Safe rice production irrigated by subsurface drip with treated urban wastewater

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Abstract: Improving practices of water saving in irrigation is a priority facing global climate changes. To cope with water scarcity, irrigation with treated wastewater (TWW) is becoming a solution, posing several health and environmental risks on agricultural fields. This preliminary study, sponsored by the MEDWATERICE project (www.medwaterice.org), aimed to assess the physicochemical impacts of rice irrigated with TWW applied with a subsurface drip irrigation (SDI) system, focusing on rice food, soil, and environmental safety. Normal water and flooding were used as a reference for comparison. The experimental scheme considered three treatments with five repetitions, namely the TWW irrigation with SDI, the normal water with SDI, and the flooded irrigation with normal water. The pots filled with 15 L of soil, sowed with a local traditional rice variety, were kept outdoors. The fertilization scheme followed the usual one under field conditions. The irrigation frequency varied from three to five times a week. Measurements of physicochemical properties of irrigation water, drainage and rice grain were carried out, according to the analytical reference methods. Results showed that the irrigation with TWW raises the salinity of drainage water, but that the rice grain does not present increased risks to public health due to the low content of arsenic, cadmium, lead and mercury. However, the irrigation method must be adapted to an SDI to avoid human and animal contact with putative contaminants present in this water and thus safeguarding Environmental and Food Safety. Long term soil effects of TWW, including winter percolation, should be assessed in the future.

Keywords: Rice irrigation, chemical impacts, wastewater reuse

1. Introduction

Rice is the world most important food crop, and the staple food for more than half the human population. Its demand in the world market has increased, and it is foreseeable a continuous rise around 24% over the next 20 years [1]. The growth of African and Asian populations, as well as the changes in diet, explain the increase of human rice consumption. In the Mediterranean countries it is cultivated on about 1.30 million hectares [2], mainly in flat alluvial regions, with a relative abundance of water. Traditionally, it is grown under continuous flooding.

To respond to the growing market demand, rice production can be increased enlarging its cultivation area; however, there are limitations hard to overcome. The main constraint is the water supply, due to its unavailability, high costs in many regions, and for countering a demand from society to restrict its use in irrigation. Moreover, flooding is effective on flat, deep, and poorly permeable soils, which are precisely the soils where rice is traditionally cultivated; conditions that are scarce in other areas to allow the expansion of rice paddies. Many studies had explored the sustainability of innovative irrigation options, to reduce water consumption for rice production and its negative environmental impacts, and to extend rice cultivation outside traditional rice areas [3].

Nowadays, improving irrigation practices to save water is a priority. Therefore, the use of drip irrigation for rice cultivation has been one of the recommended solutions [3,4], since it solves some of the most critical issues of rice continuous flooding, namely, it allows: i) reducing water consumption, especially the fraction of deep percolation; ii) the use of lower quality water, in terms of salinity and microbiology (high microbiological load in subsurface to do pose direct risk to human and animal healthy); iii) facilitating the automation of irrigation, reducing labor; and iv) to reduce the residual arsenic content in the grain.

In this context, the use of treated wastewater (TWW) for irrigation is a solution to consider dealing with water scarcity. In certain places, TWW it is a significant source of water for irrigation with guaranteed supply during the summer, despite posing several health and the environmental risks [5].

The aim of this study was to evaluate the physicochemical impact of the rice irrigation with urban TWW on drainage water from soil percolation (environmental safety) and on rice grain quality (food safety). For this purpose, some physicochemical quality parameters were monitored in the irrigation and drainage water, as well as the effect of the irrigation method on the rice grain quality.

2. Materials and Methods

To assess the impacts of reusing municipal TWW for rice irrigation, the environmental exposition of drainage water to chemical compounds of TWW was determined through the physicochemical analysis of soil water samples, whereas the rice consumer exposition to heavy metals was assessed through rice grain analysis. Two sources of irrigation water (Treated Wastewater, TWW, and Normal-Water, NW, used for comparison) and two irrigation methods (Subsurface Drip Irrigation, SDI and Continuous Flooding, F) were used for this evaluation in a pot test. The experiment carried out from 2019 to 2021 crop season.

The experimental layout considered three treatments with five repetitions, namely: i) irrigation by SDI with TWW, ii) irrigation by SDI with NW, and iii) irrigation by continuous flooding with NW. The NW was collected from a well, whereas the urban TWW was supplied by the Coimbrões WWTP, AdCL SA, Leiria. The pots with 15L of soil, seeded with a traditional variety of local rice (*Oryza sativa* L. cv Ariete), were kept outdoors. The fertilization scheme followed the usual field conditions. The irrigation frequency varied between three to five times a week for pots with SDI and flooding, respectively. The SDI with dripper at a depth of 15 cm, supplied through a small reservoir. A rice field owned and managed by a farmer, irrigated with NW, was used for comparison. Measurements of soil texture, irrigation water volume were recorded. Drainage water samples were collected by free percolation on two different dates, after harvest and after the Winter period. The physicochemical parameters of water samples and of heavy metals in the rice grain were determined according to the analytical reference methods referred in Table 1.

3. Results and discussion

3.1. Effect of irrigation on the quality of drainage water

The mean values of pH, electrical conductivity (EC) and chlorides of the irrigation and drainage water (Tables 1) reveal significant differences between the treatments associated with the type of irrigation water. The significantly higher values of conductivity and chloride content of the water drained from pots irrigated with TWW are clearly associated with the origin of the irrigation water, which also has higher values than NW.

The pots irrigated with NW had a significant impact on the pH increase of the drainage water (from 6.5 to 7.1). In the pots irrigated with same water (NW) by SDI conditions, the pH has an identical value, 6.5 and 6.7.

The total dissolved solids (TDS) were lower in the irrigation water compared to drainage, with the highest value in the TWW treatment. In turn, the total suspended solids (TSS) were higher in irrigation water, NW compared to TWW, possibly because TWW are filtered during the treatment process, with NW inversion of the order relationship in the drainage water (SDI-TWW> F-NW or SDI-NW) (Table 1).

The electrical conductivity (EC) of drainage at harvest was very high for the three treatments, between 1100 e 1700 µS/cm. Note that the F-NW treatment had no percolation drainage during crop season. The sodium adsorption ratio (SAR), being lower in irrigation water (NW and TWW) than in drainage water (SDI-TWW and F-NW+SDI-NW), and increasing between irrigation water and the respective drainage, has a higher increase in the case of NW (+1.4) than in TWW (+0.9) (Table 1). The salinity of the drainage water, deriving from that existing in the soil solution, increased due to the contribution of TWW high saline content in sodium and chlorides (sodium chloride), although other calcium and magnesium salts were also present (Table 1). The SAR indicates the ratio of exchange sodium to other non-toxic cations, such as calcium and magnesium. As sodium degrades the soil structure and raises the pH, it increases the risk of immobilization and the consequent deficiency of some micro-elements, especially zinc.

The quality of drainage water with respect to EC and Chloride (Table 1), improved after the Autumn/Winter period, without cultivation, during which the rainfall occurred allowed the leaching of the soil, with a very relevant reduction in salinity.

Table 1. Average values (2019-2021) of physical-chemical parameters of irrigation and drainage water from the pots after harvest and at the end of the Autumn/Winter period.

	Irrigation		**Drainage**					
	At irrigation season		**At harvest (October)**			**After Winter (April)**		
Parameter	**NW**	**TWW**	**SDI-TWW**	**SDI-NW**	**F-NW**	**SDI-TWW**	**SDI-NW**	**F-NW**
pH	6.5	7.8	7.2	6.7	7.1	6.9	6.4	6.8
ECondutivity(µS/cm)	300	1200	1700	1100	1400	260	130	160
Chloride (mg/L)	41.5	180	400	273	407	37.0	16.4	15.8
SAR	1.6	7.2	8.1	2.9	3.0	1.8	1.4	2.0
Nitrates (mgNO_3/L)	<3.0	14.7	24.5	5.3	7.0	13.7	3.7	17.1
TDS (mg/L)	145	690	960	617	907	142	68.5	92.5

Irrigation water: NW, normal water; TWW, treated wastewater.

Drainage water: SDI-TWW, underground drip irrigation with TWW; SDI-NW, underground drip irrigation with normal-water; F-NW, irrigationby continuous flooding with normal-water.

The values of arsenic, cadmium, cobalt, lead, chromium, lithium, nickel, selenium, and vanadium from TWW were below the detection threshold of the method, which leads us to conclude, in the first approach, that in relation to these parameters, this water has no restrictions for irrigation use. The only sample where boron was detected was in TWW (90µg/L) used for irrigation, which was not in the drainage water of the pots irrigated with this water. It should be noted that the boron content of TWW did not exceed one part per million (1 ppm = 1mg/L), a limit that should not be reached given its toxic nature for rice. The values of arsenic, chromium, lead found in irrigation and drainage water are below 0.005mg/L, and those for cadmium below 0.001mg/L. These values are below the maximum limits stipulated by the legislation [6,7] (Table 3).

Table 2. Maximum levels of heavy metals in the water, according to the legislation in force

	Irrigation		**Potable for human consumption**			**Residual**	**Surface**
Heavy Metal	MRV (mg/L)	MAV (mg/L)	MRV (mg/L)	MAV (mg/L)	VP (mg/L)	VLE (mg/L)	MAV (mg/L)
Arsenic (As)	0.10	10	0.010	0.050	0.010	1	0.1
Cadmium (Cd)	0.01	0.05	0.001	0.005	0.005	1	0.01
Lead (Pb)	5	20		0.050	0.010	0.20	0.05
Mercury (Hg)	----	----	0.0005	0.001	0.001	0.05	0.001
Nickel (Ni)	0.5	2	----	----	0.020	2	0.05

VLE, emission limit value (concentration that must not be exceeded) DL-236/98

MAV, maximum allowable value (value that must not be exceeded) DL-236/98

MRV, maximum recommended value (value that must be respected or not exceeded) [6].

VP, parametric value (maximum residual concentration of the polymer in contact with water) [7].

3.2 Effect of irrigation water on rice grain quality

Total arsenic, cadmium, lead and mercury concentrations found in rice samples are shown in Table 3. Portuguese legislation sets for limits on the content of heavy metals in water for human consumption and irrigation water; however, limits for food products are not yet defined. Considering the maximum levels of 0.2mg/kg, fixed for inorganic arsenic, total cadmium, and lead in rice by the Regulation of the European Communities [8,9], it appears that lead is below this threshold in all samples.

Mercury was not detected in any of the samples. In any case, there are no legislated maximum values for this metal for rice. The cadmium content of rice irrigated with NW (0.3mg/kg) was above the limit for this heavy metal.

The soil of the SDI pots was kept in oxic conditions, which would have increased the solubility of this element, due to the favorable conditions for the desorption of aluminum, iron and manganese oxy-hydroxides or solubilization of CdS or $CdCO_3$. In this drained soil, it is produced cadmium sulfate ($CdSO_4$), which, being soluble in water, allows its greater absorption by rice roots. Cadmium is strongly retained in flooded soils (reducing condition), accumulating less cadmium than that developed under oxidizing conditions, which is related to the formation of cadmium sulfide in anoxic conditions [10].

Table 3. Total arsenic, cadmium, lead and mercury in the unhusked rice grain (average values of 2019-2021)

Heavy metal (mg/kg)	SDI-TWW	SDI-NW	F-NW
Arsenic	0.110	0.105	0.445
Cadmium	0.055	0.270	0.195
Lead	0.073	0.070	0.120
Mercury	0.005	0.004	0.045

Treatments: SDI-TWW, underground drip irrigation with TWW; SDI-NW, underground drip irrigation with normal water; F-NW, irrigation by continuous flooding with normal water.

The arsenic content found in rice shows a direct relationship with growing conditions (aerobic or anaerobic). The rice produced in flooding contains the highest levels in pot (F-NW, 0.445 mg/kg) and in normal paddies with an average value of 0.24 mg/kg, according to Simões [11] in traditional carolino rice (japonica variety) produced in Lower-Mondego Valley.

The accumulation of arsenic in plants depends essentially on its bioavailability (arsenic speciation) and on the levels of arsenic present in the soil [12]. Given that in this trial the same soil (composition and type) was used in all treatments and that all irrigation water contained trace levels of arsenic (Table 3), the differences found are because other factors that resulted in different arsenic bioavailability in treatments.

Under conditions of almost permanent flooding, in anaerobiosis, arsenic exists mainly dissolved in the form of arsenite, its most toxic and most bioavailable form for the plant [13], which justifies the capture of arsenic by cultivated rice in flooding with NW order of magnitude greater than that of the drip irrigated with TWW. Arsenic is carried by the phloem to the seeds where it is stored in vacuoles and other tissues of the edible parts of the grain. Their storage in the grain is done mainly in the form of arsenite and dimethylarsinic acid [14].

4. Conclusions

The use of TWW in rice irrigation is a challenging issue. The experiment carried out in pots, based on physicochemical analysis of the water samples, confirmed the soil salinity risk associated with TWW. The high EC of drainage water, with 1700µS/cm, with a predominance of the element's sodium and chlorine. This issue is very important for productivity and soil conservation. It should be noted that after the autumn-winter period, in which the pots were subject to precipitation and free drainage, the EC values dropped to values like the initial ones. The results on heavy metals in irrigation and drainage water, lead to the conclusion that they are at levels below the maximum stipulated by legislation.

Regarding the levels of heavy metals detected in rice grains, it was found that the grain produced in the SDI-NW treatment has a cadmium content above the legal limit. The greater solubility of this element is explained by the redox potential and the pH of the soil in these test conditions, although no progress has been made in this evaluation. The arsenic level was higher in grains produced in the FC treatment, whereas that value in the SDI treatment is insignificant. Results showed that the irrigation with TWW rises the EC of drainage water, but that the rice grain does not present increased risks to public health due to the low content of arsenic, cadmium, lead and mercury. Moreover, the SDI method is advisable to avoid human and animal contact with putative contaminants present in this water and thus safeguarding Environmental and Food Safety. The use of TWW must imply a careful plan to monitor the soil salinity throughout the irrigation campaign, to prevent critical situations of reduced production, or soil conservation. Long term soil effects of TWW, including winter percolation, will be assessed in the future.

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