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Assessment of K^+, Na^+ and Cl^- Content in Rice Tissues and Soil Irrigated With Wastewater

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Abstract

In recent years, many studies have been devoted to investigating consequence of wastewater usage in irrigation. Herein, assessment of wastewater irrigated rice crop (selected rice cultivars such as, Shandar, Shua-92 and Sarshar) irrigated water and cultivating soil samples of Tandojam, Hyderabad city and its vicinity were selected for analysis. In this study, pH, EC, Na^+, K^+ and Cl^- ions were observed for wastewater, irrigated rice cultivars and soil, and compared with canal water irrigated rice cultivars and soil. The application of wastewater resulted an increase in Na^+, K^+ and Cl^- concentration in rice cultivars tissues as compared to canal water rice cultivar. The obtained results have shown that wastewater is not suitable for edible crops like, rice irrigation, due to high alkaline pH, EC value, and higher K^+, Na^+ and Cl^- ions concentration in this water.

Keywords: Ions content, Rice cultivars, Wastewater irrigation.

Introduction

Water of various sources (river water, groundwater and wastewater) is used to irrigate crops. Wastewater is widely used for irrigation in countries located in arid and semi-arid areas of the world [1]. Pakistan falls under arid and semi-arid zone of the world. In Pakistan, the surface water (river water) is not enough to meet the requirements of crops and its shortage is a challenge for the growers. Therefore, farmers are compelled to use groundwater or wastewater for crop production. Wastewater is commonly used for crop cultivation in the peri-urban areas of the country, for example Karachi, Faisalabad, Sheikhupura, and Peshawar [2, 3, 4,]. The urban agricultural soils of Pakistan are often irrigated with city effluents for growing vegetables [5].

Wastewater irrigation has both beneficial and harmful effects on plants and soils. Wastewater irrigation offers a number of benefits including: a rich source of macro-and-micro nutrients and organic carbon, reduces the use of synthetic fertilizers, acts as a low-cost wastewater disposal method, conserves fresh water resources, enhances crops yield, improves soil physical and chemical properties, and greater income by production of high-value crops [6-10]. In contrast, wastewater has many adverse effects, such as decrease in crop growth and yields, increase in electrical conductivity and metal contents (e.g. Cu, Zn, Co, Cd, Cr, Pb, Ni) in soils, and presence of pathogens that can cause health disorders (like cholera, typhoid, gastric ulcer, skin diseases) in humans and animals [11,12].

The high concentration of salts in wastewater and soil beyond crop tolerance level has been reported by many researchers [13,14]. The consequence of salt-enriched wastewater application is an increase in soil salinity and reduction in crop growth, yield and physiological attributes [15]. Often people associate the term salt to sodium chloride (NaCl). In reality, the salts that affect water, soils and plants are a combination of sodium, calcium, potassium, magnesium, chlorides, nitrates, sulfates, bicarbonates and carbonates ions. Municipal wastewater generally contains many salts which originate from houses, laboratories, restaurants, hospitals etc. Salts which commonly come from these sources include NaCl, $NaHCO_3$, $Na_2CO_3.10H_2O$, Na_2SO_4, K_2SO_4, $CaCO_3$, $CaCl_2$ and $CaSO_4$; these and many other salts are discharged in sewage water. These salts may get ionized into their respective cations (e.g. Na^+, K^+, Ca^{2+}) and anions (e.g. Cl^-, HCO_3^-, CO_3^{2-} and SO_4^{2-}) in water. Each one of these cations and/or anions behaves differently and are required by plants, animals and humans in different amounts [16]. Therefore, it is prerequisite to determine the quality of wastewater with respect to cations and/or anions before its application to soils and crops. The present study has been proposed to evaluate the quality of untreated wastewater with respect to three selected ions (Na^+, K^+ and Cl^-) and the buildup of these ions in rice tissues and irrigated soil.

The objectives of this study were to determine the content of Na^+, K^+ and Cl^- ions in rice cultivars tissues (straw and paddy) as a function of wastewater application and to determine the buildup of selected ions in soil with respect to depths.

Materials and Methods

Study sites

The study was conducted at farm of Nuclear Institute of Agriculture (NIA) Tandojam, Hyderabad (25º 25′ 16.17″ N, 68º 30′ 51.04″ E). Harvesting field of 75 m x 100 m was used for three rice cultivars (Shandar, Shua-92 and Sarshar), which were further divided into four subplots (25 m x 20 m) for each rice cultivar. At the wastewater irrigated (WWI) site, mixture of municipal sewage wastewater and automobile workshops effluents were used for rice cultivars irrigation. The canal water irrigated (CWI) field was located at Latif farm, Sindh Agriculture University Tandojam, Hyderabad (25º 26′31.48″ N, 68º 33′12.29″ E). The selected rice cultivar (Shandar) was cropped in subplots of size 56 m x 45 m.

Sample collection of wastewater and canal water

Wastewater (WW) and canal water (CW) used for irrigation were collected in cleaned polypropylene bottles (500 mL). The samples were collected in duplicate manner at a time interval of 10 minutes from channel adjacent to irrigated respective fields. The WW and CW samples were immediately transferred to the laboratory in Department of Soil Science, Sindh Agriculture University Tandojam, Hyderabad. These samples were instantly filtered through the Whatman (No.42) filter paper and in the filtrates pH and EC were observed by using digital pH and EC meters. Afterwards, 1 mL HNO_3 was added to control microbial activity [17]. These samples were kept at 5 ºC till further analysis. The K^+ and Na^+ were analyzed in CWI and WWI samples by flame photometer; however, Cl^- ion concentration was determined by Mohr's titration method.

Rice plant tissues collection and processing

Rice cultivars were collected at maturity. Five plants of an individual rice cultivar from each subplot were collected randomly by cutting at the soil surface with sharp sickle. By following this sequence, four replications of plant samples were collected of each rice cultivar from WW and CW irrigated areas. The collected rice plant samples were separated into straw and paddy manually. The samples were dried in an oven at 70 °C for 48 hours. Afterwards, straw and paddy samples were ground into powder through grinding mill. The powder of these rice tissues was used to determine the concentration of K^+, Na^+ and Cl^-. The K^+ and Na^+ were determined by wet digestion as reported elsewhere [18], while Cl^- was determined in plant tissues by already reported method in scientific literature [19].

Soil collection, processing and analysis

After rice harvest, soil samples were collected from each subplot of an individual cultivar at two depths (0-15 and 15-30 cm) by stainless steel auger. From each subplot, four soil samples were collected, which were composited to make one composite sample. This method was used to make four samples (four replications) for each cultivar at a defined depth. In a similar way, the soil samples at two defined depths were collected from the plots where CW is used for irrigation in rice cultivar.

The soil samples were air dried, ground using pestle and mortar, passed through 2 mm stainless steel sieve and stored in plastic bags. The samples were used for the determination of selected physico-chemical properties (EC, pH, organic matter content and texture) and ions (K^+, Na^+ and Cl^-). The EC and pH of soil samples were determined in 1:2.5 soil water extracts using EC and pH meters. The organic matter content in soils and extractable K^+ and Na^+ were determined by reported method as earlier [18], while texture was carried out by hydrometer method [20]. Soluble Cl^- in soil samples was determined by Mohr's titration method [21].

Results and Discussion

EC, pH, and ions (K^+, Na^+ and Cl^-) concentration in irrigation waters

The laboratory analysis of irrigation water samples showed that the EC of WW and CW samples were observed 3.67±0.03 dS m^{-1} and 0.66 ± 0.07 dS m^{-1}, respectively (Table 1). These values indicate that the WW sample is saline and is above the FAO standard limit (3.0 dS m^{-1}), while the CW is non-saline [22]. The increased EC in WW may be attributed to the potential presence of various soluble salts e.g. NaCl, KCl, Na_2SO_4, NaOH, Na_2CO_3, $NaHCO_3$, and NaClO which are routinely used in households. High EC of WW has also been reported previously, they found the high level of EC in sewage water (6.84 dS m^{-1}) which was above the acceptable level [23]. High EC level (0.84 to 17.58 dS m^{-1}) in WW samples of three Nullahs (Dek, Bisharat and Aik) was found [24]; this water is commonly used for rice cultivation across many sites of Punjab.

Table 1. **EC, pH, and ions (K^+, Na^+ and Cl^-) concentration in irrigation waters used for rice cultivation in selected areas around Tandojam.**

Type of irrigation	EC (dS m^{-1})	pH	K^+ (mg L^{-1})	Na^+ (meq L^{-1})	Cl^- (meq L^{-1})
Wastewater	3.67±0.03	8.7±0.10	175±15.0	16.3±0.2	23±0.50
Canal water	0.66±0.07	7.5±0.05	85±5.0	3.0±0.4	10±0.0

Each value represents mean ± SE (*n*= 2)

The pH of WW and CW samples was recorded as 8.7±0.10 and 7.5±0.05 respectively (Table 1). The pH of WW was strongly alkaline and of CW was slightly alkaline in reaction. According to FAO acceptable level for pH (8.4), the WW is unfit for irrigation [22]. A high pH in WW indicates the presence of excessive concentration of carbonate and bicarbonate salts in WW [25]. A very high pH (9.8) has also been reported by other researchers in WW [26]. Another study of lagooned urban WW has reported the high alkaline pH of WW [27].

The K^+ concentration in WW was 175±15.0 mg L^{-1} while it was 85±5.0 mg L^{-1} in CW (Table 1). This observation shows that the K^+ concentration in WW is 2.1 times higher than CW. The K^+ concentration in WW and CW were found higher than the FAO standard (2 mg L^{-1}). The high concentration of K^+ (485 mg L^{-1}) in WW is also reported in Isfhan, Iran [28]. However, another study reported K^+ concentration in WW was less (39 mg L^{-1}) than present study [26].

The Na^+ concentration in WW and CW were 16.3±0.2 meq L^{-1} and 3.04±0.4 meq L^{-1}, respectively (Table 1). The observed result shows that the Na^+ concentration in WW is 5.3 times higher than CW. Although, observed Na^+ concentration in WW was above permissible limits as reported by FAO, which is 9 meq L^{-1} [29]. However, in this regard in comparison with other studies Na^+ is found least in WW of Tandojam, Hyderabad [30, 31].

The Cl^- concentration in WW and CW were found to be 23±0.50 meq L^{-1} and 10±0.0 meq L^{-1} respectively (Table 1). This indicates that the Cl^- concentration in WW is 2.3 times higher than CW. According to FAO standards, a value of 10 meq L^{-1} of Cl^- in WW is acceptable (FAO 1985). Although, in Nabeul and Sfax, Tunisia irrigation of crops were carried out with high content of Cl^- (12-72.7 meq L^{-1}) in WW [30, 32].

Ions concentration in rice plants paddy and straw parts

The K^+ concentration (%) in paddy and straw varied in all rice cultivars (Table 2). In general, WW irrigated rice cultivars contained more K^+ in their paddy and straw than the CW irrigated rice cultivar. Maximum K^+ concentration in paddy was recorded in Sarshar (3.45±0.17%) irrigated with WW, followed by Shua-92 (2.98±0.09%) and Shandar (2.45±0.19%). Minimum K^+ concentration in paddy was recorded in Shandar (1.55±0.18%) that was irrigated with CW. In straw, the maximum K^+ concentration was recorded in Sarshar (5.63±0.43%), followed by Shua-92 (4.50±0.31%) and Shandar (2.95±0.36%) irrigated with WW. Minimum K^+ concentration in straw was observed in Shandar (2.35±0.12%) irrigated with CW. Overall, the cultivars retained more K^+ in their straw than paddy irrespective to source of irrigation. However, over all WWI rice cultivars have shown higher K^+ concentration. The rice crops possess higher concentration of K^+ as observed in Faisalabad, Pakistan by using Muriate of Potash (MOP) as fertilizer for rice crops [33].

Table 2. **Rice cultivars content of K^+, Na^+ and Cl^- (%) in rice plant's paddy and straw parts.**

Rice cultivars	K^+ in paddy	K^+ in straw	Na^+ in paddy	Na^+ in straw	Cl^- in paddy	Cl^- in straw
Shandar (canal water irrigated)	1.55 ± 0.18	2.35 ± 0.12	0.53 ± 0.17	0.55 ± 0.21	0.15 ± 0.08	0.28 ± 0.03
Shandar	2.45 ± 0.19	2.95 ± 0.36	0.33 ± 0.03	2.78 ± 0.21	0.63 ± 0.10	0.67 ± 0.04
Shua-92	2.98 ± 0.09	4.50 ± 0.31	0.35 ± 0.03	1.58 ± 0.20	0.54 ± 0.16	0.48 ± 0.11
Sarshar	3.45 ± 0.17	5.63 ± 0.43	0.30 ± 0.04	1.58 ± 0.17	0.26 ± 0.04	0.57 ± 0.09

Each value is a mean ± SE (n = 4)

Maximum Na^+ concentration in paddy was recorded in Shandar (0.53±0.17%) irrigated with CW and minimum was noticed in Sarshar (0.30±0.04%) irrigated with WW (Table 2). Shandar contained 0.33±0.03% and Shua-92 contained 0.35±0.03% Na^+ in their paddy when irrigated with WW. In straw, maximum Na^+ concentration was observed in Shandar (2.78±0.21%), followed by Shua-92 (1.58±0.20%) and Sarshar (1.58±0.17%) irrigated with WW. The minimum concentration of Na^+ in straw was observed in Shandar (0.55±0.21%) that was irrigated with CW. With respect to irrigation sources, the total Na^+ concentration (paddy + straw) in WW irrigated rice cultivars was relatively higher than the rice cultivar that was irrigated with CW. The Na^+ was retained more in straw as compared to paddy of rice cultivars that were irrigated with WW. In case of CW irrigated rice cultivar, there was more or less equal concentration of Na^+ in rice paddy and straw. In nutshell, more or less, equal Na^+ concentration was taken up by paddy of rice cultivars irrigated with both kinds of irrigation waters. In this study, we found high concentration of Na^+ in rice tissues of rice cultivars which is due to WW (Table 1), same output was reported elsewhere [34].

Maximum Cl^- concentration was observed in paddy part of rice plant for all rice cultivars in WWI such as, Shandar (0.63±0.10%), Shua-92 (0.54±0.16%) ans Sarshar (0.26±0.04%). Whereas CWI rice cultivar Shandar shown 0.15±0.08% Cl^- (Table 2). In straw part of rice plant, maximum Cl^- was observed in Shandar (0.67±0.04%), and Sarshar (0.57±0.09%), followed by Shua-92 (0.48±0.11%) in WWI rice. The minimum Cl^- concentration was observed in rice cultivar, Shandar (0.28±0.03%) which was CWI. Overall, a relatively higher concentration of Cl^- in rice tissues was observed in plants that were irrigated with WW in comparison to plants that were irrigated with CW. Among paddy and straw, the Cl^- concentration was equally distributed between these tissues in most cases, irrespective of irrigation source. The possible reason for high concentration of Cl^- in rice tissues was because of high concentration of Cl^- in WW (Table 1). The observed results of Cl^- are like Faisalabad, Pakistan reported results, where use of MOP as fertilizer has explained high content of Cl^- [33].

Physico-chemical properties and ions content of soils irrigated with canal water and wastewater

The EC of surface soil was 0.56±0.03 dS m^{-1} and of subsurface soil was 0.26±0.01 dS m^{-1} in plots that were irrigated with CW (Table 3). The soils irrigated with WW had EC from 1.02±0.09 dS m^{-1} to 1.13±0.04 dS m^{-1} at surface and from 0.84±0.10 dS m^{-1} to 1.11±0.04 dS m^{-1} at subsurface level. The CWI soil and WWI soil, both soil surfaces were observed non-saline [18]. However, the soil EC was found relatively higher for WWI than CWI. As high value of EC was observed in

WW (Table 1), which caused higher EC value of WWI soil too [35, 7].

***Table 3*. Electrical conductivity of soils irrigated with canal water and wastewater.**

Plots with rice cultivars	Soil depth (cm)	EC (dS m^{-1})
Shandar (canal water irrigated)	0-15	0.56 ± 0.03
	15-30	0.26 ± 0.01
Shandar	0-15	1.13 ± 0.04
	15-30	1.11 ± 0.04
Shua-92	0-15	1.06 ± 0.07
	15-30	1.00 ±0.06
Sarshar	0-15	1.02 ± 0.09
	15-30	0.84 ± 0.10

Each value is mean ± SE (*n* = 4)

***Table 4.* Physico-chemical properties of soils irrigated with canal water and wastewater.**

Soil	Soil depth (cm)	pH	Organic matter (%)
Canal water irrigated soil	0-15	8.4 ± 0.02	1.34 ± 0.10
	15-30	8.4 ± 0.05	1.01 ± 0.15
Wastewater irrigated soil	0-15	8.0 ± 0.08	1.44 ± 0.20
	15-30	8.3 ± 0.07	1.53 ± 0.13

Each value is mean ± SE (*n* = 4)

The pH of the CWI soil was 8.4±0.02 at the surface and 8.4±0.05 at subsurface level (Table 4). The pH of WWI soil was 8.0±0.08 at surface and 8.3±0.07 at subsurface. Categorization of soil pH, as reported elsewhere [36] indicates that the soil pH was moderately alkaline at surface and subsurface level in CWI. In contrast, the soil pH was slightly alkaline at surface and moderately alkaline at subsurface with the application of WW. The soil pH significantly increased due to WW, being more alkaline than river water [7].

Soil organic matter content of CW irrigated soil was adequate (1.34±0.10%) at surface and marginal (1.01±0.15%) at subsurface soil level (Table 4). The WW irrigated soil organic matter content was recorded adequate at both surfaces (1.44±0.20% at surface and 1.53±0.13% at subsurface level). The possible reason of high organic matter content in soil is that the municipal water is generally enriched with organic materials.

Soil extractable K^+ content was adequate where the field was irrigated with CW (112.5 to 131.3 mg K^+ kg^{-1} of soil; Table 5). In contrast, K^+ content was adequate to high (100 to 212 mg K^+ kg^{-1} of soil) where WW was applied to soil. Same results were obtained by other researchers they observed that soil K^+ increased in soil when irrigated with WW [37].

***Table 5.* Extractable K^+, Na^+ and soluble Cl^- content in soils irrigated with canal water and wastewater.**

Plots with rice cultivars	Soil depth (cm)	K^+ (mg kg^{-1})	Na^+ (%)	Cl^- (%)
Shandar (canal water irrigated)	0-15	131.3±12.0	0.77±0.15	0.010±0.00
	15-30	112.5±7.2	1.33±0.28	0.004±0.001
Shandar	0-15	187.5±16.1	0.83±0.50	0.082±0.01
	15-30	100.0±14.4	1.34±0.29	0.053±0.01
Shua-92	0-15	175.0±14.4	1.41±0.12	0.084±0.01
	15-30	106.3±15.7	1.24±0.24	0.038±0.00
Sarshar	0-15	212.5±12.5	0.75±0.05	0.057±0.01
	15-30	150.0±17.7	1.11±0.18	0.023±0.00

Each value is mean ± SE (*n* = 4)

Extractable Na^+ content was ranged from 0.77±0.15 to 1.33±0.28% in soil irrigated with CW and 0.75±0.05 to 1.41±0.12% in soil irrigated with WW (Table 5). Relatively high accumulation of Na^+ in soil of WW irrigated field is that the WW contains more Na^+ ions (Table 1). Similar results were obtained from other studies [37]; they observed that with the application of WW, Na^+ concentration in soil increased. These researchers further proposed that WW build up salinity due to the accumulation of Na^+ ions.

Relatively more soluble Cl^- was found in soil irrigated with WW (0.023±0.00 to 0.084±0.01%) as compared to CW irrigated soil (0.004±0.001 to 0.010±0.00%; Table 5). The possible reason of high amount of Cl^- in WW irrigated field corresponds to high Cl^- concentration in WW (Table 1). High content of Cl^- in soil after the application of sewage water has been reported previously [38].

Conclusions

Untreated wastewater has unacceptable levels of EC, pH, K^+, Na^+ and Cl^- ions. As a consequence, excessive concentrations of these ions are observed in rice plant tissues (paddy and straw) and irrigated soil. The current practice of using untreated wastewater should be avoided for rice cultivation. This may lead to build up of Na^+ and Cl^- in plant tissues, and may convert the fertile soil to a salt-affected soil.

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