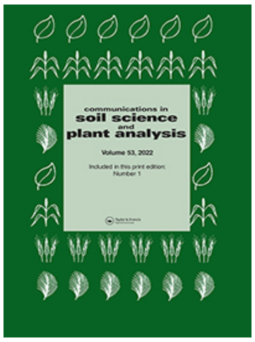


Taylor & Francis
Taylor & Francis Group

Communications in Soil Science and Plant Analysis

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/lcss20

# Can Addition of Organic Manures Mediated Sodicity Toxicity in Mustard Cultivation ?

**M. K. Meena, B. L. Yadav, M. L. Dotaniya & M. D. Meena**

**To cite this article:** M. K. Meena, B. L. Yadav, M. L. Dotaniya & M. D. Meena (2022) Can Addition of Organic Manures Mediated Sodicity Toxicity in Mustard Cultivation ?, Communications in Soil Science and Plant Analysis, 53:1, 77-88, DOI: 10.1080/00103624.2021.1984506

**To link to this article:** https://doi.org/10.1080/00103624.2021.1984506

Published online: 28 Sep 2021.

COMMUNICATIONS IN SOIL SCIENCE AND PLANT ANALYSIS
2022, VOL. 53, NO. 1, 77–88
https://doi.org/10.1080/00103624.2021.1984506

Taylor & Francis
Taylor & Francis Group

Check for updates

# Can Addition of Organic Manures Mediated Sodicity Toxicity in Mustard Cultivation ?

M. K. Meena[a,b], B. L. Yadav[b], M. L. Dotaniya[a], and M. D. Meena[a]

[a]ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur, India; [b]Department of Soil Science & Agricultural Chemistry, SKN College of Agriculture, Jobner, India

**ABSTRACT**

In India's arid and semiarid regions, soil sodicity is a restraining factor for crop productivity. There is less rainfall in these areas, and the groundwater has a high sodium adsorption ratio (SAR) and pH. However, by moderating soil fertility characteristics, these sites have a lot of potential for increasing the mustard yield. For this, a field experiment was conducted with four levels of sodicity water irrigation (6, 10, 20, and 30 SAR) and six levels of nitrogen (composed of different combinations with urea, farm yard manure-FYM, and vermicompost-VC). After harvesting of the crop, soil and plant samples were analyzed for physicochemical properties. Experimental results showed an increasing level of SAR mediating the soil parameters like soil organic carbon, available water content, and also mustard crop yield. Although replacement of N application doses with FYM and VC showed improvement in SOC and available water, it reduced soil pH, EC, SAR, and bulk density. Increasing sodicity levels from 6 to 20 SAR reduced the mustard seed yield by 16.05 q $ha^{-1}$ to 9.76 q $ha^{-1}$, whereas 50% RDN through urea and 75% RDN through VC increased the seed yield by 8.28 to 16.27 q $ha^{-1}$. Such studies have opened the door for sustainable mustard production in high sodicity areas, *i.e*. western part of Rajasthan, Gujarat, Haryana, and Punjab states by application of nitrogen through organics. It will improve the mustard growers' economic situation and contribute greatly to the country's economic growth in sodic soil areas.

**ARTICLE HISTORY**
Received 17 November 2020
Accepted 24 August 2021

**KEYWORDS**
Mustard production; organic manure; SAR; soil properties

## Introduction

The ecosystems of saline and alkaline soils are vulnerable, yet they have large potential to contribute to the Indian economy. Overexploitation of groundwater for domestic and agricultural purposes is depleting good-quality water resources in arid and semiarid areas (Beltran 1999; Meena et al. 2019b). Long-term application of saline and sodic groundwater, mostly in water-scarce locations, resulted in notable reductions in crop productivity in wide sections of fertile tract (Meena, Yadav, and Meena 2016; Srivastava and Srivastava 1993). Arid and semiarid regions face significant challenges such as low rainfall and high evaporation rates. However, saline/sodic groundwater can be extracted in large quantities from ground streams (Jalali and Merrikhpour 2008; Meena et al. 2021). Water quality indicators, particularly sodicity and salinity, are major concerns in the country's arid and semiarid regions when used for irrigation (Ayars and Tanji 1999). The groundwater in northwestern Rajasthan has a classic problem with high salt adsorption ratios (SAR) accompanied by excessive bicarbonates and nitrates. The soil structure in most of these regions is poor, and plant nutrients are scarce, making it difficult for crop plants to grow sustainably. With the help of organic and inorganic soil amendments, it is vital to regulate poor quality irrigation water.

**CONTACT** M. L. Dotaniya mohan30682@gmail.com ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur 321 303 , India

Sodium carbonate is the most common salt found in irrigation water with a high SAR followed by $NaHCO_3$ and $Na_2SO_4$ (Kaledbonkar, Meena, and Sharma 2019). The increased exchangeable sodium percentage (ESP) during long-term use of SAR irrigated water leads to a poor soil structure by formation of swelling and dispersion forms of clay particles. Thus, plants' reduced capacity of nutrient and water uptake, poor microbial activities and diversity, and toxicity of alkaline ions affected the productivity of soils, when high SAR water is used for irrigation (Singh et al. 2019). Organic manures have the benefit of transforming unusual surplus/waste into a useful agricultural product (Dotaniya et al. 2015). Organic inputs boost soil cation exchange capacity, plant nutrient availability, toxic ion adsorption, organic acid release, and soil health, all of which improve crop yield directly and indirectly. These interconnected mechanisms improved soil aggregates by forming a humus-metal complex and increased soil water-holding capacity, resulting in improved crop growth and production (Shukla et al. 2013). Organic compounds have a physicochemical buffering impact on soil. Plant nutrient dynamics in soil are mediated by low molecular organic acids released by soil microorganisms during the degradation of organic material (Dotaniya et al. 2014a, 2013b). Organic manures help reduce the negative effects of sodicity ions, which form during long-term irrigation with high SAR-containing irrigation water, by modulating the soil's pore space, infiltration capacity, and rate. Aside from these characteristics, breakdown products of organic materials generate chelates, which aid in plant nutrition and soil temperature regime regulation (Dotaniya and Datta 2014; Dotaniya et al. 2016, 2014b, 2013a).

India's population is predicted to grow to 1.73 billion people by 2050, necessitating 333 million tonnes of food grain production (Meena et al. 2019a). Enhancing food grain production in climate-restricted places, on the other hand, provides a wide range of management choices. In a sodicity-prone state like Rajasthan, the productivity of rapeseed-mustard can be boosted by using saline/sodic qualities water (represented by a high SAR) for irrigation (Singh et al. 2018). The majority of Rajasthan soils have high SAR and pH, with a total area of 10.69 lakh acre. Because the soils in the research zone are light in texture, it is possible that this sodic water can be successfully used for crop production with the right combination of inorganic fertilizer and organic manure. The rapeseed-mustard crop is hard in nature and tolerates RSC and SAR moderately. Organic carbon assimilation in sodic soil ecosystems may reduce sodic cation concentrations in soil solution and boost crop output. In this backdrop, a hypothesis was formulated to examine the impact of organic sources on crop yield, soil health parameters like bulk density, change in soil organic carbon dynamics, pH, ion concentration, moisture content and moisture stress condition, etc. To prove the above-mentioned hypothesis, a field experiment was conducted.

## Materials and methods

### *Experimental location*

The field experiment was conducted at Shri Karan Narendra College of Agriculture, Jobner, India, for two consecutive years (2012–13 and 2013–14) at the same site. Geographically, Jobner is situated 45 km west of Jaipur at $26^\circ 05'$ North latitude and $75^\circ 28'$ East longitude, at an altitude of 427 meters above the mean sea level (MSL). This area is classified as semiarid Eastern plain under agroclimatic zone III-a.

### *Climate and weather conditions*

The climate of the tract typically represented semiarid characteristics, *i.e.* aridity of the atmosphere and shortage of water availability with fluctuation in temperatures both in summer and winter. The maximum temperature ranged between 30 and 46°C, whereas winter temperature was recorded as low as 3°C. The average rainfall varied between 400 and 500 mm, most of which is received in the rainy season from July to September during the experimental period. Wells are the only source of irrigation for crop cultivation in most locations, and the water level is also relatively deep (about 45–50 meters). The tract is unique to the country's arid northern pearl millet-wheat tract, giving a long growing season for most crops; however, frost is common.

### Initial soil physicochemical properties

The surface soil samples were collected as per the standard procedure and carefully processed for physicochemical analysis. The field experiment soil was categorized as loamy sand in texture, belonging to the hyperthermic family of Typic Ustipsamments (Singh et al. 2020). The soil of the field was composed of 75 to 80% sand. During analysis, most of the soil parameters and their associated protocol were described in Singh, Chhonkar, and Pandey (2004). It had pH 8.5, $EC_e$ 2.52 dS $m^{-1}$, cation exchange capacity (CEC) 6.85 cmol (p+) $kg^{-1}$ soil, and organic carbon 2.47 g $kg^{-1.}$ The available nutrient status of the experimental soils was reported low in available nitrogen (N) (130.9 kg $ha^{-1}$) and available phosphorus (8.73 kg $ha^{-1}$) and medium in available potassium (128.7 kg $ha^{-1}$). Saturated paste extract was also used to examine soil salinity and sodicity cations and anions Table 1.

### Treatment combinations

The field experiment comprised 24 treatment combinations by making four levels of SAR water (SAR 6, 10, 20, and 30) and six nitrogen source treatments (control, 125% recommended dose of nitrogen (RDN) through urea, 75% RDN through urea +50% RDN through FYM, 75% RDN through urea +50% RDN through vermicompost (VC), 50% RDN through urea +75% RDN through FYM, and 50% RDN through urea +75% RDN through VC) in three replications. The experiment was conducted in a split-plot design (SPD) with three replications. Nitrogen was applied as per recommended dose of 60 kg N/ha. In this field experiment, four levels of sodicity (6, 10, 20, and 30 SAR) were artificially prepared and EC values were measured. The different levels of SAR were prepared by dissolving

**Table 1.** Initial physicochemical properties of experimental soil.

| Soil characteristics | 2012–13 |
|---|---|
| Coarse sand (%) | 25.30 |
| Fine sand (%) | 57.40 |
| Silt (%) | 9.50 |
| Clay (%) | 7.50 |
| Textural class | Loamy sand |
| Bulk density (Mg $m^{-3}$) | 1.52 |
| Particle density (Mg $m^{-3}$) | 2.52 |
| pH | 8.50 |
| $EC_e$ (dS $m^{-1}$) at 25 °C | 2.52 |
| CEC [cmol($p^+$) $kg^{-1}$] | 6.85 |
| Exchangeable Na [cmol($p^+$) $kg^{-1}$] | 1.58 |
| Exchage sodium percent (ESP) | 23.06 |
| $CaCO_3$ (g $kg^{-1}$) | 16.08 |
| Soluble cations (*m*mol $L^{-1}$) | |
| $Na^+$ | 22.50 |
| $Ca^{2+}$ + $Mg^{2+}$ | 2.40 |
| $K^+$ | 0.20 |
| Soluble anions (*m*mol $L^{-1}$) | |
| $CO_3^{2-}$ + $HCO_3^-$ | 11.50 |
| $Cl^-$ | 8.30 |
| $SO_4^{2-}$ | 5.40 |
| Organic carbon (g $kg^{-1}$) | 2.47 |
| Available N (kg $ha^{-1}$) | 130.9 |
| Available P (kg $ha^{-1}$) | 8.73 |
| Available K (kg $ha^{-1}$) | 128.7 |

Table 2. Chemical composition of synthetic irrigation water.

| | Ionic composition ($mMol\ L^{-1}$) | | | | | | |
|---|---|---|---|---|---|---|---|
| SAR | $Na^{+}$ | $Ca^{2+}$ | $Mg^{2+}$ | $CO_3^{-}$ | $HCO_3^{2-}$ | $Cl^{-}$ | $SO_4^{2-}$ |
| 6 (Base water) | 7.2 | 1.8 | 1.0 | 0.5 | 2.5 | 3.5 | 3.7 |
| 10 | 26.0 | 7.0 | 7.0 | 1.0 | 5.0 | 30.0 | 4.2 |
| 20 | 34.0 | 3.0 | 3.0 | 1.0 | 5.0 | 30.0 | 4.2 |
| 30 | 37.0 | 1.5 | 1.5 | 1.0 | 5.0 | 30.0 | 4.2 |

required quantities of NaCl, $Na_2SO_4$, $NaHCO_3$, $CaCl_2$, and $MgSO_4$ in base water of 6.0 SAR. Lateral movement of water and salts was prevented by keeping buffer strips around each irrigation channel (Table 2).

The FYM and VC were analyzed with the help of Singh, Chhonkar, and Pandey (2004). The FYM contained 16.3%, 0.55%, 0.25%, and 0.51% in total C, nitrogen, phosphorus, and potassium, respectively, whereas the C:N ratio of FYM was 29.6:1. The analysis data of vermicompost showed 18.0% total carbon, 1.50% N, 0.90% P, and 1.07% K, and the C:N ratio was 12:1. The organic dose of treatment was applied 25 days prior to sowing of mustard crop. Half a dose of N was applied as basal dose through urea and organic manure combination. The remaining 25% was applied at the time of the first irrigation, and the remaining 25% was applied at the 60-day-old crop.

### *Field preparation and crop cultivation*

Because mustard is a resilient crop, it requires less field preparation than other crops. In this experiment, 2–3 plowing procedures were done to achieve a good tilth for mustard crop seeding. The variety T-59 (Varuna) of mustard was used as the test crop. For proper germination, a presowing irrigation was done. Seed of mustard was sown, and three irrigations were applied at different crop growth stages. The crop was raised as per recommended package and practices of mustard. Crop was harvested; crop yield and plant nutrient uptake kinetic were computed. Again, surface soil samples were collected and analyzed for different soil parameters.

### *Analysis of soil properties after crop harvest*

To determine the bulk density (BD) and hydraulic conductivity, undisturbed soil samples were taken from the field with the help of a core (0.07 m diameter and 0.08 m in length) sample. The gravimetric method was followed to determine the soil moisture content. The processed soil samples (< 2 mm) were analyzed for pH, EC, organic carbon, and CEC by adopting standard procedures described by Jackson (1973). Available plant nutrient concentrations in soil and plants were measured as per procedure described in Singh, Chhonkar, and Pandey (2004). At the harvest of a mustard crop, seed and stover yields were also recorded and the correction was calculated using several soil factors. The SAR was measured by using the below formula:

$$SAR = \frac{[Na^{+}]}{\sqrt{[\frac{ca^{2}+Mg^{2+}}{2}]}}$$

### *Statistical analysis*

Different soil and plant nutrient yields were recorded during the two years of study. The experiments were conducted in SPD with three replications. To test the significance of proposed hypothesis, data were analyzed as method and procedure described by Fisher (1950); Gomez and Gomez (1984). Data were analyzed for the "F" test at five percent ($p$ = .05) level of least significant difference (Lsd).

## Results and discussion

### *Effect on pH, electrical conductivity ($EC_e$), and CEC*

The pH of soil samples was examined and found to be higher than presowing soil samples in both years, with increasing levels of SAR. The highest soil pH (9.25) was recorded under $W_{30}$ elevated up to the extent of 17.68, 13.64, and 5.59% over $W_6$, $W_{10,}$ and $W_{20}$, respectively in the pooled mean. This increment in soil pH with increasing levels of SAR might be contributed by the addition of different base ions through different concentrations of SAR. It decreased the activity of $Ca^{++}$ and $Mg^{++}$ due to their precipitation with carbonate. The incorporation of organic inputs brings down the soil pH from 9.10 to 8.02 in treatment $M_4$. A synergistic correlation between RSC/SAR of irrigation water with soil pH and exchangeable sodium percentage was also reported by Girdhar (1996). The electrical conductivity soil extract at the harvest stage decreased significantly ($p$ = .05) by increasing SAR levels of irrigation water over normal water ($W_6$). The highest $EC_e$ of soil was measured under $W_6$ (normal water) and minimum under $W_{30}$ (30 SAR) in the two years of mean. Increasing the N levels, on the other hand, resulted in a drop in the EC value; however; it was observed that in organic treated plots, N was replaced by FYM and VC. The significant reduction in $EC_e$ might be inferred from activities of Ca and Mg reduced in soil solution by precipitation as a carbonate, and contrary to this, exchange of soluble sodium to adsorbed state in clay complexes results in a reduction of concentration. Chauhan and Bhudayal (1988) also observed a reduction in salinity at higher levels of RSC due to precipitation carbonates. Findings were in close agreement with the experimental reports of Singh and Singh (1997); Naga (2005); Pareek and Yadav (2011).

A nonsignificant increment was observed in the CEC with an elevated level of SAR in irrigation water due to the increase in the pH of soil. This increment in CEC with increasing pH was mediated by the enhancement of negative charges and reduction in positive charges in soil solution. Different low molecular organic acid molecules were ionized and reduced proton constituent to the basic groups. The conditions of high ESP and pH, ions like $CO_3^{2-}$, and highly charged decomposed material of humus enhanced the different cations and also CEC of soil (Gupta, Bhumbla, and Abrol 1984). The results corroborate the findings of Srivastava and Srivastava (1991), which reported that CEC showed significant positive ($p$ = .05) correlation with pH of high SAR-containing soils. The application of organic sources of nitrogen significantly ($p$ = .05) lowered the soil reaction value and sodium adsorption ratio of soil, whereas a significant improvement in CEC of soil was observed. Incorporation of organic sources of N was counteracting the adverse effects of high pH and high sodicity may enhance formation of $CO_2$ and different types of low weight organic acids during microbial decomposition of organic manures. Organic acids react with the soil's inherent $CaCO_3$ to release Ca in a plant-available form, displacing Na from the exchange complex and lowering the pH and SAR. Related findings were measured by Yadav and Chippa (2007), Yaduvanshi and Sharma (2007), and Pareek and Yadav (2011). The incorporation of organic manures increased the CEC of soil after crop harvest. The native characteristics of the organics were responsible for the increase in cation exchange capacity after they were added. The positive impact of organic sources in enhancing the cation exchange capacity of the soil was also observed by Prakash, Bhadoria, and Rakshit (2002), Pareek and Yadav (2011).

Table 3. Impact of various sodic irrigation and sources of N levels on pH, $EC_e$, and CEC of soil at harvest of the crop.

| Treatments | pH | | | $EC_e$ (dS $m^{-1}$) | | | CEC{cmol ($p^+$) $kg^{-1}$} | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2012–13 | 2013–14 | Pooled | 2012–13 | 2013–14 | Pooled | 2012–13 | 2013–14 | Pooled |
| Sodic water | | | | | | | | | |
| $W_6$ (6 SAR) | 7.89 | 7.84 | 7.86 | 2.57 | 2.55 | 2.56 | 5.77 | 5.78 | 5.77 |
| $W_{10}$ (10 SAR) | 8.19 | 8.09 | 8.14 | 2.50 | 2.46 | 2.48 | 5.87 | 5.83 | 5.85 |
| $W_{20}$ (20 SAR) | 8.75 | 8.76 | 8.76 | 2.38 | 2.31 | 2.35 | 5.94 | 5.90 | 5.92 |
| $W_{30}$ (30 SAR) | 9.19 | 9.31 | 9.25 | 2.20 | 2.15 | 2.17 | 5.86 | 5.81 | 5.84 |
| SEm± | 0.09 | 0.09 | 0.08 | 0.03 | 0.02 | 0.02 | 0.06 | 0.06 | 0.05 |
| Lsd ($p$ = .05) | 0.32 | 0.32 | 0.25 | 0.09 | 0.08 | 0.07 | NS | NS | NS |
| Nitrogen sources | | | | | | | | | |
| $M_0$ – control | 9.10 | 9.08 | 9.09 | 2.44 | 2.40 | 2.42 | 5.45 | 5.41 | 5.43 |
| $M_1$-125%RDN*(Urea) | 8.87 | 8.83 | 8.85 | 2.37 | 2.34 | 2.35 | 5.80 | 5.79 | 5.80 |
| $M_2$75%RDN*(Urea)+50%RDN*(FYM) | 8.71 | 8.74 | 8.73 | 2.35 | 2.30 | 2.32 | 5.88 | 5.84 | 5.86 |
| $M_3$-75%RDN*(Urea)+50% RDN*(VC) | 8.21 | 8.22 | 8.21 | 2.44 | 2.34 | 2.39 | 5.93 | 5.82 | 5.87 |
| $M_4$-50%RDN*(Urea)+75 RDN*(FYM) | 8.03 | 8.00 | 8.02 | 2.43 | 2.39 | 2.41 | 6.12 | 6.13 | 6.12 |
| $M_5$-50%RDN*(Urea)+75% RDN*(VC) | 8.11 | 8.11 | 8.11 | 2.46 | 2.44 | 2.45 | 5.99 | 6.00 | 5.99 |
| SEm± | 0.11 | 0.12 | 0.06 | 0.04 | 0.03 | 0.02 | 0.08 | 0.07 | 0.04 |
| Lsd ($p$ = .05) | 0.30 | 0.33 | 0.18 | NS | 0.09 | 0.05 | 0.23 | 0.21 | 0.13 |

*RDN – Recommended dose of N, VC – Vermicompost.

Table 4. Impact of different sodic and N levels on bulk density and saturated hydraulic conductivity of soil at harvest.

| Treatments | Bulk density (Mg $m^{-3}$) | | | SHC (cm $h^{-1}$) | | |
|---|---|---|---|---|---|---|
| | 2012–13 | 2013–14 | Pooled | 2012–13 | 2013–14 | Pooled |
| Sodic water | | | | | | |
| $W_6$ (6 SAR) | 1.504 | 1.490 | 1.497 | 8.78 | 8.34 | 8.56 |
| $W_{10}$(10 SAR) | 1.505 | 1.493 | 1.499 | 8.57 | 8.12 | 8.35 |
| $W_{20}$(20 SAR) | 1.528 | 1.523 | 1.525 | 8.24 | 8.14 | 8.19 |
| $W_{30}$(30 SAR) | 1.550 | 1.528 | 1.539 | 8.03 | 8.24 | 8.14 |
| SEm± | 0.009 | 0.007 | 0.007 | 0.09 | 0.19 | 0.13 |
| Lsd ($p$ = .05) | 0.030 | 0.026 | 0.021 | 0.32 | NS | NS |
| Nitrogen sources | | | | | | |
| $M_0$ – control | 1.567 | 1.551 | 1.559 | 7.00 | 6.78 | 6.89 |
| $M_1$-125%RDN*(Urea) | 1.546 | 1.531 | 1.538 | 7.51 | 7.20 | 7.36 |
| $M_2$ – 75% RDN* (Urea)+50% RDN*(FYM) | 1.525 | 1.505 | 1.515 | 8.62 | 8.44 | 8.53 |
| $M_3$-75%RDN* (Urea)+50% RDN*(VC) | 1.523 | 1.508 | 1.516 | 8.43 | 8.27 | 8.35 |
| $M_4$-50% RDN* (Urea)+75% RDN*(FYM) | 1.472 | 1.468 | 1.470 | 9.49 | 9.36 | 9.42 |
| $M_5$-50% RDN* (Urea)+75% RDN*(VC) | 1.496 | 1.487 | 1.492 | 9.38 | 9.22 | 9.30 |
| SEm± | 0.009 | 0.008 | 0.005 | 0.12 | 0.22 | 0.10 |
| Lsd ($p$ = .05) | 0.026 | 0.023 | 0.014 | 0.34 | 0.62 | 0.28 |

*RDN – Recommended dose of N, VC – Vermicompost.

### *Bulk density and saturated hydraulic conductivity*

Increased sodicity in irrigation water increased bulk density. The maximum increment in bulk density was noted under the treatment $W_{30}$, which was 2.67 and 2.0% higher over $W_{10}$ and $W_{20}$, respectively, in pooled mean (Table 4). Contrary to this, it has been observed that saturated hydraulic conductivity of soil lowered with increasing levels of SAR in irrigation water. A maximum reduction in saturated hydraulic conductivity was observed under the treatment of $\mathbf{W_{30}}$ over the $W_6$ in pooled data. The occurrence of higher bulk density and a marked reduction in saturated hydraulic conductivity with elevated sodicity during experiment might be governed by degradation of the soil structure and poor soil aggregation, which resulted in a decrease in the soil pore volume. The reduction in SHC with growing residual sodium carbonate of water results in developing swelling and disperse conditions in soil was also reported by Girdhar (1996). It was analyzed from the experimental data presented in Table 3. Addition of organic manures significantly ($p$ = .05) reduced bulk density of soil, and significant improvement in saturated hydraulic

**Table 5.** Impact of different sodic water and N sources on SOC after harvest of the crop.

| | SOC (g kg$^{-1}$) | | |
|---|---|---|---|
| Treatments | 2012–13 | 2013–14 | Pooled |
| Sodic water | | | |
| $W_6$ (6 SAR) | 2.802 | 2.783 | 2.792 |
| $W_{10}$ (10 SAR) | 2.555 | 2.535 | 2.545 |
| $W_{20}$ (20 SAR) | 2.389 | 2.369 | 2.379 |
| $W_{30}$ (30 SAR) | 2.163 | 2.151 | 2.157 |
| SEm± | 0.032 | 0.032 | 0.028 |
| Lsd ($p$ = .05) | 0.111 | 0.110 | 0.085 |
| Nitrogen sources | | | |
| $M_0$ – control | 2.044 | 2.025 | 2.035 |
| $M_1$-125%RDN*(Urea) | 2.148 | 2.129 | 2.139 |
| $M_2$-75%RDN*(Urea)+50%RDN*(FYM) | 2.472 | 2.454 | 2.463 |
| $M_3$-75%RDN*(Urea)+50% RDN*(VC) | 2.445 | 2.428 | 2.437 |
| $M_4$-50%RDN*(Urea)+75%RDN*(FYM) | 3.086 | 3.068 | 3.077 |
| $M_5$-50%RDN*(Urea)+75%RDN*(VC) | 2.669 | 2.652 | 2.661 |
| SEm± | 0.031 | 0.031 | 0.018 |
| Lsd ($p$ = .05) | 0.090 | 0.090 | 0.051 |

*RDN – Recommended dose of N, VC – Vermicompost.

conductivity and moisture retention was observed over the control. The highest reduction in BD and maximum improvement in SHC (36.72%) and water retention (37.05%) were observed under the treatment of $M_4$ as compared to control. A favorable physical environment to the field soils was developed due to the application organic sources of nitrogen, which results in an improvement in the soil structure and is reflected through low bulk density and high soil porosity, increment in soil micro/macro aggregates, and change of state in soil water storage capacity. Lower BD and increase in soil aggregate formation during application of organic sources result in significant improvement in the hydraulic conductivity of soil (Meena et al. 2019b; Selvi, Santhy, and Dhakshinamoorthy 2005).

## *Soil organic carbon*

The analysis results were compared with each other treatment to find out the change in the soil organic carbon content during the course of study. The increasing level of SAR significantly ($p$ = .05) reduced the SOC content in both the years over control (Table 5). The maximum pooled organic carbon was noted under $W_6$ (normal water), and it was 9.84, 17.22, and 29.16% higher over $W_{10}$, $W_{20}$, and $W_{30}$, respectively. The reduction in the SOC amount in postharvest soil samples may be attributed to higher pH and ESP/SAR of the soil on account of irrigation with high SAR rich water. At higher soil pH and lower $Ca^{2+}$ activity, dissolution, dispersion, and hydrolysis of the organic matter are the possible mechanisms, which increased the rate of organic carbon mineralization, resulting in its decreased contents under saline-sodic conditions (Singh and Singh 1997; Srivastava and Srivastava 1993). Yadav, Chand, and Tomar (2007) also reported that increasing the soil pH reduced SOC due to emission of C and also conversion of labile C into nonlabile pool of C. The addition of the C content by incorporation of organic treatments significantly ($p$ = .05) increased the SOC content as compared to control treatment in both the years' experimental findings. The highest SOC amount was measured under the treatment of $M_4$, and it was 51.72, 43.92, 25.20, 26.23, and 15.79% higher over $M_0$, $M_1$, $M_2$, $M_3$, and $M_5$, respectively (Table 4). The positive buildup of SOC in most of the organic input treatments were contributed by direct addition of C in soils (Vasanthi and Kumarswamy 1999). The highest SOC content of the soil under $M_4$ treatment was observed due to incorporation of the highest amount of FYM compared to other organic sources of nitrogen. These organic treatments are highly responsive for enhancing the microbial population and diversity, which may enhance labile pool of C in soils. Findings are also supported by computing the significant positive correlation coefficient

Table 6. Impact of sodic and N source levels on available water (%) and sodium adsorption ratio at harvest of the crop.

| | Available water | | | SAR | | |
|---|---|---|---|---|---|---|
| Treatments | 2012–13 | 2013–14 | Pooled | 2012–13 | 2013–14 | Pooled |
| Sodic water | | | | | | |
| $W_6$ (6 SAR) | 7.87 | 7.82 | 7.85 | 14.24 | 13.85 | 14.04 |
| $W_{10}$ (10 SAR) | 8.14 | 7.90 | 8.02 | 16.48 | 15.96 | 16.22 |
| $W_{20}$ (20 SAR) | 8.06 | 8.07 | 8.06 | 19.99 | 19.42 | 19.71 |
| $W_{30}$ (30 SAR) | 8.17 | 8.14 | 8.16 | 24.82 | 24.06 | 24.44 |
| SEm± | 0.14 | 0.10 | 0.11 | 0.25 | 0.23 | 0.21 |
| Lsd ($p$ = .05) | NS | NS | NS | 0.87 | 0.81 | 0.65 |
| Nitrogen sources | | | | | | |
| $M_0$ – control | 6.65 | 6.62 | 6.64 | 19.75 | 19.16 | 19.46 |
| $M_1$-125%RDN*(Urea) | 7.37 | 7.26 | 7.32 | 19.55 | 18.99 | 19.27 |
| $M_2$-75%RDN*(Urea)+50%RDN*(FYM) | 7.73 | 7.78 | 7.76 | 19.22 | 18.64 | 18.93 |
| $M_3$-75%RDN*(Urea)+50%RDN*(VC) | 8.35 | 8.26 | 8.30 | 18.78 | 18.23 | 18.50 |
| $M_4$-50%RDN*(Urea)+75%RDN*(FYM) | 9.17 | 9.03 | 9.10 | 18.03 | 17.50 | 17.77 |
| $M_5$-50%RDN*(Urea)+75%RDN*(VC) | 9.08 | 8.94 | 9.01 | 17.97 | 17.41 | 17.69 |
| SEm± | 0.20 | 0.09 | 0.09 | 0.23 | 0.23 | 0.13 |
| Lsd ($p$ = .05) | 0.56 | 0.27 | 0.25 | 0.67 | 0.65 | 0.38 |

*RDN – Recommended dose of N, VC – Vermicompost.

between the SOC content and the total nitrogen content of soil. It is a well-known fact that enhancing the N concentration in soil mediated the C mineralization process in applied fresh organic inputs. Most of the crop residue management practices suggested that addition dose of N enhanced C mineralization rate and improved soil health parameters (Kumawat and Jat 2005; Sukmal et al. 2004; Wu et al. 2013).

## Soil moisture content and SAR

In experimental soils, increasing the sodicity levels had no effect on the available moisture content, whereas elevating the N application rate through FYM and VC enhanced available water from 6.64 to 9.01% (Table 6). Further reference to data indicated that the moisture content of soil was significantly ($p$ = .05) increased in most of the nitrogen treatments in both the years and combined mean over control. Increasing levels of sodicity, on the other hand, increased SAR values due to an increase in Na ions in the soil. In contrast, the replacement of the N application requirement of the crop by organic inputs reduces the SAR ratio from 19.46 to 17.69 in VC treatment during the experiment. These

Table 7. Sodic and N levels' effect on seed and stover yield (q $ha^{-1}$) of mustard.

| | Seed yield | | | Stover yield | | |
|---|---|---|---|---|---|---|
| Treatments | 2012–13 | 2013–14 | Pooled | 2012–13 | 2013–14 | Pooled |
| Sodic water | | | | | | |
| $W_6$ (6 SAR) | 15.93 | 16.16 | 16.05 | 37.82 | 38.59 | 38.21 |
| $W_{10}$ (10 SAR) | 13.46 | 14.34 | 13.90 | 33.61 | 34.57 | 34.09 |
| $W_{20}$ (20 SAR) | 12.02 | 12.16 | 12.09 | 29.63 | 30.66 | 30.14 |
| $W_{30}$ (30 SAR) | 9.70 | 9.82 | 9.76 | 26.12 | 27.07 | 26.60 |
| SEm± | 0.29 | 0.30 | 0.26 | 0.82 | 0.85 | 0.73 |
| Lsd ($p$ = .05) | 1.01 | 1.03 | 0.79 | 2.85 | 2.96 | 2.24 |
| Nitrogen sources | | | | | | |
| $M_0$ – control | 8.16 | 8.40 | 8.28 | 24.44 | 25.39 | 24.92 |
| $M_1$-125%RDN*(Urea) | 9.43 | 10.53 | 9.98 | 26.11 | 26.73 | 26.42 |
| $M_2$-75%RDN*(Urea)+50% RDN*(FYM) | 12.22 | 12.45 | 12.33 | 29.98 | 31.20 | 30.59 |
| $M_3$-75%RDN*(Urea)+50% RDN*(VC) | 15.45 | 15.53 | 15.49 | 34.82 | 35.67 | 35.24 |
| $M_4$-50%RDN*(Urea)+75%RDN*(FYM) | 15.29 | 15.41 | 15.35 | 35.23 | 36.43 | 35.83 |
| $M_5$-50%RDN*(Urea)+75%RDN*(VC) | 16.12 | 16.42 | 16.27 | 40.21 | 40.92 | 40.56 |
| SEm± | 0.37 | 0.39 | 0.22 | 0.83 | 0.88 | 0.49 |
| Lsd ($p$ = .05) | 1.04 | 1.11 | 0.61 | 2.36 | 2.52 | 1.39 |

*RDN – Recommended dose of N, VC – Vermicompost.

**Table 8.** Correlation coefficient (r) between mustard yield and different soil properties.

| | SHC | pH | CEC | SOC | AW | SAR | yield |
|---|---|---|---|---|---|---|---|
| SHC | 1.000 | −.617** | 0.322 | 0.713** | 0.742** | −0.276 | 0.655** |
| pH | | 1.000 | −.336 | −.739** | −0.515** | 0.831** | −0.883** |
| CEC | | | 1.000 | 0.573** | 0.349 | −0.226 | 0.452* |
| OC | | | | 1.000 | 0.582** | −.644** | 0.834** |
| AW | | | | | 1.000 | −0.117 | 0.632** |
| SAR | | | | | | 1.000 | −0.749** |
| yield | | | | | | | 1.000 |

findings are supported by computing synergistic correlation between SOC and available water content (r = 0.582*). The water retention of the soil enhanced by adding organic treatments was attributed to the improvement in soil aggregate formation in favorable pore size and numbers in soil (Acharya, Bishnoi, and Yaduvanshi 1988; Kaledbonkar, Meena, and Sharma 2019).

## *Effect on mustard yield potential*

The seed and stover yield of mustard reduced significantly ($p$ = .05) by elevated SAR treatments during the experiments. It was observed that increasing the SAR value reduced the soil fertility parameters and lowered the yield of mustard crop (Table 7). The interactive effect of data showed that a reduction in the pooled seed yield at $M_0$ was 52.21%, which decreased to 43.70 and 22.87. The application of $M_1$ and $M_2$, after the adverse effect of SAR water, was overcome due to the increased level of nitrogen sources, and after that, the yield increased by 9.92, 8.33, and 15.51% with the application of $M_3$, $M_4$, and $M_5$, respectively, at the same level of SAR water ($W_{30}$) over $W_0M_0$ (normal water + control). The reduction in the yield might also be the result of the overall deleterious effect of Na ions on soil health parameters due to an increase in bulk density, soil reaction (pH), and exchangeable sodium percent, whereas a negative increment was observed in hydraulic conductivity of soil, which is responsible for poor rhizospheric plant growth and nutrient dynamics. These changes in the environment resulted in inferior biomass production and a decreased mustard economic yield. Similarly, Pareek and Yadav (2011) also observed a decremental growth in the stover and seed of mustard by increasing the sodium ions in irrigation water in arid and semiarid areas of Rajasthan. They has also suggested that the negative effect of sodium ions could be managed through addition of FYM and crop residue and with the help of gypsum application. For mustard production, these sources increased N supply and improved soil health. This might be because higher pH and exchangeable sodium percentage of experimental soil due to high SAR irrigation water reduced the accessibility of essential nutrients and organic carbon content in the soil, under such conditions, incorporation of organic substances enhanced the plant nutrient dynamics in soil and promoted the crop yield (Kaledbonkar, Meena, and Sharma 2019; Meena et al. 2019b). It also observed that addition of organic matter by incorporation of crop residue, FYM, kitchen waste, and agricultural industrial waste improved the soil health by lowering soil parameters like BD, chemical reaction (pH), ECe, and SAR and by enhancing SHC, soil moisture, ECE, SOC amount, microbial biomass C, and secretion and release of enzyme derivatives in soil. Experimental findings showed a similar trend, which was observed by Bhat, Singh, and Kohli (2007), Pareek and Yadav (2011), Wu et al. (2013), Yaduvanshi (2015), and Meena, Yadav, and Meena (2016) in different crops, and soil was used to manage the sodium concentration during the crop growth period and enhanced the mustard production in physically degraded soils.

Correction was also calculated and found strong positive correction in the mustard crop yield, and soil parameters (SHC, CEC, SOC, and available water) showed positive correction, whereas negative correlation in SOC and pH (r = −0.883**) and SAR (r = −0.749**) of soil (Table 8). The addition of N through fertilizers enhanced N in soil solution and ultimately improved the mustard crop yield. Incorporation of organic matter in soil, after decomposition, produced different types of organic acids. These acids had made a firm chemical bond with plant nutrients and enhanced availability in the rhizosphere environment. Another way is that the negative surface of the organic matter makes a complex with sodium ions and reduces the Na availability in solution, which also helps to enhance the mustard yield in arid and semiarid regions. Similar experiments were also conducted by Pareek and Yadav (2011) and Jat, Sharma, and Jat (2012) to enhance the mustard production in western part of Rajasthan.

## Conclusions

India's arid and semiarid regions have enormous potential for producing food grain to feed the country's expanding population. These places have salt and sodicity issues, which can be addressed through crop management and improved soil health. In this experiment, different N application modules in combination with organic and inorganic N sources were applied in the mustard crop. We also computed the impact of sodicity on soil parameters and observed increasing SAR values from 6 to 30 significantly ($p$ = .05) and reduced soil fertility parameters. Experimental results showed that 50% RDN through urea +75% RDN through FYM ($M_4$) significantly improved the water retention at 33 kPa, 1500 kPa, and available soil moisture at crop harvest, whereas treatment $M_5$ also showed *at par* response. The BD and soil reaction was reduced significantly ($p$ = .05), while SHC, SOC, and cation exchange capacity were improved significantly in 50% RDN through urea +75% RDN through FYM ($M_4$) applied plots. Most of the organic treatments improved the mustard grain yield from 8.28 q $ha^{-1}$ (control) to 16.27 q $ha^{-1}$ in treatment $M_5$ (composed of 50% RDN through urea + 75% RDN through vermicompost). These findings show that urea supply in mustard crops should be based on a combination of organic and inorganic components. Such research is critical for increasing the mustard yield in Indian states with high sodic groundwater irrigated lands.

## Acknowledgments

The authors are very grateful to the scientific and technical staff of the Division of Soil Science & Agricultural Chemistry, SKN College of Agriculture, Jobner, for their valuable help during the analysis.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

## References

Acharya, C. L., S. K. Bishnoi, and H. S. Yaduvanshi. 1988. Effect of long-term application of fertilizers, organic and inorganic amendments under continuous cropping on soil physical and chemical properties in an Alfisol. *Indian J Agric Sci* 58:509–16.

Ayars, J. E., and K. K. Tanji. 1999. Effects of drainage on water quality in arid and semiarid lands. In *Agricultural drainage*, ed. R. W. Skaggs and J. Van Schilfgaarde, 831–67, Madison, WI, USA: ASA-CSSASSSA.

Beltran, J. M. 1999. Irrigation with saline water: Benefits and environmental impact. *Agric Water Manage* 40 (2–3):183–94. doi:10.1016/S0378-3774(98)00120-6.

Bhat, M. A., R. Singh, and A. Kohli. 2007. Effect of integrated use of farmyard manure and fertilizer nitrogen with and without sulphur on yield and quality of Indian mustard (*Brassica Juncea* L.). *J Indian Soc Soil Sci* 55:224–66.

Chauhan, R. P. S., and C. C. P. S. Bhudayal. 1988. Effect of residual sodium carbonate in irrigation water on soil and bread wheat (*Triticum aestivum* L.). *Indian J Agric Sci* 58:454–58.

Dotaniya, M. L., D. Prasad, H. M. Meena, D. K. Jajoria, G. P. Narolia, K. K. Pingoliya, O. P. Meena, K. Kumar, B. P. Meena, A. Ram, et al. 2013a. Influence of phytosiderophore on iron and zinc uptake and rhizospheric microbial activity. *Afr J Microbiol Res* 7 (51):5781–88. doi:10.5897/AJMR2013.6461.

Dotaniya, M. L., H. M. Meena, M. Lata, and K. Kumar. 2013b. Role of phytosiderophores in iron uptake by plants. *Agri Sci Digest* 33 (1):73–76.

Dotaniya, M. L., and S. C. Datta. 2014. Impact of bagasse and press mud on availability and fixation capacity of phosphorus in an Inceptisol of north India. *SugarTech* 16 (1):109–12.

Dotaniya, M. L., S. C. Datta, D. R. Biswas, C. K. Dotaniya, B. L. Meena, S. Rajendiran, K. L. Regar, and M. Lata. 2016. Use of sugarcane industrial byproducts for improving sugarcane productivity and soil health-a review. *Intl J Recycl Org Wast Agric* 5 (3):185–94. doi:10.1007/s40093-016-0132-8.

Dotaniya, M. L., S. C. Datta, D. R. Biswas, H. M. Meena, and K. Kumar. 2014a. Production of oxalic acid as influenced by the application of organic residue and its effect on phosphorus uptake by wheat (*Triticum aestivum* L.) in an Inceptisol of north India. *Natl Acad Sci Lett* 37 (5):401–05. doi:10.1007/s40009-014-0254-3.

Dotaniya, M. L., S. C. Datta, D. R. Biswas, H. M. Meena, S. Rajendiran, and A. L. Meena. 2015. Phosphorus dynamics mediated by bagasse, press mud and rice straw in Inceptisol of North India. *Agrochimica* 59 (4):358–69.

Dotaniya, M. L., S. C. Datta, D. R. Biswas, and K. Kumar. 2014b. Effect of organic sources on phosphorus fractions and available phosphorus in Typic Haplustept. *J Indian Soc Soil Sci* 62 (1):80–83.

Fisher, R. A. 1950. *Statistical methods for research workers*. London: Oliver and Boyd Edinburg.

Girdhar, I. K. 1996. Effect of leaching with waters of varying residual sodium carbonate, SAR and electrolyte concentration on properties of a Haplusalf. *J Indian Soc Soil Sci* 44:495–99.

Gomez, K., and A. Gomez. 1984. *Statistical procedure for agriculture research*. 2nd ed. New York: John Willey and Sons Anc.

Gupta, R. K., D. R. Bhumbla, and I. P. Abrol. 1984. Effect of soil pH, organic matter and calcium carbonate on the dispersion behaviour of alkali soils. *Soil Science* 137 (4):245–51. doi:10.1097/00010694-198404000-00006.

Jackson, M. L. 1973. *Soil chemical analysis*. New Delhi: Prentice Hall of India (Pvt.).

Jalali, M., and H. Merrikhpour. 2008. Effects of poor quality irrigation waters on the nutrient leaching and groundwater quality from sandy soil. *Environ Geol* 53 (6):1289–98. doi:10.1007/s00254-007-0735-5.

Jat, G., K. K. Sharma, and N. K. Jat. 2012. Effect of FYM and mineral nutrients on physio-chemical properties of soil under mustard in western arid zone of India. *Ann Plant Soil Res* 14:167–166.

Kaledbonkar, M. J., B. L. Meena, and P. C. Sharma. 2019. Reclamation and nutrient management for salt affected soils. *Indian J Fert* 15 (5):566–75.

Kumawat, P. D., and N. L. Jat. 2005. Effect of organic manure and nitrogen fertilization on productivity of barley (*Hordium valgare*). *Indian J Agron* 50:200–02.

Meena, A. L., P. Jha, M. L. Dotaniya, B. Kumar, B. P. Meena, and R. L. Jat. 2019a. Carbon, nitrogen, phosphorus mineralization as influenced by type of organic residues and soil contact variation in vertisol of central India. *Agric Res*. doi:10.1007/s40003-019-00425-7.

Meena, M. D., R. K. Yadav, B. Narjary, G. Yadav, H. S. Jat, P. Sheoran, M. K. Meena, R. S. Antil, B. L. Meena, H. V. Singh, et al. 2019b. Municipal solid waste (MSW): Strategies to improve salt affected soil sustainability: A review. *Waste Manag* 84:38–53. doi:10.1016/j.wasman.2018.11.020.

Meena, M. K., B. L. Yadav, and N. R. Meena. 2016. Effect of organic sources of nitrogen on quality and yield of Indian mustard under sodic water irrigation. *J Oilseed Brassica* 7 (2):148–55.

Meena, V. S., M. K. Meena, M. L. Dotaniya, M. D. Meena, R. S. Jat, R. L. Choudhary, H. Singh, and P. K. Rai. 2021. Improvement in growth and yield of Indian mustard by using micro and secondary nutrients fortified FYM in calcareous soil. *J Oilseed Brassica* 12 (1):38–43.

Naga, S. R. 2005 Response of wheat to zinc and iron fertilization under irrigation with different RSC water. PhD Thesis, RAU, Bikaner

Pareek, N., and B. L. Yadav. 2011. Effect of organic manure on soil physio-chemical properties, soil microbial biomass and yield of mustard under irrigation of different residual sodium carbonate water. *J Indian Soc Soil Sci* 59:336–42.

Prakash, Y. S., P. B. S. Bhadoria, and A. Rakshit. 2002. Comparative efficiency of organic manures on the changes in soil properties and nutrient availability in Alfisol. *J Indian Soc Soil Sci* 50:219–21.

Selvi, D., P. Santhy, and Dhakshinamoorthy. 2005. Effect of inorganic alone and in combination with farm yard manure on physical properties and productivity of Vertic Haplustepts under long term fertilization. *J Indian Soc Soil Sci* 53:302–07.

Shukla, M., R. H. Patel, R. Verma, and P. M. L. Deewan. 2013. Effect of bio-organics and chemical fertilizers on growth and yield of chickpea (*Cicer arietinum* L.) under middle Gujarat conditions. *Vegetos* 26 (1):183–87. doi:10.5958/j.2229-4473.26.1.026.

Singh, D., and B. Singh. 1997. Influence of residual sodium carbonate in sodic water on the yield and oil content of lemon grass (*Cymbopogon cytratus*). *J Indian Soc Soil Sci* 45:354–57.

Singh, D., P. K. Chhonkar, and R. N. Pandey. 2004. *Soil plant water analysis: A methods manual*. New Delhi: Westville Publishing House.

Singh, R., A. K. Singh, S. R. Yadav, S. P. Singh, A. S. Godara, M. J. Kaledhonkar, and B. L. Meena. 2019. Effect of saline water and fertility levels on pearl millet- psyllium crop sequence under drip irrigation in arid region of Rajasthan. *J Soil Salinity Water Qual* 11 (1):56–62.

Singh, R. B., M. J. Kaledhonkar, S. K. Chaudhari, P. K. Shishodia, and B. L. Meena. 2018. Effect of saline and alkaline water on mustard yield under sprinkler irrigation. *J Soil Salinity Water Qual* 10 (2):246–53.

Singh, R. B., S. K. Chauhan, M. J. Kaledhonkar, P. K. Shishodiya, R. S. Chauhan, and B. L. Meena. 2020. Survey, characterization and mapping of groundwater of Agra region and Bharatpur district for irrigation purpose. In *ICAR-AICRP on management of salt affected soils and use of saline water in agriculture*, 76. Technical Bulletin, published by ICAR-AICRP. Karnal: CSSRI.

Srivastava, A. K., and O. P. Srivastava. 1991. Cation exchange capacity in relation to pH in salt affected soils. *J Indian Soc Soil Sci* 39:355–57.

Srivastava, A. K., and O. P. Srivastava. 1993. Forms of soil nitrogen in relation to pH. *J Indian Soc Soil Sci* 41:551–53.

Sukmal, C., M. Anwar, D. D. Patra, and S. P. S. Khanuja. 2004. Effect of mint distillation waste on soil microbial biomass in a mint-mustard cropping sequence. *Soil Sci Plant Anal* 35 (1–2):243–54. doi:10.1081/CSS-120027647.

Vasanthi, D., and Kumarswamy. 1999. Efficacy of vermicompost to improve soil fertility and rice yield. *J Indian Soc Soil Sci* 47:268–72.

Wu, Y., Y. Li, C. Zheng, Y. Zhang, and Z. Sun. 2013. Organic amendments application influence soil organism's abundance in saline alkali soil. *Eur J Soil Biol* 54:32–40. doi:10.1016/j.ejsobi.2012.10.006.

Yadav, K. K., and B. R. Chippa. 2007. Effect of FYM, gypsum and iron pyrites on fertility status of soil and yield of wheat irrigated with high RSC water. *J Indian Soc Soil Sci* 55:324–29.

Yadav, V., T. Chand, and N. K. Tomar. 2007. Effect of long-term irrigation with sodic waters on soil properties and phosphate fractions. *J Indian Soc Soil Sci* 55:157–60.

Yaduvanshi, N. P. S. 2015. Nutrient management strategies for sustaining crop production with sodic water. *Ann Plant Soil Res* 17:114–24.

Yaduvanshi, N. P. S., and D. R. Sharma. 2007. Use of wheat residue and manures to enhance nutrient availability and rice-wheat yields in sodic soil under sodic water irrigation. *J Indian Soc Soil Sci* 55:330–34.