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Response of Soil Microbial Population and Grain Yield of Wheat Cultivars Irrigated with RSC Water

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ABSTRACT

Soil microbes are the vibrant components of rhizospheric microbiome and control vital biogeochemical processes. This investigation assessed the effect of long-term irrigation with water containing high residual sodium carbonate (RSC) and crop cultivars on microbial populations and wheat yields. Five types of irrigation water having different levels of residual sodium carbonate comprised: T_1–Best available groundwater, T_2–Residual sodium carbonate water 1 (RSC- 5 me/L), T_3–RSC water 2 (RSC 10 me/L), T_4–RSC water 3 [RSC 10 treated with gypsum (RSC 10 neutralized to RSC 5 me/L with gypsum) and T_5–RSC water 4 [RSC 10 treated with sulphur (RSC 10 neutralized to RSC 5 me/L with sulphur) continuously applied under lysimeters. RSC water significantly deteriorated soil microbial population under both wheat cultivars. The maximum reduction was noticed under RSC 10 water irrigation. Soil microbial population negatively associated with soil exchangeable percentage (R^2 = 0.467-0.743) and sodium adsorption ratio of soils (R^2= 0.485-0.831) after harvest of both the crop cultivars. Moreover, wheat yield was also significantly reduced with continuous irrigation having high level of RSC in water. Decline was more in HD 3226 compared to KRL 210 cultivars. Partial neutralization of RSC from 10 to 5 me/L through gypsum and sulphur recovered the soil microbial population and wheat yield. However, it was not reasonable to sustain the soil microbial population and wheat yield under long term. Amelioration of RSC through different amendments below RSC 5 me/L further requires research to obtain acceptable soil microbial population and yield.

Key words: Wheat varieties, soil microbial populations, residual sodium carbonate, irrigation

INTRODUCTION

Soil microbes are the important indicators of soil health and crop productivity (Shaaban *et al.*, 2023). Different microbes are involved in biogeochemical processes in soil and thus control the nutrient recycling (Neemisha and Sharma, 2022; Singh *et al.*, 2023). But, the microbial populations depend upon nature of soil, irrigation water quality, fertilizers, pesticides and amendment application, rainfall, nature of crops and their varieties (Meier *et al.*, 2021). Crop productivity largely depends on residual sodium carbonate (RSC) content in irrigation water under arid to semi-arid region of the country (Minhas *et al.*, 2021; Yadav *et al.*, 2023). In, Haryana, Punjab, Rajasthan, Uttar Pradesh, Andhra Pradesh and Tamil Nadu, the underground water used for irrigation contains high amount of RSC than the permissible limits (Singh *et al.*, 2022a). Continuous irrigation with high RSC water degrades soil quality and crop yield due to presence of carbonates (CO_3^{2-}) and or bicarbonate (HCO_3^-), beyond the threshold limits (Dagar *et al.*, 2019; Kumar *et al.*, 2022). The main reason of soil alkalinization/sodification is the long-term application of ground water for irrigation having high amount of RSC. Resulting in accumulation of salts to higher level and also changes the appropriate ionic balances which magnifies soil alkalinization, therefore, decreases the crop yield. Although, the effects of irrigation water having high RSC are mostly seen on soil physical and chemical properties of soils, however, it also negatively affects soil microbial populations (Singh *et al.*, 2022a). The crop varieties are vital factors that affect the soil microbial populations to greater extent (Semchenko *et al.*, 2021). Therefore, it is critical to assess the soil microbial populations (population of bacteria, fungi and actinomycete) and yield of two wheat varieties irrigated with RSC water since 2004.

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MATERIALS AND METHODS

This investigation was carried out at ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India in lysimeters of 2 m^3 size. The initial soils belonged to sandy loam texture having exchangeable sodium percentage value of 5.3, soil pH (1:2) 7.8 and electrical conductivity of saturation extract 0.7 dS/m.

Factor one had five treatments of irrigation water quality which included T_1: Best available water (BAW), T_2: RSC 5, T_3: RSC 10, T_4: RSC 10 (T_3) neutralized to RSC 5 with application of gypsum (RSC 10 treated with gypsum) and T_5: RSC 10 (T_3) neutralized to RSC 5 with application of sulphuric acid (RSC 10 treated with sulphuric acid). RSC were calculated by the equation:

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$$

Five qualities of irrigation water were applied in respective plots and two different wheat varieties, namely, T_1–KRL-210 and T_2–HD 3226 were grown (2021-22) in each plot with adopting recommended agronomic packages of practices. First irrigation was applied @ 100 L per plot before sowing, using respective RSC water. Afterward, five irrigations of 200 L (each plot) per plot were applied according to critical growth stages of wheat.

After wheat harvest, soil samples were collected from 0-15 cm soil depth and fresh samples were sieved using a 2 mm sieve and kept at 4°C for analysis of microbial population. Bacterial population was enumerated on nutrient agar (NA) medium through pour plating. The NA plates were kept in incubation for 48 h at 28°C. Fungal populations was enumerated on potato dextrose agar (PDA) added with streptomycin @ 30 µg/mL to hinder bacterial growth (Chandra *et al.*, 2020). The PDA plates were kept for incubation for 72 h at 30°C. Actinomycete population was enumerated on actinomycete isolation agar (AIA) added with nalidixic acid @ 50 µg/mL to check fungal growth. AIA plates were kept for incubation for 120 h at 28°C. Data were stated (mean of triplicate) as colony forming units (CFU)/g dry soil (Choudhary *et al.*, 2018). Exchangeable sodium percentage and sodium adsorption ratio of soil were measured. Both varieties of wheat were harvested in first fortnight of April 2022. The grain yield of wheat was determined by weighing and expressing the harvested wheat grains from each plot in terms of metric tons per hectare (t/ha) after the threshing and sorting processes. The measurement of biological yield of wheat involved the determination of weight for sun-dried plants with earheads, which was then expressed as t/ha. The analysis of variance (ANOVA) was made in randomized complete block design on SAS (9.4) under factorial experiment for calculation of significance at $P \leq 0.05$.

RESULTS AND DISCUSSION

Soil microbial populations were significantly declined with RSC water irrigation (Table 1). Irrigation with RSC water decreased bacterial population to 7.0, 11.2, 13.9 and 26.3% with RSC 5, RSC 10 treated with gypsum, RSC 10 treated with sulphur and RSC 10, respectively,

Table 1. Effect of RSC water irrigation and crop cultivars on soil microbial population

Properties		Irrigation treatments					Crop cultivars	
		BAW	RSC 5	RSC 10	RSC 10 treated with gypsum	RSC 10 treated sulphuric acid	KRL 210	HD 3226
Bacterial population (CFU × 10^5/g soil)	Mean	145.06[a]	134.87[b]	106.88[d]	128.88[bc]	124.87[c]	127.69[a]	128.53[a]
	SE (m)	2.57	3.55	2.94	2.36	3.17	3.42	3.37
Fungal population (CFU × 10^2/g soil)	Mean	39.95[a]	36.28[ab]	24.64[c]	34.68[b]	33.41[b]	32.90[a]	34.69[a]
	SE (m)	2.30	1.58	1.17	1.80	1.22	1.59	1.46
Actinomycete population (CFU × 10^5/g soil)	Mean	132.80[a]	111.26[b]	71.47[d]	84.09[c]	83.52[c]	96.12[a]	97.14[a]
	SE (m)	2.48	3.32	1.53	2.38	2.02	5.37	5.26

BAW = Best available water, RSC 5 = Residual sodium carbonate (RSC ~ 5.0 me/L), RSC 10 = Residual sodium carbonate (RSC ~ 10 me/L), RSC 10 treated with gypsum = RSC 10 neutralized to RSC 5 with application of gypsum, RSC 10 treated with sulphuric acid = RSC 10 neutralized to RSC 5 with application of sulphuric acid and CFU = Colony forming unit. Different superscripts significantly differ at $P < 0.05$.

compared to BAW. Wheat cultivars had comparable value of bacterial population. Fungal population reduced with RSC 10, RSC 10 treated with sulphur, RSC 10 treated with gypsum and RSC 5 irrigation in order of 38.3, 14.4, 13.2 and 9.2%, respectively, over the best available water; though the varietal effects remained unaffected. The highest reduction in actinomycete population was noticed with irrigation of RSC 10 (46.2%) followed by RSC 10 treated with sulphur (37.1%), RSC 10 treated with gypsum (36.7%), RSC 5 (16.2%) over best available water. All the microbial populations were negatively associated with exchangeable sodium percentage and sodium adsorption ratio of soils under both the varieties. The association of bacterial population to exchangeable sodium percentage was higher under KRL 210 cultivar (Fig. 1b, d), while its association to sodium adsorption ratio was greater under HD 3226 cultivar (Fig. 1a, c). Further, the value of association of fungal population to exchangeable sodium percentage and sodium adsorption ratio was higher under KRL 210 compared to HD 3226 cultivar (Fig. 2). However, association of actinomycete population to exchangeable sodium percentage and sodium adsorption ratio was higher under HD 3226 cultivar compared to KRL 210 (Fig. 3). Grain yield was significantly affected by RSC water irrigation (Fig. 4a, b). The maximum reduction was noticed with irrigation of RSC 10 (27.1 and 39.4%) followed by RSC 5 (21.9 and 35.9%), RSC 10 treated with sulphur (21.8 and 34.9%), RSC 10 treated with gypsum (15.7 and 33.4%) over BAW in grain yield of KRL 210 and HD 3226 wheat cultivars, respectively. Grain yield was comparable among treatments of RSC 5, RSC 10 treated with gypsum and RSC 10 treated with sulphuric acid. Further, biological yield was significantly affected by continuous irrigation through RSC water (Fig. 4 c, d). Decrease in biological yield was from 11.6-21.4 and 25.1-46.4% in KRL 210 and HD 3226 cultivars, respectively, under RSC water irrigations. Biological yield was comparable under treatments of RSC 5, RSC 10 treated with gypsum and RSC 10 treated with sulphuric acid.

Irrigation water contained CO_3^{2-} and HCO_3^- of Na^+, responsible for enhancing exchangeable sodium percentage and sodium adsorption

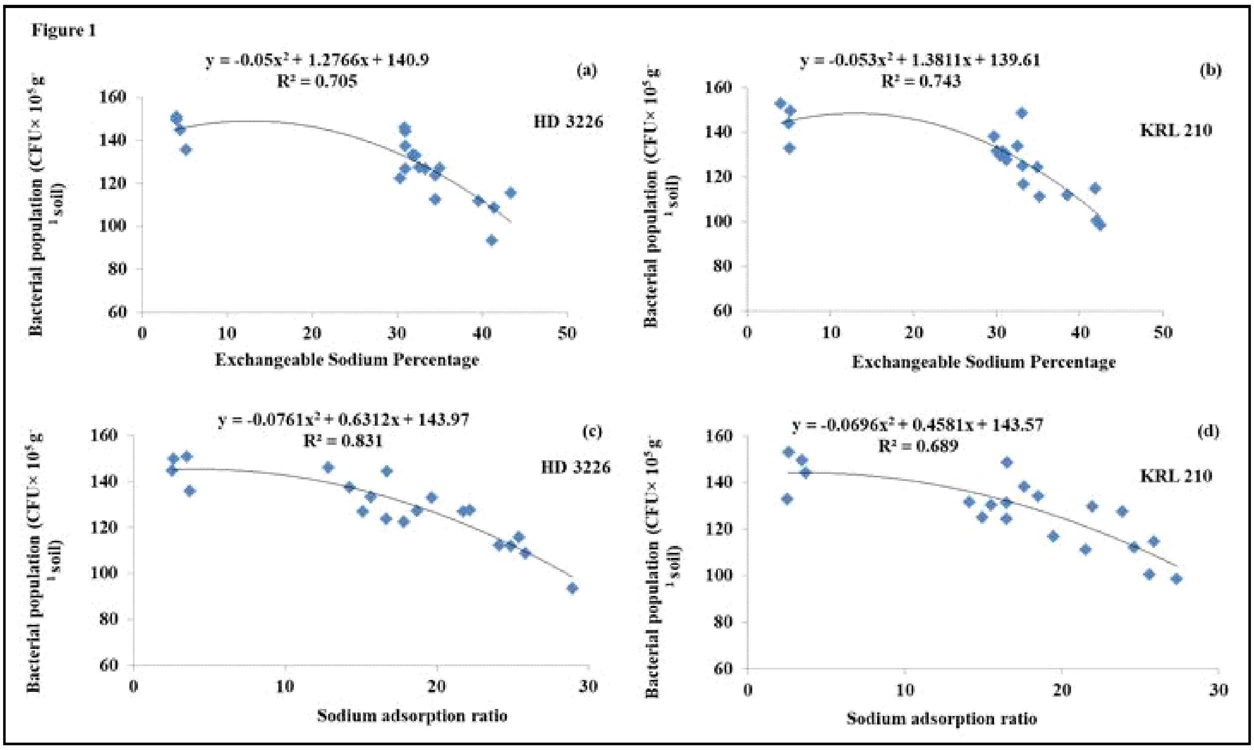

Fig. 1. Relationship between microbial population and soil properties (a) relationship of bacterial population with exchangeable sodium percentage under cultivar HD 3226, (b) relationship of bacterial population with exchangeable sodium percentage under cultivar KRL 210, (c) relationship of bacterial population with sodium adsorption ratio under cultivar HD 3226 and (d) relationship of bacterial population with sodium adsorption ratio under cultivar KRL 210.

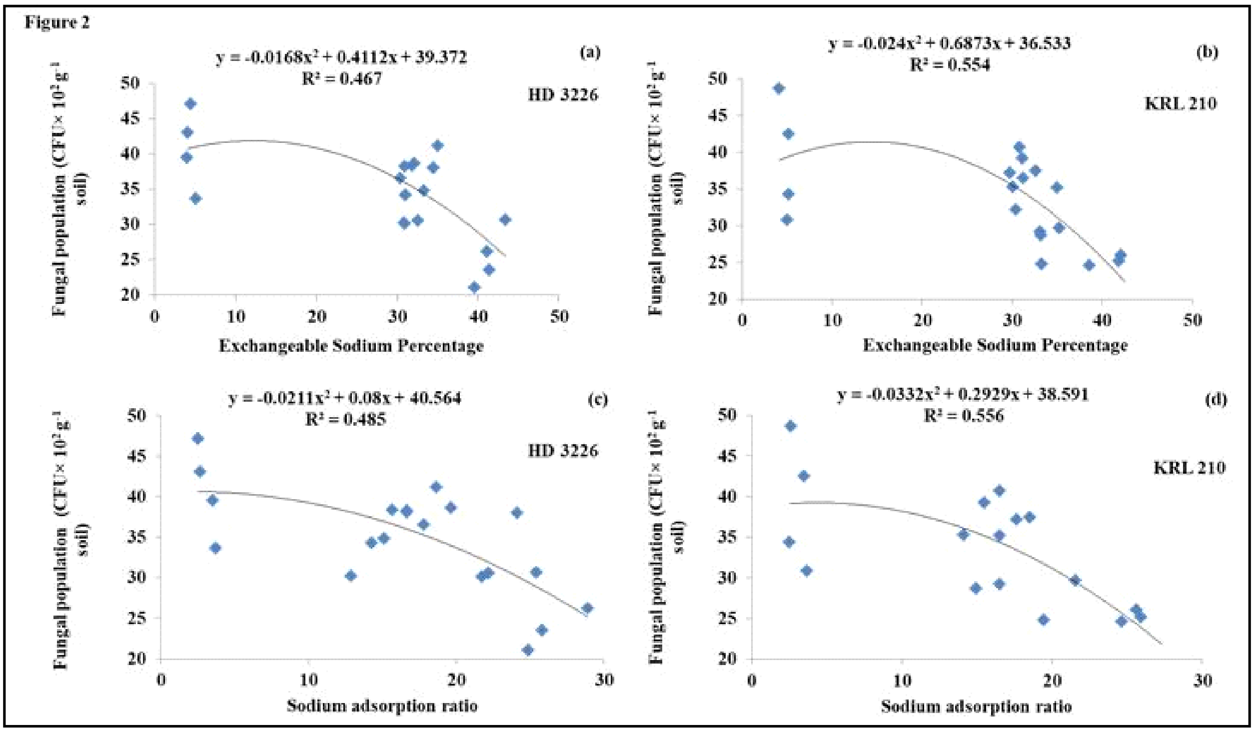

Fig. 2. Relationship between microbial population and soil properties (a) relationship of fungal population with exchangeable sodium percentage under cultivar HD 3226, (b) relationship of fungal population with exchangeable sodium percentage under cultivar KRL 210, (c) relationship of fungal population with sodium adsorption ratio under cultivar HD 3226 and (d) relationship of fungal population with sodium adsorption ratio under cultivar KRL 210.

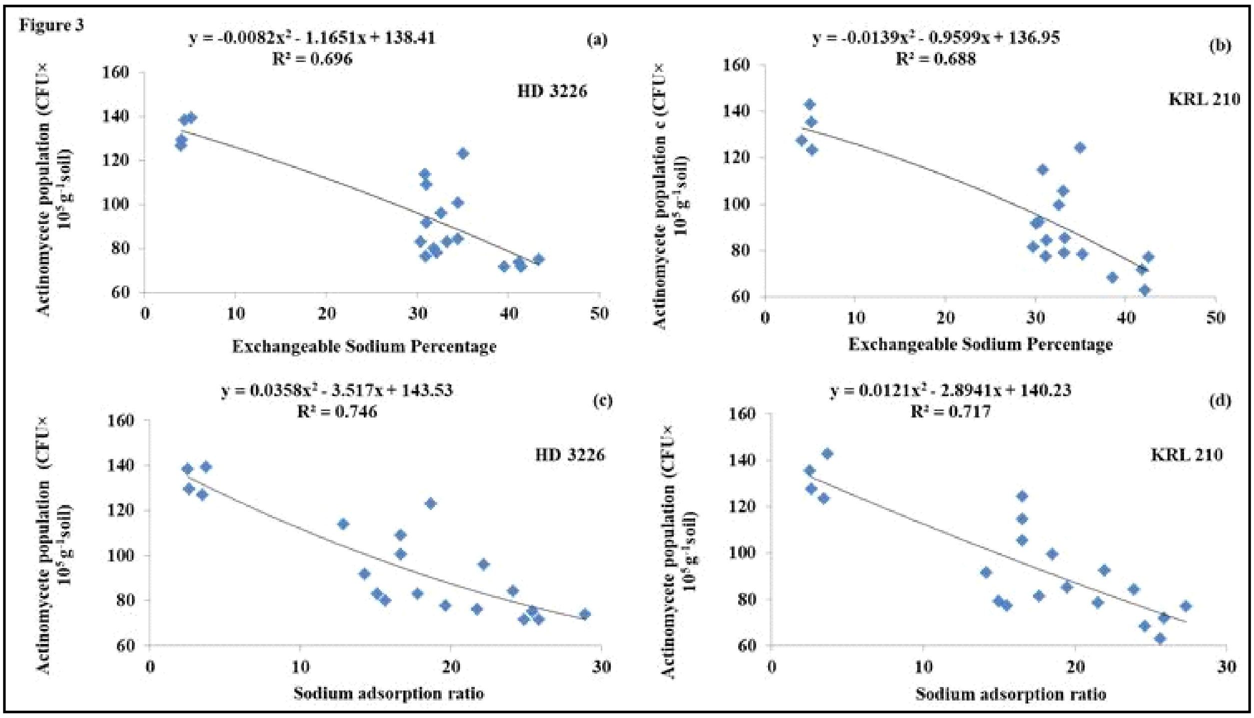

Fig. 3. Relationship between microbial population and soil properties (a) relationship of actinomycete population with exchangeable sodium percentage under cultivar HD 3226, (b) relationship of actinomycete population with exchangeable sodium percentage under cultivar KRL 210, (c) relationship of actinomycete population with sodium adsorption ratio under cultivar HD 3226 and (d) relationship of actinomycete population with sodium adsorption ratio under cultivar KRL 210.

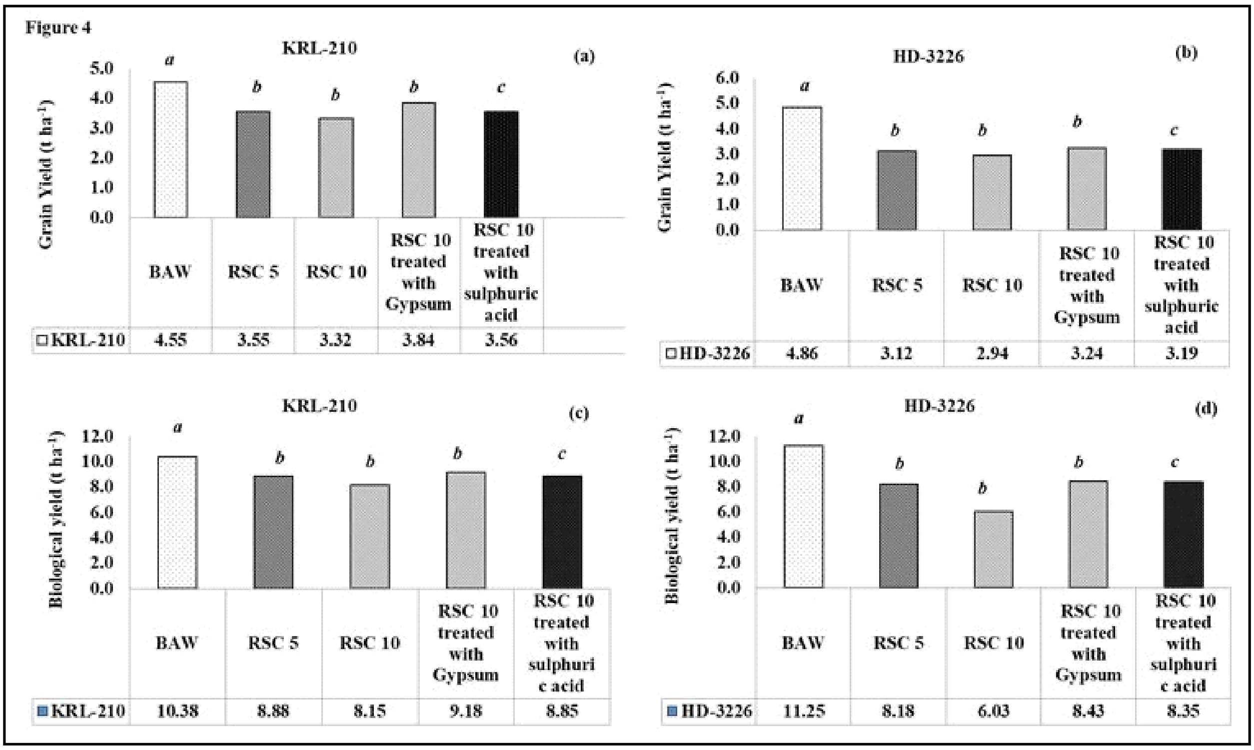

Fig. 4. Grain yield of wheat cultivars affected by RSC water irrigation (a) grain yield of cultivar KRL 210, (b) grain yield of cultivar HD 3226, (c) biological yield of cultivar KRL 210 and (d) biological yield of cultivar HD 3226.

BAW-Best available water, RSC 5 = Residual sodium carbonate (RSC ~ 5.0 me/L), RSC 10 = Residual sodium carbonate (RSC ~ 10 me/L), RSC 10 treated with gypsum = RSC 10 neutralized to RSC 5 with application of gypsum, RSC 10 treated with sulphuric acid = RSC 10 neutralized to RSC 5 with application of sulphuric acid.

ratio of soil and consequently disrupted the soil structure (Minhas *et al.*, 2021), hampering soil aeration and thus the soil microbial population was severely affected (Shaaban *et al.*, 2023). The high sodicity stress injured the soil microbial populations and changed the rhizospheric environment of respective crop cultivars (Singh *et al.*, 2022a). The reduced grain yields of wheat cultivars that were irrigated with high residual sodium carbonate waters could be attributed to the deficiency of calcium in the soil solution (Bali *et al.*, 2020). This deficiency was caused by the high residual sodium carbonate levels in the irrigation water, resulting in lower calcium levels in plants compared to sodium levels. The loss in grain yield could be attributed to the deleterious impact of high pH on other soil properties and the inadequate aeration resulting from elevated levels of exchangeable sodium percentage.

CONCLUSION

Irrigation with high RSC water declined the soil microbial populations under both the wheat varieties. Soil microbial population was negatively associated with exchangeable sodium percentage and sodium adsorption ratio of soils under both the crop cultivars. Further, wheat yield was also drastically affected with continuous application of RSC water. Reduction was more under HD 3226 variety compared to KRL 210. Partial neutralization of RSC from 10 to 5 me/L through gypsum and sulphur recovered the soil microbial population and yield of both the cultivars. But, it was not satisfactory to sustain the soil microbial population and yield under long term. Investigation on neutralization of RSC by amendments below RSC 5 me/L will be required to obtain satisfactory soil microbial population and wheat yield.

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