scheme was applied as for the fore-crops, and therefore, a higher amount of sodium was measured in the soil of EW lysimeters (Table 3).

Harvesting was organized on August 22, 2018. After the harvest, whole aboveground parts of the rice plants were cut into small particles and after careful drying, samples were stored at room temperature.

Laboratory analysis

Effects of different irrigation water types on the chemical composition of rice varieties were analyzed at the NAIK ÖVKI Laboratory for Environmental Analytics (Szarvas, Hungary). After basic preparations (cleaning and drying), each sample was wet digested in 6 ml HNO_3 and 2 ml H_2O_2 and after 1 day; the samples were kept in a microwave oven at a temperature of 180 °C for 1.5 h.

Calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) were measured with an atomic absorption spectrophotometer (Thermo Scientific Solaar M6, AAS). Phosphorous (P) was determined by using inductively coupled plasma atomic emission spectroscopy (Thermo Scientific ICAP 6000, ICP-OES). The determination of minerals was carried out in accordance with MSZ EN ISO 11885:2000 international and Hungarian standards.

Statistical analysis

Changes of the nutrient composition of plant samples were statistically analyzed in IBM SPSS 22 statistical environment. The collected data were subjected to the analysis of variance (ANOVA). The significant differences among irrigation treatments were determined with the Tukey test at 0.1%, 1%, 5% levels of probability, respectively.

Results

Statistical analysis of the combined data of varieties from 2017 (Table 4) shows that rice response varied markedly under different irrigation treatments. The Ca content of rice aboveground biomass was increased significantly ($p \leq 0.001$) after EWG irrigation, similarly to the Mg content ($p \leq 0.05$). While EW and EWG irrigation did not have a significant effect on these elements, although the Mg content was also higher after EW irrigation, the difference was statistically insignificant ($p = 0.06$). After EW and EWGR irrigation,

Table 3 The average (n = 4) chemical properties of soil in individual block lysimeters, 2018

Lysimeters	EW		EWG		EWGR		RW	
Depth of the sample (cm)	0–45	45–90	0–45	45–90	0–45	45–90	0–45	45–90
pH (KCl)	6.8	6.5	6.7	6.5	6.4	6.5	6.8	6.7
Phosphorus-pentoxide (AL-P_2O_5) m/m %	537.75	356.5	413	414.75	479	424.5	752.5	654.75
Potassium-oxide (AL-K_2O) m/m %	423.25	455.5	440	452	402.25	456.5	459.25	475.25
Exchangeable cations								
Na ($BaCl_2$)meq/100 g	1.33	0.90	1.19	1.04	1.02	0.83	0.94	0.98
K ($BaCl_2$)meq/100 g	1.01	1.13	1.00	1.09	0.99	1.08	1.11	1.09
Ca ($BaCl_2$)meq/100 g	25.85	29.45	25.34	29.95	26.59	32.38	25.93	32.93
Mg ($BaCl_2$)meq/100 g	8.23	10.17	8.94	10.27	9.31	9.69	8.27	9.02

EW effluent water, *EWG* effluent water supplemented with gypsum, *EWGR* effluent water diluted with river water and supplemented with gypsum, *RW* river water

Table 4 The average mineral content in aboveground biomass of rice, 2017

Treatment	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)
EW	3938	2921	1538***	10691	1109***
EWG	4651***	2944*	1520***	10229	1013***
EWGR	3718	2679	1860	10789	607**
RW (control)	3558	2644	2063	11567	383

EW effluent water, *EWG* effluent water supplemented with gypsum, *EWGR* effluent water diluted with river water and supplemented with gypsum, *RW* river water

*, **, ***—the mean difference is significant at the 0.05, 0.01 and 0.001 levels, respectively

a significant ($p \le 0.001$) decrease in the P content was observed. At the same time, all the treatments had no significant ($p \ge 0.05$) effect on the K content. Sodium was one of the main targets of the analysis, and after EW ($p \le 0.001$), EWG ($p \le 0.001$) and even EWGR ($p \le 0.01$) irrigation the Na content increased significantly.

In 2018, none of the treatments significantly ($p \ge 0.05$) affected the Ca, Mg and P content of rice aboveground biomass (Table 5). After EW irrigation, the K content statistically ($p \le 0.05$) increased, but the other treatments did not cause significant ($p \ge 0.05$) changes. As in the previous year, the Na content was statistically ($p \le 0.001$) higher in case of all effluent water containing treatments.

Analysis of individual varieties shows that Ca absorption of the M 488 rice variety increased after the irrigation with EW, EWG and EWGR in the first year (Table 6). Although we have observed a statistically significant difference only between EWG and RW ($p \le 0.01$), the average Ca content was 4967 mg/kg and 3527 mg/kg for EWG and RW irrigation, respectively. Neither the amount of Mg, nor K in aboveground biomass of M 488 was statistically affected by treatments. However, a notable change was observed in case of Mg content after EWG irrigation (3035 mg/kg) ($p = 0.06$) compared to the control. Despite the high amount of P in the effluent water, its application did not increase the level of P in aboveground biomass of M 488. On the contrary, the P amount after EWGR irrigation was statistically similar to RW ($p \ge 0.05$), but it was statistically lower after EW ($p \le 0.05$) and EWG ($p \le 0.01$) utilization. The average P was 1575 mg/kg, 1445 mg/kg, 1675 mg/kg and 2027 mg/kg for EW, EWG, EWGR and RW irrigation, respectively. Largest changes were recorded in case of Na content, where all effluent water containing treatments increased significantly the amount of Na in aboveground biomass of M 488. However, dilution and gypsum supplementation tend to decrease sodium accumulation. The average Na was 1155 mg/kg, 1057 mg/kg, 685 mg/kg and 404 mg/kg for EW, EWG, EWGR and RW irrigation, respectively.

In the first year, the amount of Ca, Mg, K in aboveground biomass of Janka has changed as a result of EW, EWG and EWGR irrigation (Table 7), but these changes were not statistically significant compared to the RW control ($p \ge 0.05$). Similar to M 488, there was no increase in P content, although treatments contained higher levels of P. The lowest P content was observed after EW irrigation, which was a statistically significant ($p \le 0.01$) difference compared to the control treatment. The average P was 1500 mg/kg and 2097 mg/kg for EW and RW irrigation, respectively. Under the EWG irrigation, the P content in Janka was also lower, but there was no statistical ($p = 0.07$) difference. Opposite to M 488, the amount of Na after the EWGR irrigation in aboveground biomass of Janka gave statistically similar results with RW ($p \ge 0.05$). But EW ($p \le 0.001$) and EWG ($p \le 0.05$) showed the same significant effects. The average

Table 5 The average mineral content in aboveground biomass of rice, 2018

Treatment	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)
EW	2376	2327	2358	13725*	1029***
EWG	2580	2126	2285	11714	885***
EWGR	2618	2179	2159	11690	879***
RW (control)	2685	2176	2441	10910	370

EW effluent water, *EWG* effluent water supplemented with gypsum, *EWGR* effluent water diluted with river water and supplemented with gypsum, *RW* river water

*, ***—the mean difference is significant at the 0.05 and 0.001 levels, respectively

Table 6 The average mineral content in aboveground biomass of M 488 rice variety, 2017

Treatment	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)
EW	4092	2902	1575^{*}	10795	1155^{***}
EWG	4967^{**}	3035	1445^{**}	10180	1057^{***}
EWGR	4055	2770	1675	10372	685^{**}
RW (control)	3527	2635	2027	10900	404

EW effluent water, *EWG* effluent water supplemented with gypsum, *EWGR* effluent water diluted with river water and supplemented with gypsum, *RW* river water

*, **, ***—the mean difference is significant at the 0.05, 0.01 and 0.001 levels, respectively

Na was 1062 mg/kg, 967 mg/kg, 528 mg/kg and 361 mg/kg for EW, EWG, EWGR and RW irrigation, respectively.

In the second year (Table 8), the average amount of Ca, Mg and P in aboveground biomass of M 488 has remained stable; there was non-significant difference between treatments and control irrigation ($p \geq 0.05$). However, non-significant differences were also found in case of K content after treatments, but EW irrigation resulted noticeable higher amounts than in control irrigation, 14057 and 11817 mg/kg, respectively. Like in the previous year, the percentage of Na in the aboveground biomass was increased due to the effluent water containing treatments. The differences were statistically significant compared to the control method ($p \leq 0.01$). The average amount of Na at EW, EWG, EWGR and RW irrigation was 1006 mg/kg, 885 mg/kg, 982 mg/kg and 344 mg/kg, respectively.

Similar results were also observed in the aboveground biomass of the Janka (Table 9), where the average content of Ca, Mg and P remains statistically similar to the control after irrigation with EW, EWG and EWGR ($p \geq 0.05$). However, compared to the M 488 rice variety, irrigation with EW increased the average content of K, which was statistically significant ($p \leq 0.01$) compared to EWGR and control irrigation. As in M 488, the average sodium content in Janka was also increased after the irrigation with EW, EWG and EWGR. The highest average Na content (1051.5 mg/kg) was measured after the EW irrigation. There was statistically significant difference between EW, EWG, EWGR and control

Table 7 The average mineral content in aboveground biomass of Janka rice variety, 2017

Treatment	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)
EW	3782	2940	1500**	10587	1062***
EWG	4335	2852	1595	10277	967*
EWGR	3380	2587	2045	11205	528
RW (control)	3587	2652	2097	11802	361

EW effluent water, *EWG* effluent water supplemented with gypsum, *EWGR* effluent water diluted with river water and supplemented with gypsum, *RW* river water

*, **, ***—the mean difference is significant at the 0.05, 0.01 and 0.001 levels, respectively

Table 8 The average mineral content in aboveground biomass of M 488 rice variety, 2018

Treatment	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)
EW	2455	2180	2242	14057	1006**
EWG	2432	1890	2382	11892	885**
EWGR	2825	2212	2100	13186	982**
RW (control)	2655	2217	2605	11817	344

EW effluent water, *EWG* effluent water supplemented with gypsum, *EWGR* effluent water diluted with river water and supplemented with gypsum, *RW* river water

**—the mean difference is significant at the 0.01 level

Table 9 The average mineral content in aboveground biomass of Janka rice variety, 2018

Treatment	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)
EW	2297	2437	2472	13392**	1051***
EWG	2727	2362	2187	11535	884***
EWGR	2410	2145	2217	10567	776**
RW (control)	2715	2135	2277	10002	395

EW effluent water, *EWG* effluent water supplemented with gypsum, *EWGR* effluent water diluted with river water and supplemented with gypsum, *RW* river water

**, ***—the mean difference is significant at the 0.01 and 0.001 levels, respectively irrigation. The average amount of Na at EWG, EWGR and RW irrigation was 884 mg/kg, 776 mg/kg and 395 mg/kg, respectively.

Discussion

According to our initial assumption, comparative analysis of combined data from 2 years of studies suggests that both rice varieties were significantly influenced by the irrigation treatments, however not exactly in the same levels. The different results reflect the individual characteristics of rice varieties. The greatest role in this effect can be associated with the presence of Na in the effluent water from intensive fish farm. For the reduction of harmful effects of the EW on soil and plant development, in EWG and EWGR gypsum were also applied as it was developed by Kun et al. (2018).

As a consequence of EW irrigation, the average Na content increased after the first irrigation season (2017), while the average P content reduced in the above ground biomass of M 488. During irrigation with EWG, an increase in the average amount of Ca and Na and a decrease in P content were also observed. We have also found that Na increased the most among the analyzed elements as a result of EWGR in our study, while other elements remained stable. The effect of gypsum on higher Ca content was detected by means of EWG irrigation.

We have found some differences in case of the other temperate japonica rice variety, but as in M 488, EW irrigation caused increasing amount of Na in Janka too, and the average amount of P was also decreased. After the EWG irrigation only the Na content increased in case of Janka. But EWGR did not cause any changes in the amount of minerals after the first year.

In 2018, EW, EWG and EWGR irrigation increased the average amount of Na in both varieties. In Janka, EW also increased the amount of K. With EWG and EWGR, the other elements remained statistically similar.

According to El-Sharkawi et al. (2004), the mineral content of plants is closely related to the quality of water, and excessive salt content in water can reduce the uptake of minerals from the soil. In their experiment, Akter and Oue (2018) and Thu et al. (2017) also noted that a high Na^+ content can affect and decrease the absorption of several minerals as it creates a stressful environment for the plants, which was also observed in our experiment. Reduced absorption of P by M 488 and Janka was measured after effluent water application. But reducing stress conditions (e.g., EWG and EWGR) allows plants to make better utilize of minerals from water and soil. The application of limited irrigation in 2018 meant mild stress compared to the previous year, which ultimately did not have a considerable effect on the accumulation of minerals. However, the plants were exposed to the Na accumulated in the soil as a result of previous year's irrigation, and the amount of Na in the aboveground biomass of both varieties increased.

Altogether, one of the main indicators of 2 years of experience was that the aboveground biomass of both types of varieties accumulate a large amount of Na, influenced by environmental conditions and the amount of irrigation (treatments). The accumulation of Na in both genotypes is directly related to the fact that the Na transport mechanism is different from the transport mechanism of other (Ca, Mg, P, K) elements (Ochiai and Matoh 2002; Goel et al. 2011; Tanoi et al. 2011; Yang et al. 2014; Sasaki et al. 2016; Kant et al. 2018). Although the main goal of plants is to protect the seeds from the surplus of this toxic element, depending on the amount of sodium, it can be accumulated in the aboveground biomass (leaves, stems) (Marschner 1995; Reddy et al. 2017). At the same time, salinization can limit the uptake and accumulation of other important minerals (Hussain et al. 2017; Razzaq et al. 2020). We found that pre-treatment of salt containing effluent waters can moderate the stress effect of high sodium content in EW. However, further research is needed to find better irrigation water combinations.

Wastewater irrigation is a promising method that can provide plants sufficient water and essential nutrients, especially in arid and semi-arid regions. However, quality of the wastewater (e.g., total salt content, heavy metals) must be investigated frequently to avoid unnecessary damages in the agricultural and natural environments. In our experiment, in general, the assimilation of minerals by the plants was normal, but the presence of Na in the effluent water indicates that it can threaten the transformation and accumulation of minerals. On the other hand, the ability of both rice varieties to absorb Na suggests that rice production could be conditionally part of bioremediation of salt-affected soils and water bodies after further studies.

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