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FULL-LENGTH RESEARCH ARTICLE

Frequency of Deep Tillage and Residual Sodium Carbonate Neutralization of Sodic Water on Soil Properties, Yield and Quality of Clusterbean and Wheat Grown in a Sequence

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Abstract Use of sodic water for irrigation deteriorates the soil and adversely affects the yield and quality of crops. While use of gypsum for amelioration of sodic water effects is well established, the effect of frequency of deep tillage along with residual sodium carbonate (RSC) neutralization through application of gypsum on clusterbean (*Cyamopsis tetragornolob* L.)—wheat (*Triticum aestivum* L.) crop sequence irrigated with sodic water is not very well understood. The results of a field experiment designed to study these effects revealed that deep tillage significantly increased the grain and straw yields and improved the grain quality of clusterbean and wheat. Two years gap in deep tillage significantly reduced the grain and straw yields of clusterbean and wheat during the third year of experimentation when compared with continuous tillage or 1 year gap in deep tillage practices. The yield and quality of clusterbean (crude protein and gum content of grain) and wheat (protein, starch and lysine content of grain) were positively influenced by the application of gypsum @ 50 and 100 % RSC neutralization of sodic irrigation water and good quality irrigation water compared to untreated sodic irrigation water. The infiltration rate decreased with sodic water irrigation under farmer's practice of tillage. Application of gypsum @ 50 and 100 % RSC neutralization of sodic water and good quality irrigation water improved significantly infiltration rate after harvesting of wheat, compared with sodic water irrigated plots. Similarly, deep tillage also significantly influenced infiltration rate. Sodic water irrigation for 4 years significantly increased electrical conductivity, pH and sodium adsorption ratio of soil compared to 50 and 100 % neutralization of RSC and good quality irrigation water. This study shows that only up to 1 year gap in deep tillage in the month of May and 100 % RSC neutralization through gypsum application at the beginning of monsoon had a positive effect on yield and quality of clusterbean and wheat in sodic water irrigated conditions.

Keywords Clusterbean · Wheat · Sodic water · Amelioration · Deep tillage

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Introduction

In India, about 50 % of the groundwater is either marginal or poor in quality. Of this, 37 % has high sodicity, 20 % has high salinity and remaining 43 % has high salinity as well as sodicity [26]. Irrigation water of category IV (RSC > 4, DCR < 0.25) required addition of gypsum to neutralize alkalinity, whereas category II water (RSC < 4, DCR > 0.25) could be used safely for crop production [17]. Long-term use of water containing excess of sodium and carbonate, bicarbonate and chloride for irrigation increased soil pH, electrical conductivity (EC) and exchangeable sodium percentage (ESP), and as a result, physical properties of soil such as aeration and permeability were adversely affected [8, 16, 20]. Additionally surface sealing, crusting and clay migration leading to clogging of pores and deposition of clay below the plough layer in soil took place and created hard pan in subsurface soil, particularly where rains followed [11, 19, 21, 23], and these adversely affected the yield, quality and profitability of field crops.

Use of sodic water with application of gypsum alone or in combination with organic amendments for irrigating cotton, wheat, paddy, sunflower, has been reported by several workers [4, 7, 9, 18]. For amelioration of sodic water irrigation effects, application of gypsum was commonly recommended [3]. Also, mixing of good quality water in varying quantities or cyclic use of canal/pond water was recommended [24]. However, limited information was available on the effect of frequency of deep tillage along with gypsum application for sustainable management of sodic water. Keeping this in view, present field study was carried out to investigate the frequency of deep tillage and RSC neutralization of sodic water through gypsum application on clusterbean—wheat crop sequence grown on sandy loam soil.

Materials and Methods

Experiment and Weather Condition

A field experiment was conducted at the Research Farm, Banasthali University, Rajasthan, India (23°3′–30°12′N latitude and 69°30′–78°17′E longitude, 264.3 m above mean sea level) during 2004–2008. The experiment was laid out in a split plot design with three replications. The main plot treatments consisted of frequency of deep tillage while subplot treatments represented different qualities of irrigation water (good quality and RSC neutralized sodic water). Total rainfall received during the experimentation period was 396, 473, 361 and 506 mm in 2004–2005, 2005–2006, 2006–2007 and 2007–2008, respectively. Out of total, 95.6 % rainfall occurred in monsoon season from June end to mid-September and maximum intensity of rain was observed during July and August. Except monsoon season, potential evaporation was higher than rainfall every year. Maximum evaporation occurred in May and June when the fields were fallow.

Soil

The physico-chemical characteristics of the soil profile (0–0.90 m) at the start of the experiment are given in Table 1. Sodic water had been used to irrigate different crop rotations from last 5 years before initiation of experiment. The soil electrical conductivity (ECe), pH, sodium adsorption ratio (SAR) and bulk density were slightly higher in 0.10–0.20 m horizon compared to upper (0.0–0.10 m) and lower (0.60–0.90 m) horizons of the soil. The water table was 13 m below the surface. The experimental plots (5.0 × 5.0 m^2) were effectively isolated from one another by polyethylene sheet laid to 1.0 m depth on all the four sides of a plot and walkways of 1 m width between the plots to avoid lateral fluxes of water and salt.

Treatments

Sixteen treatments consisted of combinations of four frequencies of deep tillage in summer viz. farmer's practice of tillage (FPT), every year deep tillage (EYDT), 1 year gap in deep tillage (OYGDT) and 2 years gap in deep tillage (TYGDT) and four qualities of irrigation water viz. 0, 50, 100 % of RSC neutralization of sodic water through gypsum and good quality irrigation water. The depth of tillage in farmer's practice was 12 cm, whereas that of deep tillage was 23 cm. The tillage operations were carried out in the month of May after harvest of wheat by cultivator in FPT and by disc plough in case of deep tillage. The composition of sodic underground water and good quality rain water conserved in farm pond is given in Table 2.

The quantity of gypsum for neutralization of each $mmol_c\ L^{-1}$ of RSC was 86 kg ha^{-1} per 1,000 m^3 (for 10 cm deep irrigation) of water. The agricultural grade gypsum used was 70 % pure and 7 cm deep irrigation was applied to wheat crop, which was measured by V-notch. The quantity of gypsum required was calculated by the formula: neutralizable RSC (4.5) × 86 × number of irrigation (6) × depth of irrigation (7 cm) × purity of gypsum [17]. The quantity of gypsum required for the treatment was:

$$4.5 \times 86 \times 42/10 \times 100/70$$
$$= 2,322\,\text{kg or } 2.32\,\text{tonnes}\,\text{ha}^{-1}$$

The quantity of gypsum for 50 and 100 % RSC neutralization was 1.16 tonnes and 2.32 tonnes ha^{-1}, respectively. Application of gypsum as per treatment was broadcasted and mixed before rainy season in each year of experimentation.

Crops

Clusterbean (cv. RGC 986) and wheat (cv. Raj 3765) were grown during rainy and winter season, respectively, for 4 years (2004–2005 to 2007–2008). A recommended basal dose of 30 kg N, 17.2 kg P and 30 kg S ha^{-1} for clusterbean and 90 kg N, 25.8 kg P, 33.2 kg K and 5 kg Zn ha^{-1} for wheat was applied using urea, diammonium phosphate and muriate of potash, as sources for N, P and K, and gypsum and zinc sulphate as sources of S and Zn, respectively. Clusterbean was sown during first week of July after

Table 1 Initial physicochemical characteristics of soil profile

Soil depth (m)	Sand (%)	Silt (%)	Clay (%)	Texture	ECe (dS m^{-1})	pH	OC (g kg^{-1})	BD (g cm^3)	S A Re ($mmol_c$ L^{-1})	Available nutrients						
										N	P	K	Cu	Fe	Zn	Mn
										kg ha^{-1}			mg kg^{-1}			
0.00–0.10	69.3	16.2	15.5	Sandy loam	1.92	8.1	3.1	1.48	19	146	13	260	0.36	5.28	0.42	3.44
0.10–0.20	63.7	18.2	18.1	Sandy loam	3.08	8.4	2.4	1.61	29	174	11	285	0.41	5.51	0.54	3.81
0.20–0.30	63.1	20.7	16.2	Sandy loam	2.61	8.2	2.3	1.50	16	171	09	336	0.31	5.41	0.61	3.80
0.30–0.60	60.2	23.0	16.8	Sandy loam	1.92	7.9	1.2	1.48	18	149	09	327	0.28	5.64	0.65	3.28
0.60–0.90	50.3	29.7	20.0	Sandy loam	1.61	7.7	0.7	1.50	09	137	08	325	0.20	6.50	0.55	3.07

ECe electrical conductivity of saturation extract, *OC* organic carbon, *BD* bulk density, *SARe* sodium adsorption ratio of saturation extract

Table 2 Composition of irrigation waters

Characteristic	Good quality water (GW)	Sodic water (SW)
Electrical conductivity (dS m^{-1})	0.35	1.37
Ion concentration ($mmol_c$ L^{-1})		
Ca^{2+}	1.6	3.7
Mg^{2+}	0.3	0.7
Na^+	0.9	21.8
$CO_3^{2-} + HCO_3^-$	2.7	12.9
Cl^-	0.5	3.6
RSC (residual sodium carbonate)	0.8	8.5
SAR (sodium adsorption ratio)	0.92	14.7

RSC = $(CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$ (all ions expressed in $mmol_c$ L^{-1})

SAR = $Na^+/[(Ca^{2+} + Mg^{2+})/2]^{1/2}$ (all ions expressed in $mmol_c$ L^{-1})

receiving first monsoon rain, while wheat was sown during first week of December every year. The clusterbean was rainfed every year, whereas wheat crop was irrigated as per treatment and six irrigations were applied including pre-sowing one.

Measurements

Soil samples were collected initially and after harvest of wheat crop from each plot from 0 to 0.10, 0.10 to 0.20, 0.20 to 0.30, 0.30 to 0.60 and 0.60 to 0.90 m depths with an auger 4.0 cm in diameter. The soil samples were air dried, ground to pass through a 2-mm sieve, and analyzed for sand, silt and clay fraction [10], pH (saturation paste), ECe and SAR of saturation paste extracts [25], bulk density (Soil core method), available N (Kjeltec-II auto analyzer) and P, K, Cu, Fe, Zn and Mn [12]. After harvest of wheat infiltration rate was measured in situ every year from all treatments plot by double ring infiltrometer method [5]. Root density of wheat crop at flowering stage was computed by dividing the dry weight of roots by the volume of core. Crude protein and gum content of clusterbean and protein, starch and lysine content of wheat grain were determined by standard methods [15].

Results and Discussion

Yield

Deep tillage treatments significantly increased the grain and straw yield of clusterbean and wheat (Table 3) as compared to farmer's practice of tillage (FPT). Non-significant difference was found in grain and straw yield of clusterbean and wheat during first and second year,

Table 3 Effect of frequency of deep tillage and RSC neutralization of sodic water on seed and straw yield (kg ha^{-1}) of clusterbean and wheat crops

Treatments	2004 Clusterbean	2005	2006	2007	Pooled	2004–2005 Wheat	2005–2006	2006–2007	2007–2008	Pooled
Frequency of deep tillage										
FPT	1,545 (2,816)	1,447 (2,713)	1,407 (2,595)	1,190 (2,178)	1,397 (2,576)	3,706 (4,330)	3,508 (4,082)	3,244 (3,773)	2,967 (3,449)	3,356 (3,909)
EYDT	1,766 (3,278)	1,740 (3,274)	1,701 (3,143)	1,522 (2,829)	1,682 (3,131)	4,006 (4,596)	3,911 (4,501)	3,833 (4,434)	3,550 (4,107)	3,825 (4,410)
OYGDT	1,697 (3,117)	1,684 (3,182)	1,666 (3,087)	1,510 (2,808)	1,639 (3,049)	3,938 (4,558)	3,877 (4,524)	3,824 (4,396)	3,545 (4,378)	3,796 (4,464)
TYGDT	1,679 (3,207)	1,725 (3,204)	1,570 (2,926)	1,463 (2,737)	1,609 (3,019)	4,008 (4,643)	3,846 (4,449)	3,545 (4,100)	3,556 (4,128)	3,739 (4,330)
LSD ($p = 0.05$)	130 (144)	118 (58)	54 (91)	75 (143)	46 (76)	84 (101)	91 (74)	28 (45)	46 (55)	105 (111)
RSC neutralization of sodic water through gypsum										
0 %	1,134 (2,144)	998 (1,992)	694 (1,335)	431 (990)	814 (1,615)	3,465 (4,307)	3,243 (3,432)	2,530 (3,006)	1,847 (2,188)	2,771 (3,233)
50 %	1,571 (2,890)	1,505 (2,813)	1,502 (2,805)	1,442 (2,687)	1,505 (2,799)	3,886 (4,614)	3,760 (4,464)	3,634 (4,317)	3,440 (3,993)	3,680 (4,347)
100 %	1,975 (3,624)	1,880 (3,693)	2,005 (3,182)	1,878 (3,458)	1,935 (3,489)	4,194 (4,785)	4,196 (4,775)	4,005 (4,530)	4,017 (4,640)	4,103 (4,683)
Good quality water	2,008 (3,763)	2,106 (3,875)	2,141 (3,928)	1,934 (3,525)	2,047 (3,773)	4,323 (4,909)	4,303 (4,885)	4,276 (4,851)	4,314 (4,992)	4,304 (4,909)
LSD ($p = 0.05$)	77 (81)	79 (39)	46 (77)	52 (114)	40 (68)	52 (65)	65 (55)	23 (34)	32 (35)	79 (83)

Figure in parenthesis indicates straw yield

FPT farmer's practice of tillage, *EYDT* every year deep tillage, *OYGDT* 1 year gap in deep tillage, *TYGDT* 2 year gap in deep tillage

whereas, during third year of experimentation grain and straw yields of both crops were significantly reduced in the treatment of two years gap in deep tillage (TYGDT) compared to every year deep tillage (EYDT) and one year gap in deep tillage (OYGDT). As compared to FPT, EYDT, OYGDT and TYGDT increased the yield (pooled for four years) of clusterbean grain by 20.4, 17.3 and 15.2 % and that of straw by 21.5, 18.4 and 17.2 %, respectively. Similarly, EYDT, OYGDT and TYGDT increased the yield of wheat grain by 14.0, 13.1 and 11.4 % and that of straw by 12.8, 14.2 and 10.8 %, respectively, compared to FPT. Similarly deep tillage significantly increased the yield of corn grown in sandy loam soil [2].

Sodic water irrigation to wheat crop significantly reduced grain and straw yield of clusterbean (rainfed) and wheat during each successive year compared with good quality water irrigation to wheat and minimum yields were recorded in the fourth year (Table 3). The 50 and 100 % RSC neutralization of sodic water through gypsum significantly increased the grain and straw yield of clusterbean and wheat during each year as compared to no neutralization of RSC. Neutralization of RSC of sodic irrigation water through gypsum application @ 50, 100 % of gypsum requirement and use of good quality irrigation water increased the average yield of clusterbean grain by 84.9, 137.7 and 151.5 %, and that of clusterbean straw by 73.3, 116.0 and 133.6 %, that of wheat grain by 32.8, 48.1 and 55.3 % and that of wheat straw by 34.5, 44.8 and 51.8 %, respectively, compared to yields obtained with sodic water irrigation. The minimum yield obtained under sodic water irrigated condition may be ascribed to Ca-deficit in the soil solution [17, 22], deteriorating effects due to high pH on other soil properties [6] and poor aeration due to higher ESP level [4, 13]. Except grain yield of clusterbean in first year (2004–2005), grain and straw yields of both crops were significantly higher with good quality irrigation water than 100 % RSC neutralization of sodic water. This was further clear from pooled analysis of yield-data.

Quality

Quality parameter of clusterbean grain (crude protein and gum) and wheat grain (protein, starch and lysine) was significantly and positively influenced by different frequencies of deep tillage as compared to FPT (Table 4). This was attributed to proliferation of root to a greater depth and consequently, a greater plant growth. Deeper and denser rooting system helped to extract more water and nutrients from the soil and thus resulted in high yield and quality of clusterbean and wheat. However, differences between different frequencies of deep tillage were not significant. The quality parameters of clusterbean grain (crude protein and gum) and wheat grain (protein, starch

Table 4 Effect of frequency of deep tillage and RSC neutralization of sodic water on grain quality of clusterbean and wheat (four years mean)

Treatments	Clusterbean		Wheat		
	Crude protein (%)	Gum (%)	Protein (%)	Starch (%)	Lysine (%)
Frequency of deep tillage					
FPT	29.66	28.25	11.01	69.11	2.70
EYDT	31.36	29.20	11.63	70.14	2.77
OYGDT	31.43	29.15	11.68	69.74	2.79
TYGDT	31.37	29.16	11.66	70.00	2.79
LSD ($p = 0.05$)	0.81	0.70	0.53	0.80	0.09
RSC neutralization of sodic water through gypsum					
0 %	29.52	28.09	9.15	66.10	2.70
50 %	31.65	29.17	12.34	70.90	2.81
100 %	31.60	29.26	12.53	71.14	2.85
Good quality water	31.04	29.25	12.01	70.87	2.74
LSD ($p = 0.05$)	0.57	0.51	0.39	0.60	0.07

FPT farmer's practice of tillage, *EYDT* every year deep tillage, *OYGDT* one year gap in deep tillage, *TYGDT* two year gap in deep tillage

and lysine) were significantly influenced by RSC neutralization through gypsum. The effect on quality parameters brought about by 50 and 100 % RSC neutralization of sodic water and good quality irrigation water was not significant. Neutralization RSC through gypsum had favourable effect on physico-chemical property of soil affected more extraction of nutrients due to improvement in aggregate stability [1, 14].

Root Mass Density of Wheat

The data on profile distribution of root mass at flowering stage (Table 5) revealed that maximum root mass was located in the 0–0.15 m soil horizon and it decreased with depth. Deep tillage significantly influenced the root mass density and maximum root mass density 654 g m^{-3} was observed in EYDT followed by 619 g m^{-3} in OYGDT and 585 g m^{-3} in TYGDT. Maximum rooting depth was beyond 1.2 m under deep tillage treatments, and only 0.90 m under FPT. The root mass density of wheat increased from 26.1 to 40.9 % with different frequencies of deep tillage as compared to FPT. Deep tillage improved physical environment of soil, which facilitated better root proliferation and penetration and consequently resulted in higher root mass density. Increase in root density resulted in greater extraction of water and nutrients from the lower soil layer which were relatively less deteriorated due to sodic water irrigation.

As shown in Table 5, the rooting depth of wheat was greater than 1.2 m under 50 and 100 % RSC neutralization of sodic water and under good quality irrigation water, whereas rooting depth was only 0.60 m under sodic water irrigation. The root density in 0–1.2 m soil profile was maximum (689 g m^{-3}) under good quality irrigation water followed closely by 100 % RSC neutralization of sodic water (672 g m^{-3}) and minimum (335 g m^{-3}) under sodic water irrigation.

Infiltration Rate

At the end of winter crop every year, final infiltration rate (FIR) was measured in all the treatment plots (Table 6). Deep tillage improved the infiltration rate and the highest mean infiltration rate was 2.23 cm h^{-1} under EYDT treatment, although the difference between various frequencies of deep tillage was not significant. Minimum mean infiltration rate 1.16 cm h^{-1} was observed under FPT. Different frequencies of deep tillage EYDT, OYGDT and TYGDT increased the infiltration rate by 92.2, 77.6 and 70.7 %, respectively, as compared to FPT. The higher infiltration rate in deep tillage plots was due to the fact that deep tillage shattered the plough sole and thereby made the soil more pervious.

In sodic water irrigated plots the infiltration rate decreased every year and it was minimum (0.37 cm h^{-1}) at the end of fourth year. The infiltration rate possibility decreased due to clay dispersion, its migration and the resultant clogging of soil pores under irrigation with sodic water which also appeared to cause structural problems and thereby decline in infiltration rate [11, 13, 23]. Maximum mean value infiltration rate (2.61 cm h^{-1}) was observed in good quality water irrigated plots but it was not significantly different from infiltration rate under 100 % RSC neutralization of sodic water. The treatment 100 % RSC neutralization resulted in significantly higher infiltration rate as compared to 50 % RSC neutralization of sodic water. Favourable effect of RSC neutralization on infiltration rate might be due to improvement in aggregate stability [1, 14].

Soil Properties

After four consecutive year cultivation of clusterbean and wheat significant changes in pH, ECe and SARe of soil

Table 5 Effect of frequency of deep tillage and RSC neutralization of sodic water on soil profile distribution of root density (g m^{-3}) of wheat at flowering stage (four years mean)

Treatments	Root density in soil horizon (m)					
	0–0.15	0.15–0.30	0.30–0.60	0.60–0.90	0.90–1.20	0–1.20
Frequency of deep tillage						
FPT	334	100	22	08	00	464
EYDT	390	165	48	30	21	654
OYGDP	374	162	44	25	14	619
TYGDP	363	149	39	23	11	585
LSD ($p = 0.05$)	8.3	4.2	1.8	1.5	0.9	11.6
RSC neutralization of sodic water through gypsum						
0 %	230	82	23	00	00	335
50 %	394	154	38	25	13	624
100 %	423	164	42	28	15	672
Good quality water	413	175	51	32	18	689
LSD ($p = 0.05$)	4.7	2.8	1.5	0.9	0.8	8.7

FPT farmer's practice of tillage, *EYDT* every year deep tillage, *OYGDT* one year gap in deep tillage, *TYGDT* two year gap in deep tillage

Table 6 Effect of frequency of deep tillage and RSC neutralization of Sodic water on infiltration rate (cm h^{-1}) after harvest of wheat

Treatments	Infiltration rate (cm h^{-1})				Mean
	2004–2005	2005–2006	2006–2007	2007–2008	
Frequency of deep tillage					
FPT	0.77	1.43	1.21	1.22	1.16
EYDT	1.71	2.52	2.56	2.12	2.23
OYGDP	1.83	2.10	2.39	1.90	2.06
TYGDP	1.92	2.06	1.73	2.20	1.98
LSD ($p = 0.05$)	0.57	0.48	0.61	0.66	0.56
RSC neutralization of sodic water through gypsum					
0 %	1.56	0.92	0.58	0.37	0.86
50 %	1.70	1.48	1.60	1.45	1.56
100 %	1.36	2.48	2.72	2.62	2.30
Good quality water	1.62	3.33	2.74	2.76	2.61
LSD ($p = 0.05$)	N.S.	0.31	0.47	0.43	0.41

FPT farmer's practice of tillage, *EYDT* every year deep tillage, *OYGDT* 1 year gap in deep tillage, *TYGDT* 2 year gap in deep tillage

Table 7 Effect of frequency of deep tillage and RSC neutralization of Sodic water on soil properties after the harvest of crops

Treatments	pH			ECe (dS m^{-1})			SARe (mmol L^{-1})		
	Clusterbean	Wheat	Average	Clusterbean	Wheat	Average	Clusterbean	Wheat	Average
Frequency of deep tillage									
FPT	8.60	8.69	8.65	2.79	3.00	2.88	21.38	24.36	22.84
EYDT	8.39	8.57	8.49	1.47	2.25	1.88	12.06	21.86	16.85
OYGDT	8.46	8.58	8.52	1.70	2.26	1.98	13.50	22.06	17.71
TYGDP	8.48	8.58	8.54	1.74	2.32	2.03	14.15	22.52	18.23
LSD ($p = 0.05$)	0.12	0.07	–	0.14	0.21	–	2.15	2.64	–
RSC neutralization of sodic water through gypsum									
0 %	8.82	8.85	8.84	2.46	3.33	2.90	26.19	32.24	29.11
50 %	8.51	8.58	8.55	1.79	2.43	2.14	12.93	25.13	19.53
100 %	8.31	8.50	8.40	1.84	2.68	2.31	10.60	16.52	13.56
Good quality water	8.29	8.46	8.38	1.61	1.51	1.54	12.34	17.18	14.67
LSD ($p = 0.05$)	0.08	0.05	–	0.09	0.14	–	1.41	1.72	–

FPT farmer's practice of tillage, *EYDT* every year deep tillage, *OYGDT* 1 year gap in deep tillage, *TYGDT* 2 year gap in deep tillage were observed (Table 7). Deep tillage significantly reduced the pH, ECe and SARe compared to FPT but the differences between different frequencies of deep tillage were not significant. Beneficial effects of deep tillage are likely due to increased soil-aeration and improved water penetration resulting in more leaching.

Soil pH was reduced significantly on irrigation with RSC-neutralized water and 100 % neutralization of RSC was as effective as good quality water for irrigation. Even more contrasting effects of RSC-neutralization were observed on SARe values which were considerably reduced by RSC-neutralization. Significant reduction in ECe was observed under good quality irrigation water and 50 and 100 % of RSC neutralization of sodic water compared with sodic water irrigated plots. Beneficial effects of RSC neutralization on pH and SAR can be ascribed to beneficial effect of Ca^{++} supplied through gypsum.

Conclusions

Long-term use of sodic water for irrigation significantly decreased the grain and straw yields and quality parameters of clusterbean and wheat grains due to increase in soil pH, ECe and SARe. On 100 % neutralization of RSC of sodic water with gypsum, grain and straw yields increased 137.7 and 116.0 %, respectively, in case of clusterbean and 48.1 and 44.8 % in wheat, compared with sodic water irrigation. Deep tillage in 1 year gap could sustain grain and straw yields of both clusterbean and wheat. Similarly, quality of clusterbean grain (crude protein and gum content) and wheat grain (protein, starch and lysine content) improved due to neutralization of RSC and deep tillage. Reduction in pH (0.44), ECe (0.59 dS m^{-1}), SARe (15.55) and increase in infiltration rate (1.44 cm h^{-1}) were also observed on 100 % RSC-neutralization as compared with sodic water irrigation. Similarly, deep tillage reduced the pH, ECe, SARe and increased the infiltration rate. Concludingly, 1 year gap in deep tillage in the month of May and 100 % RSC neutralization through gypsum application at the beginning of monsoon (last week of June) had a positive effect on yield and quality of clusterbean and wheat with sodic water irrigation on sandy loam soil in arid region.

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References

1. Agassi M, Shainberg I, Morin I (1981) Effect of electrolyte concentration and soil sodicity on the infiltration rate and crust formation. Soil Sci Soc Am J 45:845–851
2. Arora VK, Gajri PR, Prihar SS (1991) Tillage effects on corn in sandy soil in relation to water retentively nutrient and water management and season evaporativity. Soil Tillage Res 21:1–21
3. Ayer RS, Westcot DW (1985) Water quality for agriculture. FAO irrigation and drainage paper 29, Rev 1, FAO, Rome
4. Bajwa MS, Choudhary OP, Josan AS (1992) Effect of continuous irrigation with sodic and saline-sodic waters on soil properties and crop yields under cotton-wheat in north-western India. Agric Water Manag 22:345–356
5. Bouwer H (1986) Intake cylinder infiltrometer. In: Klute A (ed) Methods of soil analysis. Part 1. Physical mineralogical properties, Am Soc Agron Monogr, no. 9, Madison, USA, pp 825–844
6. Choudhary OP, Josan AS, Bajwa MS (2001) Yield and fiber quality of cotton cultivars as affected by sustained sodic irrigations in semi-arid conditions. Agric Water Manag 49:1–9
7. Choudhary OP, Josan AS, Bajwa MS (2002) Role of organic materials in mobilizing intrinsic calcium carbonate to ameliorate sodic irrigations. In: Proceedings of the 17th world congress soil science, symposium no. 34, abstracts vol. III, Symposia 22–36, p 162
8. Choudhary OP, Josan AS, Bajwa MS, Kapur ML (2004) Effect of sustained sodic and saline sodic irrigation and application of gypsum and farmyard manure on yield and quality of sugarcane under semi-arid conditions. Field Crops Res 87:103–116
9. Choudhary OP, Ghuman BS, Josan AS, Bajwa MS (2006) Effect of alternating irrigation with sodic and non-sodic waters on soil properties and sunflower yield. Agric Water Manag 85:151–156
10. Gee GW, Bauder JW (1986) Particle size analysis. In: Klute A (ed). Method of soil analysis. Part 1: physical and mineralogical methods. Monograph no. 9, (2nd edn) ASA, Madison, WI
11. Grattan SR, Oster JD (2003) Use and reuse of saline-sodic water for irrigation of crop. J Crop Prod 7:131–162
12. Jackson ML (1967) Soil chemical analysis. Prentice hall of India (P) Ltd., New Delhi
13. Josan AS, Bajwa MS, Choudhary OP (1998) Effect of sustained sodic irrigations on physical properties and root growth in a *Typic Ustochrept* soil under two cropping systems. J Res 35:125–131
14. Keren R, Shainberg I (1981) The efficiency of industrial mined gypsum in reclamation of a sodic soil: rate of dissolution. Soil Sci Soc Am J 45:103–107
15. McCleary BV (1981) An enzymic technique for the quantitation of galactomannan in guar seeds. Lebensm Wiss U Technol 14:188–191
16. Minhas PS, Bajwa MS (2001) Use and management of poor quality waters for the rice-wheat based production system. J Crop Prod 4:273–305
17. Minhas PS, Gupta RK (1992) Quality of irrigation water. Assessment and management. ICAR, New Delhi, pp 123–124
18. Minhas PS, Sharma DR, Singh YP (1995) Response of rice and wheat to applied gypsum and farmyard manure on an alkali water irrigated soil. J Ind Soc soil Sci 43:452–455
19. Minhas PS, Singh YP, Chhabba DS, Sharma VK (1999) Changes in hydraulic conductivity of highly calcareous and non-calcarious soils under cycles of irrigation with saline and simulatated rain water. Irrig Sci 7:159–167
20. Oster JD, Jayawardene NS (1998) Agricultural management of sodic soil. In: Sumner ME, Naidu R (eds) Sodic soils: distribution, processes, management and environmental consequences. Oxford University Press, Oxford, pp 125–147
21. Oster JD (2004) Amendment use to mitigate the adverse effects of sodic water. In: Proceedings of the international conference on sustained management of sodic lands, extended summaries, UP-CAR, Lukhnow, India, pp 89–91
22. Pearson GA (1960) Tolerance of crops to exchangeable sodium. Issue 216 of Agriculture information bulletin. Agricultural Research Service, U.S. Dept. of Agriculture, 4pp

23. Pratt PF, Suarez DL (1990) Irrigation water quality assessment. In: Tanji KK (ed) Agricultural salinity assessment and management. ASCE Manuals and Reports on Engineering Practices, vol 71. New York, The United States of America, pp 220–236
24. Rhoades JD, Bingham FT, Letey J, Hoffman GJ, Dedrick AR, Pinter PJ, Pepryoyle JA (1989) Use of saline drainage water for irrigation: Imperial Valley study. Agric Water Manag 16:25–36
25. Richards LA (1954) Diagnosis and improvement of saline alkali soils, vol. 60. US Department of Agriculture Handbook, 83 pp
26. Yadav HD, Kumar V (1995) Management of sodic water in light textured Soil. In: Rao KVGK, Agrawal MC, Singh OP, Ooster baan RJ (eds) Reclamation and management of water logged saline soils. National seminar proceeding, CSSRI, Karnal and HAU, Hisar, pp 226–241