Indian Journal of Agronomy **62** (3): 287–294 (September 2017)

Research Paper

Effect of alkali and canal waters in cyclic and blended mode on potato (*Solanum tuberosum*)–sunflower (*Helianthus annuus*)–sesbania (*Sesbania sesban*) cropping sequence

S.K. CHAUHAN[1] AND S.K. SINGH[2]

Raja Balwant Singh College, Bichpuri, Agra, Uttar Pradesh 283 105

Received : January 2016; Revised accepted : April 2017

ABSTRACT

Response of potato (*Solanum tuberosum* L.)–sunflower (*Helianthus annuus* L.)–sesbania [*Sesbania sesban* (L.) Merr.] cropping sequence to conjunctive use of good quality canal water [EC_{CW} 1.1 dS/m, residual sodium carbonate (RSC) nil, sodium adsorption ratio (SAR) 1.7] and alkali water (EC_{AW} 3.8 dS/m, RSC 15.5 me/L, SAR 11.8) was evaluated for 6 years (2007–2008 to 2012–2013) on a well-drained sandy-loam soil [ECe 2.3 dS/m, *p*H 8.1, exchangeable sodium percentage (ESP) 5.5]. Increase in soil *p*H (8.9–9.1), salinity (3.4–4.7 dS/m) and sodicity (ESP 24.1–39.5) as a consequence of irrigation with alkali water affected the growth and yields of all the crops. When averaged for 6 years, the relative yields ranged between 48 and 78% for potato and 55 and 73% for sunflower in case of cyclic use of alkali water compared to canal water. However, the relative yields ranged 58 to 83% for potato and from 52 to 78% for sunflower when alkali water was used in blended mode. Considerable deterioration in the quality of potato in terms of grade, size and keeping quality, and reduction in oil content of sunflower was observed. The change in soil properties in different modes of water application was in accordance with the proportions of alkali water applied. The analysis on use of canal and alkali waters in similar proportion further indicated that cyclic application of canal water during the initial stages would minimize the adverse effects of alkali water.

Key words : Alkali water, Canal water, Conjunctive use, Cyclic and blending mode, Potato–sunflower–sesbania crop sequence

Degradation of soil with the use of alkali groundwaters constitutes a major threat to irrigated agriculture in semi-arid regions, particularly in South Asia (Qadir and Oster, 2004). In Indo-Gangetic plains, which is the most intensively cultivated area, high incidence of alkali groundwater (30–50%) is found where annual rainfall is between 500 and 700 mm.

Use of alkali water for irrigation to crops leads to increase in soil Sodicity, thus adversely affects physical behaviour of soil in terms of crusting, hard-setting and low infiltration rates. It not only deteriorates the soil quality, but also affects the crop yields and limits the choice of crops that can be grown on such soils. Appropriate selection of crops, improved water-management practices and application of amendment are important in maintaining soil structure/ permeability. Therefore, specialized soil-crop-irrigation management practices, which helps to maintain sodicity levels within permissible limit in crop root zone depth are needed for irrigation with alkali groundwaters for sustainable yield.

Under certain situations, where limited quantity of good quality canal water is available, it should be applied efficiently either in cyclic or blended mode to obtain acceptable crop yield. In case of saline water, germination and seedling establishment stages have been identified as most sensitive for most of the crops. Thus use of good quality water is advocated for pre-sowing and early growth stages before switching to saline water when crops attain higher tolerance. However, with use of alkali waters, where sodication occurs with depletion of Ca^{2+} due to its precipitation as calcite ($CaCO_3$), strategies that would either minimize calcite precipitation or maximize the dissolution of precipitated calcite would be expected to perform better. Usually groundwater aquifers are in equilibrium

[1]**Corresponding author's Email:** sandipsingh11@rediffmail.com
[1]Junior Scientist (Agronomy); AICRP (SAS and USW) Centre, R.B.S. College, Bichpuri, Agra, Uttar Pradesh 283 105; [2]Subject Matter Specialist (Agronomy) Krishi Vigyan Kendra, Parwaha, Auraiya, ATARI, ICAR, Zone-VI, Kanpur, Uttar Pradesh 206 244

with inherent calcite, thus it seems that blending of groundwaters of higher alkalinity and low calcium with canal waters would result in their under-saturation with respect to calcite. Consequently, in addition to dilution of soil solutions, irrigation with blended water/ better quality canal waters should have a tendency to pick up calcium through dissolution of native calcite. Earlier reports (Minhas *et al*., 2007) indicated that cyclic use of alkali and canal waters decreased sodication of soils and thus helped in sustaining paddy–wheat yields. However, resultant benefits in terms of a decrease in calcite precipitation or its increased dissolution yet to be quantified, where better quality canal and alkali waters are combined for irrigating moderately sensitive crops like potato and sunflower. Therefore, the aim of the study was to evaluate the impact of use of cyclic (annual/crop) and blended mode of alkali water with canal water in potato–sunflower–sesbania cropping sequence on yield, quality and soil health.

MATERIALS AND METHODS

The experiment was conducted at the Research Farm of Raja Balwant Singh College of Agriculture, Bichpuri, Agra, Uttar Pradesh (27° 2' N and 77° 9' E). The climate in the region is semi-arid which receives an average annual rainfall of 650 mm, of that about 80% is received during July–September. The soils in the region are generally well-drained (water table 10–12 m below ground level) sandy loam with an electrical conductivity of the saturated paste extract (ECe) of 2.7 dS/m, *p*H of the saturated paste (*p*Hs) of 7.9, exchangeable sodium percentage (ESP) of 5.3, organic matter content of 2.9 g/kg soil and clay content of 14%. The groundwater quality in the region varies, with EC 2–4 dS/m, residual sodium carbonate (RSC) 14–18 me/L and sodium adsorption ratio (SAR) 10–14. The experiment was initiated in 2007 for potato-sunflower-sesbania cropping sequence with potato as the first crop and continued for 6 years (2007–08 to 2012–13). Treatments comprised combinations of irrigation with good quality canal water and alkali water applied alone, in cyclic (annual/ crop-wise) or in blended mode. Nine treatments combinations, comprising (*i*) all irrigation with canal water (CW), (*ii*) all irrigation with alkali water (AW), (*iii*) 1-year canal water (CW) : 2 year alkali water (AW), (*iv*) 2-year alkali water (AW): 1 year canal water (CW), (*v*) 2-year canal water (CW): 1-year alkali water (AW), (*vi*) 1-year alkali water (AW): 2-year canal water (CW) (*vii*) alkali water in potato (AWp) and canal water in sunflower (CWs), (*viii*) mixing 2 parts canal water + 1 part of alkali water (2 CW + 1 AW) (*ix*) mixing 1 part canal water + 2 parts of alkali water (2 AW + 1 CW). One cycle of potato–sunflower–sesbania (GM) crop rotation was 3 years than further cycle of this rotation was next 3 years. The treatments were imposed in a randomized block design with 4 replications. The plot size was 20 m^2 (5 m × 4 m) and to control lateral fluxes of salt and water, each plot was lined with polyethylene sheet down to a depth of 90 cm. Alkali water was synthesized by dissolving the required quantities of sodium bicarbonate in canal water. The equivalent weight of $NaHC_3$ is dissolved in 1L of canal water for our RSC purpose. The analysis of the canal water indicated its quality as 1.1 dS/m, RSC nil and SAR 1.8 whereas the average quality of the synthesized alkali water was EC_{AW} 3.6 dS/m, RSC 15.8 me/L, and SAR 12.4. Potato seed (cv. ‘Kufri Bahar’) was planted in the last week of October and harvested during the last week of February or first week of March. The recommended dose of fertilizer (N P K 100 21 35 kg/ha) was applied to potato crop. After potato, sunflower (‘MSFH 17’) crop was sown in the middle of March and harvested in middle of June. It was fertilized with N : P : K 80 : 16 : 18 kg/ha. Sesbania crop was raised during July–August in the rainy season but no fertilizers or irrigation water was applied. The biomass of the 55 days old sesbania crop was incorporated into the soil. The potato crop sown on beds and the irrigation depth was kept 5 cm; however, sunflower crop was sown in flat field. The irrigation depth was 7 cm but sesbania crop was growing without irrigation in all 6 years experimentation (Table 1). The rainfall received during the potato, sunflower and sesbania seasons averaged 31.1, 39.6 and 362.0 mm respectively (Table 1). The tuber yield was recorded grade-wise, i.e. A grade (> 60 g), B grade (40–60 g) and C grade (< 40 g) in all the treatments. The keeping quality of potato tuber in the form of weight loss (%) was recorded in 3 months potato tuber storage at room temperature.

Sustainability indices (sustainable yield index, SYI) were also calculated. The quantitative assessment of the sustainability of agricultural practices was developed by Singh *et al.* (1990). The SYI was calculated as follows:

$$SYI = \frac{Ym - Sd}{Y_{max}}$$

where, Ym is the mean yield, Sd the standard deviation, Ym ax is the maximum yield obtained under a set of management practices.

Soil samples were collected to a depth of 90 cm at planting and at harvesting of the crops and soil water storage (SWS) was determined using gravimetric method. The quantity of water used (WU) was calculated as difference in soil storage during the season (SWS) plus irrigation (IW) and rainfall (R). The water-use efficiency (WUE, kg/ha-cm) was calculated as the ratio of yield (kg/ha) to WU (cm).

RESULTS AND DISCUSSION

Soil properties

The salt build up in the surface soil layer (0–30 cm), where most of the dense crop roots are confined and has high potential for clay dispersion, surface crusting thus low infiltration rate, was most influenced by the quality of irrigation water. The effect of various modes of irrigation on soil properties, though monitored up to 90 cm in the effective root zone depth, is presented limited to agriculturally important surface soil layer (Fig.1). Continuous irrigation with alkali water (AW) significantly increased the salt built up in soil profile as compared to continuous use of canal water (CW). The average values of *p*H, ECe, SARe and ESP at the harvesting of different crops or sowing of next crops during the sixth year ranged from 7.6 to 9.1, 2.6 to 4.7 dS/m, 3.3 to 21.2 and 9.1 to 39.5, respectively, with higher values being observed at the harvest of sunflower crop.

Soil sodication due to irrigation with alkali waters has been reported in the north-west parts of India (Minhas *et al*., 2007; Chauhan *et al.* 2007). The sodicity build up in soils irrigated with alkali waters in the north-west region has been observed to be the outcome of equilibrium between the processes of precipitation and dissolution of calcite. Precipitation occurs mainly due to concentration of the soil solution due to water uptake during the cropping season, while the monsoon rains induce the release of divalent cations both from exchange sites and dissolution of calcite and other minerals. In these cases, a quasi-equilibrium is established within about 4–5 years of irrigation, depending on the nature of crops grown, soil characteristics and the climate especially rainfall at the site. Due to sodicity-induced reductions in water infiltration, the opportunity for alkali waters to penetrate deeper is farther reduced. The application of alkali waters further increases sodicity in the upper soil layers when concentrated through the loss of water due to evapotranspiration. However, sodicity build up in soil (ESP–2.5 × SAR_{AW}) was greater than the earlier reported values of about 1.2–1.5 × SAR_{AW} for upland double crop rotations like maize/ millet–wheat (Manchanda, 1993). This was in spite of the fact that the content of Ca^{2+} and Mg^{2+} (10.2 me/L) in alkali water used for the irrigation was much higher and the field was regularly incorporated with green manure (sesbania) during the monsoon season. The latter is known to induce bioremediation in soils through dissolution of precipitated calcite in the rhizosphere because of enhanced partial pressure of carbon dioxide and the production of organic acid during its decomposition (Qadir *et al.*, 2002). Moreover, with incorporation of sesbania, the Ca and Mg taken up by the crop during its growth, was being returned to the soil. It is documented that legumes like sesbania rely on N_2-fixation to release protons (H^+) that contribute to a decrease in soil *p*H in calcareous soils and thus dissolve calcite (Qadir and Oster, 2004). These effects were evident, as the ESP in surface soil up to 30 cm averaged between 9.1 and 24.1 at the harvesting of sesbania/ sowing of potato after the cessation of monsoon while it was between 11.1 and 39.5 at the harvesting of sunflower/ sowing of sesbania, thus an average increase in ESP by 2.0 in case of CW alone and 15.4 in case of AW alone (Fig.1). Proportionately higher build up of sodicity in the soils under the present study can be ascribed to the higher quantity of water applied (550 mm – 700 mm) and the proportion of alkali water used for irrigation of potato and sunflower when the soils were in a precipitation phase (October–June). Further, it is interesting to note that the annual rainfall in the region is adequate to sustain the soil ESP (slight reduction in case of CW and slight increase in case of AW despite high inter-seasonal increase) over 6 years of study period (Fig.2). In comparison, wheat was the main winter crop in rotation during the earlier documented studies (Manchanda, 1993) and it required 350–420 mm of irrigation water. The data in the present study corroborate the recent analysis by Minhas and Sharma (2006) that in addition to the ion chemistry of irrigation waters, applied irrigation water, rainfall and evapo-transpiration of the crops

Table 1. Pan evaporation (PE), rainfall (R) and applied irrigation water (IW) to different crops

Crop	Parameters	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	Mean
Potato	PE (mm)	229.0	257.0	285.0	232.0	245.0	266.0	252.0
	R (mm)	25.8	10.3	Nil	87.1	1.3	Nil	31.1
	IW (mm)	250.0	250.0	300.0	300.0	300.0	300.0	283.0
Sunflower	PE (mm)	787.0	775.0	768.0	758.0	769.0	782.0	773.0
	R (mm)	20.2	16.1	61.5	50.0	57.0	32.8	39.6
	IW (mm)	420.0	420.0	420.0	350.0	280.0	280.0	362.0
Sesbania	PE(mm)	223.0	231.0	168.0	211.0	231.0	189.0	208.0
	R (mm)	262.5	367.5	581.6	219.6	212.4	210.8	309.6
	IW (mm)	Nil	Nil	Nil	Nil	Nil	Nil	Nil

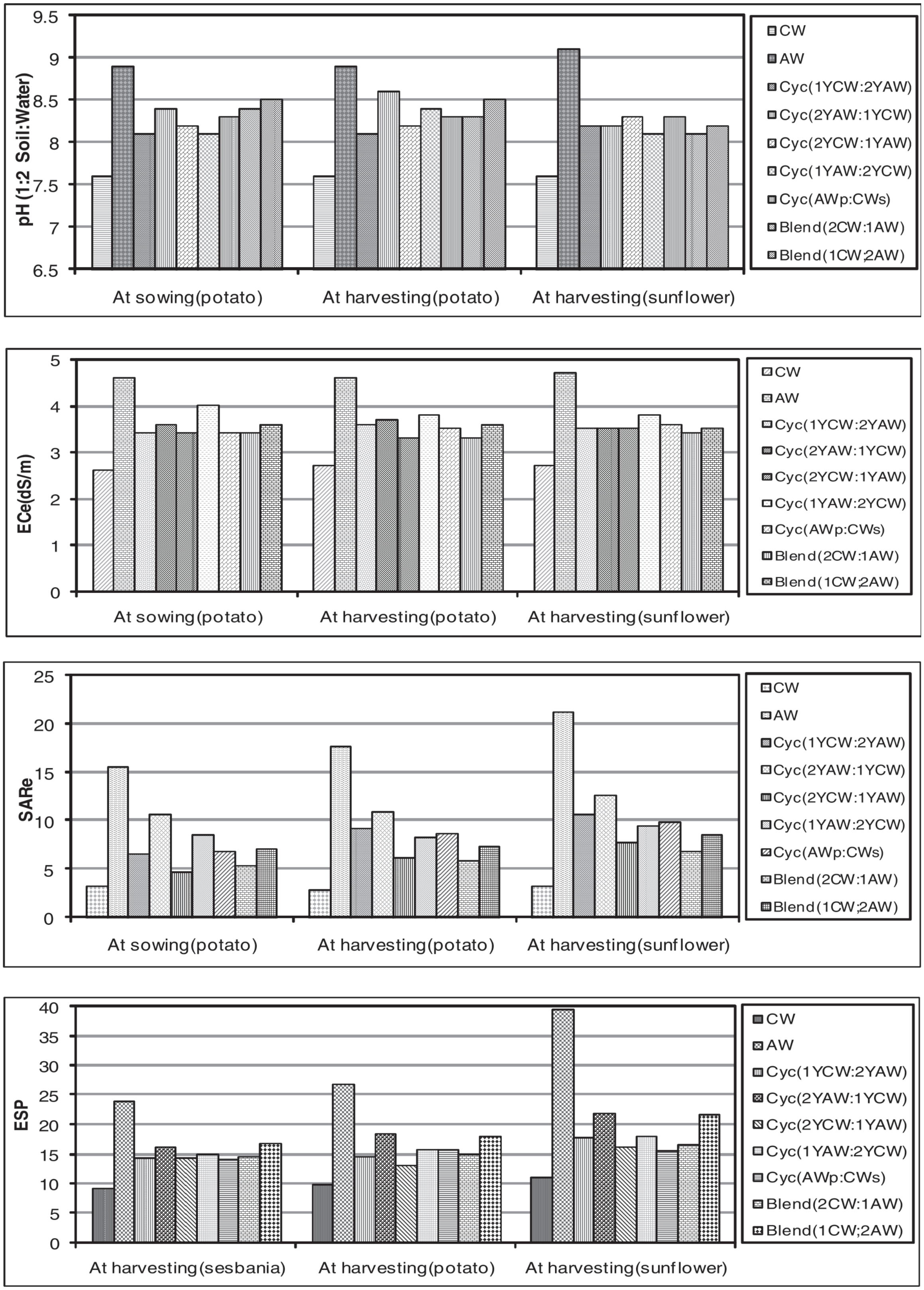

Fig. 1. Effect of use of canal and alkali waters in cyclic (annual) and blended mode on soil Properties (0–30 cm) during 6th year of cropping (SARe, Sodium adsorption ratio; ESP, exchange sodium percentage)

also influence the extent of sodicity buildup in soils irrigated with alkali waters.

The buildup of salinity and sodicity in soils was also related to the proportion of AW used in various modes of irrigation, while little difference was observed between respective use in cyclic and blended modes. The *p*H of the surface soil up to 30 cm ranged between 8.1 and 8.6 though considerable differences in ESP (14.1–22.0) were observed under different modes of combined use of canal and alkali waters during the sixth year (Fig. 1). The average ESP were estimated 17.8, 22.0, 16.3 and 18.0 for 1 YCW 2 YAW, 2 YAW 1 YCW, 2 YCSW: 1 YAW and 1 YAW : 2 YCW cyclic treatments, indicating an enhanced buildup of sodicity with higher proportion of AW used (Fig.1). The increase in ESP was more prevalent when AW was used in initial year(s) and CW was used in subsequent

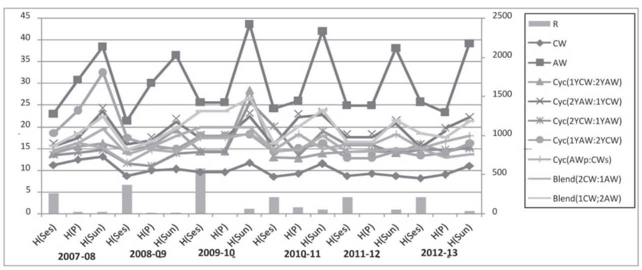

Fig. 2. Effect of different modes of canal and alkali water use on exchangeable sodium percentage (0–30 cm) during study period (2007–08 to 2012–13)

year(s). Further, reduction in ESP after 6 years of study period was observed in treatments when 2YCW was used, whereas, ESP increased marginally when 1YCW was used (Fig. 2). However, the ESP under the crop wise cyclic treatment (AWp : CWs) and blends of canal and alkali waters (2 CW + 1 AW, 1 CW + 2 AW) on sixth year were observed in the range of 15.7–21.8 (Fig. 1). Further, the ESP remained nearly static after 6 years of experiment for AWp : CWs and 2 CW + 1 AW, whereas increased marginally for 1 CW + 2 AW used in blended mode. Among all treatments of combined use of canal and alkali waters, cyclic application of 2 YCW + 1 YAW and blended use of 2 CW : 1 AW were found best in terms of reduction of soil ESP. Minhas *et al.* (2007) also reported similar results with paddy-wheat where keeping the proportion of added AW as the same; the sodicity build up was similar with cyclic use and blending.

Crop

Irrigation with AW alone significantly reduced the average yields over a period of 6 years of potato (85%), sunflower (88%) and sesbania (65%), though the reduction in yields were comparatively lower in the first year (potato 71%, sunflower 74% and sesbania 64%) than subsequent years (Table 2). Both potato and sunflower have been rated as moderately sensitive crops (Maas and Grattan, 1999). Higher relative yield of sesbania than potato and sunflower was observed mainly on account of high

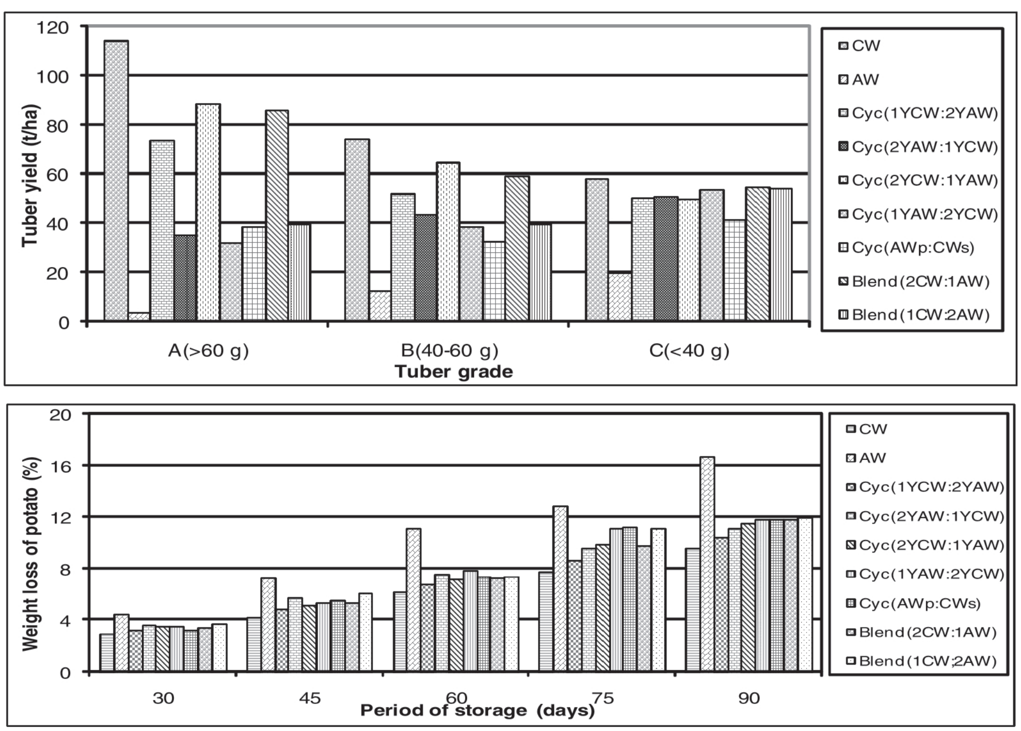

Fig. 3. Effect of different modes of application of canal and alkali water on graded tuber yield (top) and weight loss (bottom) of potato tuber

amount of rainfall received during the crop season. The significant reduction in crop yields can be ascribed to bicarbonate toxicity and build up of alkalinity and sodicity in soils leading to structural deterioration and poor permeability. These factors ultimately result in nutritional imbalances (Qadir and Oster, 2004). The restricted movement of water in soils irrigated with alkali water may also result in the retention of salts in surface layers, which simultaneously induces salinity stresses affecting crop growth (Minhas *et al*., 2003). The salinity during the crop-growth period, though not high (2.9–4.9 dS/m), was above the threshold values reported for the test crops under consideration (Maas and Grattan, 1999).

The yields for each crop improved under various combinations of CW and AW usage compared with AW alone. The crops performed better with yearly water use compared to blending. When averaged over the 6 years, the RY of potato were 66, 54, 78, 60 and 48% under the cyclic 1 YCW : 2 YAW, 2 YAW : 1 YCW, 2 YCW : 1 YAW, 1 YAW : 2 YCW and AWp : CWs treatments respectively, while the relative yield was 83 and 58% for waters blended in the ratio 2 CW + 1 AW and 1 CW + 2 AW re-

Table 2. Effect of modes of irrigation with alkali and canal water on yield of crops

Mode of irrigation	Potato tuber yield (t/ha)								
	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	Mean	RY (%)	SYI
All canal water (CW)	24.5	28.2	25.9	31.2	25.7	36.3	28.6	100	0.83
All alkali water (AW)	7.1	4.3	3.4	2.6	2.3	6.6	4.4	15	0.34
Cyclic (1 YCW : 2 YAW)	23.1	17.9	16.6	23.6	15.9	17.3	19.1	66	0.65
Cyclic (2 YAW : 1 YCW)	18.8	10.8	18.4	13.7	8.4	20.8	15.2	54	0.56
Cyclic (2 YCW : 1 YAW)	19.7	24.1	20.9	24.9	23.4	22.9	22.7	78	0.82
Cyclic (1 YAW : 2 YCW)	9.3	16.8	18.9	13.7	14.1	31.1	17.3	60	0.72
Cyclic (AWp : CWs)	11.4	13.5	15.9	12.7	9.9	19.6	13.8	48	0.73
Blending (2 CW + 1 AW)	21.0	22.4	21.7	23.9	21.3	31.8	23.7	83	0.94
Blending (1 CW+ 2 AW)	13.8	15.3	17.2	16.6	12.8	24.4	16.7	58	0.86
SEm±	0.6	0.7	0.6	0.7	0.8	0.6	-	-	-
CD (P=0.05)	1.8	2.1	1.7	2.1	2.3	1.9	-	-	-
	Sunflower seed yield (t/ha)								
All canal water (CW)	1.29	1.54	1.23	1.48	1.05	1.30	1.32	100	0.73
All alkali water (AW)	0.33	0.17	0.11	0.14	0.11	0.10	0.16	12	0.22
Cyclic (1 YCW : 2 YAW)	1.20	0.65	0.50	11.4	0.61	0.61	0.79	60	0.40
Cyclic (2 YAW : 1 YCW)	0.77	0.71	0.83	0.65	0.58	0.76	0.72	55	0.75
Cyclic (2 YCW : 1 YAW)	0.98	1.37	0.61	1.13	0.95	0.69	0.96	73	0.49
Cyclic (1 YAW : 2 YCW)	0.45	0.96	0.99	0.61	0.68	0.75	0.74	56	0.53
Cyclic (AWp : CWs)	0.82	0.95	0.71	0.79	0.69	0.78	0.79	60	0.73
Blending (2 CW + 1 AW)	1.03	1.32	0.86	1.09	0.94	0.95	1.03	78	0.76
Blending (1 CW + 2 AW)	0.81	0.74	0.65	0.72	0.61	0.63	0.69	52	0.65
SEm±	0.06	0.07	0.07	0.04	0.04	0.03	-	-	-
CD (P=0.05)	0.19	0.23	0.22	0.12	0.13	0.11	-	-	-
	Sesbania biomass yield (t/ha)								
All canal water (CW)	20.1	19.1	19.6	19.9	20.0	20.9	19.9	100	0.93
All alkali water (AW)	7.2	6.8	6.7	6.8	6.9	7.5	7.0	35	0.89
Cyclic (1 YCW : 2 YAW)	19.7	17.9	16.7	17.3	17.6	18.5	18.0	90	0.86
Cyclic (2 YAW : 1 YCW)	18.7	17.0	17.2	17.1	17.3	17.2	17.4	87	0.90
Cyclic (2 YCW : 1 YAW)	17.0	16.8	16.9	16.6	16.7	16.9	16.8	84	0.98
Cyclic (1 YAW : 2 YCW)	12.1	13.0	17.9	12.8	17.8	16.8	15.1	76	0.69
Cyclic (AWp : CWs)	18.2	14.7	17.9	17.5	17.7	18.3	17.4	87	0.88
Blending (2 CW + 1 AW)	18.9	17.4	17.6	17.8	17.9	18.5	18.0	92	0.93
Blending (1 CW + 2 AW)	17.9	16.8	16.4	17.0	17.2	17.6	17.2	86	0.92
SEm±	0.3	0.2	0.2	0.3	0.3	0.4	-	-	-
CD (P=0.05)	1.0	0.7	0.7	1.0	1.1	1.3	-	-	-

RY, Relative yield; SYI, sustainable yield index spectively. Similarly, the relative yield for sunflower were 60, 55, 72, 56 and 60% for cyclic uses of 1 YCW : 2 YAW, 2 YAW : 1 YCW, 2 YCW : 1 YAW, 1 YAW : 2 YCW and AWp : CWs whereas 78 and 52% for blended waters in the ratio 2 CW : 1 AW and 1 CW : 2 AW respectively. The sustainable yield index (SYI) ranged from 0.56–0.94 to 0.40–0.76 for potato and sunflower, respectively, for various yearly modes (Table 2). The values of SYI (0.69–0.92) was higher for sesbania than potato and sunflower. Results of the present study further corroborate that cyclic use of good quality canal and poor quality alkali groundwater performs at par with their use in blended mode in same proportion when good quality canal water is applied initially.

Quality

The system productivity of different crop in potato–sunflower–sesbania cropping sequence given in Table 3. The maximum system yield was observed in all canal (CW) treatment and minimum in all alkali treatment. The other best treatments for system productivity were blending (2 CW + 1 AW) 42.73 t/ha, cyclic (2 YCW : 1 YAW) 40.42 t/ha, and cyclic (1 YCW : 2 YAW) 37.80 t/ha respectively. The rest treatments gave system yield in between for these treatments.

The water use efficiency (WUE) declined with reduced yields and sodicity development under various treatments (Table 3). For different treatments of CW and AW, WUE was found 944–162 kg/ha-cm for potato and 31.4–3.8 kg/ha-cm for sunflower. The highest WUE was estimated for all CW, whereas the lowest for all AW. Among different modes of combined use of alkali and canal waters, WUE was the highest in case of blending of canal and alkali waters in 2 CW : 1 AW for both potato (816 kg/ha-cm) and sunflower (24.8 kg/ha-cm) crops.

Quality of produce

The effect of sodicity build up in the soil profile due to combined use of alkali and canal water under different treatments were evaluated in terms of quality of potato and sunflower. The quality of potato was measured in terms of the tuber grade (A > 60 g, B 40–60 g and C < 40 g) and keeping quality (percentage weight loss in storage) and have been depicted in Fig.2. The quality of sunflower was measured in terms of size of sunflower seed (1,000-seed weight) and its oil content (percentage oil content) as

Table 3. Effect of modes of irrigation on system productivity (Mean data of 2 years)

Treatment	Potato yield (t/ha)	Sunflower yield (t/ha)	Sesbania yield (t/ha)	System yield (t/ha)
All canal water (CW)	28.63	1.32	19.93	49.88
All alkali water (AW)	4.38	0.16	6.98	11.52
Cyclic (1 YCW : 2 YAW)	19.06	0.79	17.95	37.80
Cyclic (2 YAW : 1 YCW)	15.15	0.72	17.42	33.28
Cyclic (2 YCW : 1 YAW)	22.65	0.96	16.81	40.42
Cyclic (1 YAW : 2 YCW)	17.32	0.74	15.07	33.12
Cyclic (AWp : CWs)	13.83	0.79	17.38	32.00
Blending (2 CW + 1 AW)	23.68	1.03	18.02	42.73
Blending (1 CW + 2 AW)	16.68	0.69	17.15	34.52

Table 4. Effect of modes of irrigation on water-use efficiency (WUE) of potato, sunflower and quality produce of sunflower (Mean data of 2 years)

Modes of irrigation	WUE (kg/ha-cm)		Quality of sunflower	
	Potato	Sunflower	1,000-seed weight (g)	Oil content (%)
All canal water (CW)	944	31.4	27.0	42.1
All alkali water (AW)	162	3.8	22.2	37.3
Cyclic (1 YCW : 2 YAW)	650	18.8	24.2	39.9
Cyclic (2 YAW : 1 YCW)	528	17.4	23.8	39.6
Cyclic (2 YCW : 1 YAW)	776	22.9	24.8	39.9
Cyclic (1 YAW : 2 YCW)	605	18.1	25.4	38.9
Cyclic (AWp : CWs)	473	19.4	24.3	39.6
Blending (2 CW + 1 AW)	816	24.8	25.7	40.7
Blending (1 CW + 2 AW)	573	16.8	24.4	39.8
SEm±	-	-	0.6	0.5
CD (P=0.05)	-	-	1.7	1.4

given in Table 3. It was observed that the small-grade potatoes (C grade), increased with the decline in yield under different treatments respectively. Storage quality of potato also deteriorated with AW irrigation (e.g. the potatoes shriveled with two-thirds weight loss (17.8%) on storage for 90 days under AW treatments, whereas the weight loss was just about two-fifths (8.2%) under CW). Similarly, the quality of sunflower produce was also poor with AW due to lower 1,000-seed weight and oil content. Our results confirm findings of Chauhan (2010) and Chauhan *et al.* (2011).

It can be concluded that the combined use of alkali and good quality canal waters can maintain the soil sodium saturation at relatively low levels, depending on the proportion of the 2 types waters. Amongst the various treatment options, the cyclic use should be preferred especially when canal waters are utilized for initial irrigations since it would have both operational and performance advantages over the blending of the water supplies. The use of alkali water should be avoided during the initial stages of crop growth.

REFERENCES

Chauhan, S.K. 2010. Effect of conjunctive use of alkali and canal water on oil content per cent and oil production in sunflower. *Bhartiya Kirshi Anushandhan Patrika* **25**(2 and 3): 123–27.

Chauhan, S.K., Chauhan, C.P.S. and Singh, S.K. 2011. Effect of conjunctive use of tuewell/canal water on sunflower. *Annals Agricultural Research New Series* **32** (1 and 2): 55–56.

Chauhan, S.K., Chauhan, C.P.S. and Minhas, P.S. 2007. Effect of cyclic use and blending of alkali and good quality waters on soil properties, yield and quality of potato, sunflower and sesbania. *Irrigation Science* **26**: 81–89

Maas, E.V. and Grattan, S. 1999. Crop yields as affected by salinity. (In) Agricultural Drainage Agronomy Monograph 38. Skaggs, R.W. and van Shilfgaarde, J. (Ed.). pp. 55–108. ASA, CSSA, SSSA, Madison, USA.

Manchanda, H.R. 1993. Long-term use of sodic waters in North India and the reliability of equations for predicting their sodium hazard. Lieth, H. and Ali, Masoom (Eds) *Towards the Rational Use of High Salinity Tolerant Plants*, pp. 433–438 Kluwer, The Nethrlands.

Minhas P.S., Sharma D.R. and Chauhan C.P.S. 2003. Management of saline and alkali waters for irrigation. (In) *Advances in Sodic Land Reclamation*. pp. 122–162. UPCAR, Lucknow, Uttar Pradesh.

Minhas, P.S. and Sharma, D.R. 2006. Predictability of existing indices and an alternative coefficient for estimating sodicity build-up using adj. R_{Na} and permissible limits for crops grown on soils irrigated with waters having residual alkalinity. *Journal of the Indian Society of Soil Science* **54:** 331–338.

Minhas, P.S. Dubey, S.K. and Sharma, D.R. 2007. Comparative effects of intra/inter-seasonal cyclic uses and blending of alkali and good quality water on soil properties and crop yields under paddy–wheat system. *Agriculture Water Management* **87**(1): 83–90.

Qadir, M. Gafoor, A. and Martaza, G. 2002. Use of saline-sodic waters through phytoremediation of calcareous sodic soils. *Agriculture Water Management* **11**: 501–521.

Qadir, M. and Oster, J.D. 2004. Crop and irrigation management strategies for saline sodic soils and waters aimed at environmentally sustainable agriculture. *Science of the Total Environment* **32**: 1–19.

Singh, R.P., Das, S.K., Rao, B.U.M. and Reddy, N.M. 1990. *Towards sustainable dryland agricultural practices*. Central Research Institute for Dryland Agriculture, Hyderabad, India, pp. 106.