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# Effects of long-term use of sodic water irrigation, amendments and crop residues on soil properties and crop yields in rice–wheat cropping system in a calcareous soil

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ABSTRACT

One of the options to ameliorate the deleterious effects of sodic water irrigation is to apply gypsum to soil. We examined whether the application of organic manures or crop residue can reduce the need for gypsum in calcareous soils. A long-term field experiment with annual rice–wheat cropping rotation was conducted for 15 years (1991–2006) on a non-saline calcareous sandy loam soil (*Typic Ustochrept*) in northwestern, India. The irrigation water treatments included good quality canal water (CW) and sodic water (SW) with residual sodium carbonate (RSC) of 10 $mmol_c\,L^{-1}$ from 1991 to 1999 and of 12.5 $mmol_c\,L^{-1}$ from 2000 onwards. Gypsum was applied at 0, 12.5, 25, and 50% of the gypsum requirement (GR), to neutralize RSC of the SW. Three organic material treatments consisted of application of farmyard manure (FYM) at 20 $Mg\,ha^{-1}$, *Sesbania* green manure (GM) at 20 $Mg\,ha^{-1}$, and wheat straw (WS) at 6 $Mg\,ha^{-1}$. The organic materials were applied every year to the rice crop. Continuous irrigation with sodic water for 15 years without gypsum or organic materials resulted in a gradual increase in soil pH and exchangeable sodium percentage (ESP), deterioration of soil physical properties, and decrease in yields of both rice and wheat. The cumulative yield loss in SW irrigated plots without gypsum and organic materials remained <1.5 $Mg\,ha^{-1}$ for up to eight years in the case of rice and up to nine years in the case of wheat. Thereafter, marked increase in pH and ESP resulted in further depression in yields of rice by 1.6 $Mg\,ha^{-1}\,year^{-1}$ and wheat by 1.2 $Mg\,ha^{-1}\,year^{-1}$. Application of gypsum improved physical and chemical properties of the soil. The beneficial effects on crop yields were visible up to 12.5% GR in rice and up to 50% GR in wheat in most of the years. All the organic materials proved effective in mobilizing $Ca^{2+}$ from inherent and precipitated $CaCO_3$ resulting in decline in soil pH and ESP, increase in infiltration rate, and a increase in the yields of rice and wheat crops. Although the application of organic materials resulted in comparable reductions in pH and ESP, the increase in yield with SW was higher for both crops with FYM. Pooled over the last six years (2000–2006), application of FYM resulted in 38 and 26% increase in rice and wheat yields, respectively, over SW treatment; corresponding increases in 50% GR treatment (recommended level) was 18 and 19%. During these years, application of GM and WS increased wheat yields by 20%; for rice, GM resulted in 22% increase compared to 17% in WS amended SW irrigated plots. Combined application of gypsum and organic materials did not increase the yields further particularly in the case of FYM and GM treated plots. This long-term study proves that organic materials alone can be used to solubilize Ca from inherent and precipitated $CaCO_3$ in calcareous soils for achieving sustainable yields in sodic water irrigated rice–wheat grown in annual rotation. The results can help reduce the dependency on gypsum in sodic water irrigated calcareous soils.



## 1. Introduction

Groundwater surveys indicate that the poor quality waters being utilized for irrigation purposes in different states of India range between 32 and 84% of the total groundwater development (Minhas and Gupta, 1992; Choudhary, 2003). The problem is particularly acute in northwestern India where 40–60% of the groundwater show high incidence (30–50%) of residual alkalinity

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(Minhas and Bajwa, 2001). Sodic groundwater with high residual alkalinity exist in semi-arid regions (annual rainfall 500–700 mm) whereas saline waters are generally concentrated in arid parts (annual rainfall 330–350 mm) (Sharma and Minhas, 2005).

Rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) grown in an annual rotation constitute a popular and profitable cropping system for the farmers of the Indo-Gangetic Plains in South-Asia. It occupies about 9.8 million hectares area in this region (Bijay-Singh et al., 2008; Yadvinder-Singh et al., 2004) and is also followed on a sizable area having sodic groundwater (Sharma et al., 2001). Irrigation with sodic waters high in carbonates and bicarbonates leads to increase in soil pH and sodium (Na) saturation of soils, aeration and permeability problems due to clay dispersion, crusting, and clay migration leading to clogging of pores (Grattan and Oster, 2003; Levy et al., 2003; Oster, 2004) thereby adversely affecting crop productivity (Josan et al., 1998; Choudhary et al., 2004, 2006b; Sharma and Minhas, 2005; Minhas et al., 2007a,b). Even under monsoonal climate, characterized by rainfall concentrated in a short time span, a quasi-stable salt balance is reached within 4–5 years of sustained sodic water irrigation, while a further rise in pH and exchangeable sodium percentage (ESP) is very low (Tyagi, 2003). This is generally true for soils having no or low calcium carbonate content but what occurs in calcareous soils irrigated with sodic waters high in residual alkalinity has not been studied adequately under field conditions.

Amelioration of sodic and sodic-water irrigated soils needs gypsum as a source of calcium ($Ca^{2+}$) that replaces the excess $Na^+$ from the exchange complex and makes the root zone soil congenial for absorption of water and nutrients by crop plants (Qadir et al., 2007). Calcareous soils contain calcite ($CaCO_3$) as source of $Ca^{2+}$. Owing to its extremely low solubility, however, calcite does not contribute significantly to supply adequate levels of $Ca^{2+}$ needed for soil amelioration as do the chemical amendments such as gypsum. Thus, if solubilization of $Ca^{2+}$ from $CaCO_3$ present in soil can be induced, dependence on chemical amendments like gypsum can be substantially reduced. In addition, chemical amendment application and subsequently the drainage with high electrolyte concentration may also bring adverse effects on environmental protection (Qadir and Oster, 2004; Qadir et al., 2006). According to Bower and Goertzen (1958), availability of soil-$CaCO_3$ should be adequate for amelioration of the sodic soils.

Application of organic materials leads to increase in concentrations of soil atmospheric $CO_2$ and production of organic acids, which in turn, results in increased solubility of $CaCO_3$ and other calcic minerals (Minhas et al., 1995; Choudhary et al., 2006a; Li and Keren, 2009). Sekhon and Bajwa (1993), in a pot experiment, reported that incorporation of farmyard manure (FYM), *Sesbania aculeata* green manure (GM) or rice straw in a soil irrigated with sodic water decreased the precipitation of $CaCO_3$, increased Na in drainage waters, decreased soil pH and ESP and improved crop yields. In fact, the use of organic materials, particularly FYM, has long been advocated as an organic amendment for the reclamation of sodic soils (Rao, 1998). Since soils irrigated with sodic waters generally are poor in organic matter, have very low soil fertility and poor physical properties (Bajwa et al., 1998; Choudhary, 2003), organic materials apart from the ameliorative action can help in restoring soil quality of these degraded soils through improvement in organic matter status, physical conditions of the soil and increased nutrient availability (Choudhary et al., 2010).

In a column study, Jalali and Ranjbar (2009) demonstrated that application of organic manures (sheep and poultry manures) decreased soil sodicity produced due to application of sodic water. The organic manures resulted in greater adsorption of $Ca^{2+}$, $Mg^{2+}$ and $K^+$ than $Na^+$ leading to lower soil ESP. Murtaza et al. (2009) observed that application of gypsum and FYM under irrigation with saline-sodic water having no residual alkalinity successfully reclaimed a native saline-sodic soil. Working with a sodic soil, Yaduvanshi and Sharma (2008) observed no significant change in soil properties under sodic water irrigation but reported benefits of residual effects of amendments on yields of wheat. While Murtaza et al. (2009) used good quality water in conjunction with saline-sodic water, Yaduvanshi and Sharma (2008) focused on the tillage effects (no tillage vs. conventional tillage) and did not have good quality water irrigation treatment for comparing results obtained with sodic water. Moreover, both these studies were short-term (2–3 years). In a long-term investigation on sugarcane in a non-calcareous soil, Choudhary et al. (2004) observed complimentary effects of applying FYM with gypsum under sodic water irrigation. However, dissolution of $CaCO_3$ through addition of organic materials as a practical means to reduce the need for applying gypsum to reclaim a calcareous soil sodified due to irrigation with sodic waters needs to be studied on a long-term basis. We, therefore, carried out a long-term field investigation to study the effect of sodic water irrigation on salt and Na build-up in the soil, and how organic amendments (FYM and GM) and crop residue incorporation vis-à-vis gypsum can lead to improvement in soil properties and crop productivity under rice–wheat cropping system in a calcareous soil.

**Table 1**
Composition of irrigation waters.

| Characteristics | CW | SW[a] | SW[b] |
|---|---|---|---|
| Electrical conductivity, EC ($dS\,m^{-1}$) | 0.52 | 1.65 | 2.11 |
| Soluble salts ($mmol_c\,L^{-1}$) | | | |
| $Ca^{2+}$+$Mg^{2+}$ | 3.20 | 2.45 | 2.30 |
| $Na^+$ | 0.33 | 14.7 | 16.1 |
| $CO_3^{2-}$+$HCO_3^-$ | 3.39 | 12.4 | 14.8 |
| $Cl^-$ | 0.50 | 0.50 | 0.55 |
| Residual sodium carbonate, RSC[c] | 0.0 | 9.96 | 12.50 |
| Sodium adsorption ratio, SAR[d] | 1.85 | 9.40 | 10.61 |

[a] SW, composition of sodic water used from 1991–1999.
[b] SW, composition of sodic water used from 2000 onwards.
[c] $RSC = (CO_3^{2-}+HCO_3^-) - (Ca^{2+}+Mg^{2+})$ (all cations and anions in $mmol_c\,L^{-1}$).
[d] $SAR = Na^+/\sqrt{(Ca^{2+}+Mg^{2+})/2}$.

## 2. Materials and methods

The field experiment with annual rice–wheat cropping rotation was conducted from 1991 through 2006 on a sandy loam soil (*Typic Ustochrept*) at Ludhiana (30°56′N, 75°52′E, 247 m above msl) in northwestern India. The 0–180 cm soil profile initially had pH varying between 7.9 and 8.5, electrical conductivity (EC) between 0.22 and 0.27 $dS\,m^{-1}$, organic C between 3.0 and 3.5 $g\,kg^{-1}$, $CaCO_3$ between 28 and 44 $g\,kg^{-1}$ and ESP between 3.4 and 4.5%. The clay content (18 to 26%) and CEC (7.6 to 15.0 $cmol(+)\,kg^{-1}$) increased with soil depth. The soil at the experimental site was well drained with a water table always remaining below 10 m.

The 60 plots each measuring 1.5 m × 2 m were separated from one another by polythene sheet to a depth of 1 m to check lateral salt and water movement. Rice (cv. PR 106, PR 114, PR 118) and wheat (cv. HD 2329, PBW 343) were grown in a rotation on fixed plots with different irrigation water, gypsum and organic amendment treatments. The irrigation treatments consisted of good quality canal water (CW) and sodic water (SW) with residual sodium carbonate (RSC) of 10 $mmol_c\,L^{-1}$ from 1991 to 1999 and of 12.5 $mmol_c\,L^{-1}$ from 2000 onwards. Sodic waters high in bicarbonates and SAR used in the study were synthesized for each plot separately by dissolving a known quantity of $NaHCO_3$ in good quality water (0.84 g and 1.05 g of commercial grade $NaHCO_3$ for RSC of 10 and 12.5 $mmol_c\,L^{-1}$, respectively) (Table 1) in the 180 L of CW in large steel drums (marked for requisite volume) before each irrigation. The synthesized water was conveyed to the plots through a rubber hose pipe (6 cm diameter). Gypsum was applied