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Impact of Irrigation on Soil Characteristics of Saline Vertisols of Bara Tract under Sardar Sarovar Canal Command of Gujarat

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Detailed characterisation of soil profiles occurring at village Vagra of Bharuch district in Gujarat under pre-and post-canal irrigation situation was carried out to study the effect of irrigation. Salt accumulation was observed in surface layer when saline tube well water was used for irrigation to cotton crop on saline Vertisols. The development of secondary salinisation was observed in the soil profiles irrigated with saline ground water. The same soils when irrigated with fresh canal water for wheat cultivation, showed reduction in soil salinity. The electrical conductivity of saturation extract (ECe) reduced to 0.65 dS m^{-1} from 9.8 dS m^{-1} in the surface layer, depicting desalinisation. It was also noticed in canal irrigated soils that exchangeable sodium percentage (ESP) increased to 17.2 from 7.8 in the lower horizon which indicated the initiation of pedogenic process *i.e.* sodification. Based on the 65 observations, it is noted that changes in the pedogenic processes operate insidiously and the farmers become aware of the problem after considerable damage has been done. It is also observed that bulk density of soils under canal irrigation is higher (1.8 Mg m^{-3}) than those of soils under tube well irrigation/rainfed condition (1.3 Mg m^{-3}) whereas hydraulic conductivity is drastically reduced in soils under canal irrigation. Therefore, a suitable management like conjunctive use of saline water with canal water, cultivation of low water requiring crops, use of pressurised irrigation system are required to be suggested in such a situation to avoid further degradation of soil characteristics.

Key words: Canal irrigation, salinisation, sodification, Vertisol, pedogenic processes

Irrigation has been found to be beneficial in increasing productivity of land, provided all the conditions for irrigation suitability of particular land is optimum but if any one of the parameters is limiting, then irrigation may not be so sustainable. Saline Vertisols and associated soils constitute a major portion of 2.22 million hectare (Mha) salt affected area present in Gujarat State (Mandal *et al*. 2009). The productivity of these soils even at low salinity is poor because of the typical physicochemical characteristics. Pedogenic processes specific to salt-affected soils are salinization and sodification. Bara tract has 111300 ha gross command area covering three tehsils *viz*., Vagra, Jambusar and Amod of Bharuch district of Gujarat State. These saline Vertisols of Bara tract area are being limited irrigated for the crops like cotton and wheat using Sardar Sarovar canal irrigation water besides saline water from tube wells in the region and the soils of this region has significant concentration of soluble salts in the sub-soils, although the concentration is low in surface layer (Chinchmalatpure *et al*. 2010).

Availability of canal water while bringing changes in the cropping pattern of the region, increase crop production and yield. The farmers of the region complained about the hardness of surface soils and formation of big clod which has also been reported by Jena and Natarajan (2013) in Cavery command area of Karnataka. Singh *et al.* (2008) reported that sodic lands are mainly concentrated in the Gangetic alluvial plains but the problem of sodicity is particularly acute in the canal-irrigated areas. They further reported that concentration of sodicity is much higher (25.7%) in the villages of canal command area as compared to 18.1% area in non-canal irrigated areas. So looking into this scenario and changes like

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hardening of soils due to canal irrigation, the present study was undertaken with an objective to study the impact of canal irrigation on soil properties in saline Vertisols of Bara tract area of Gujarat under Sardar Sarovar canal command area.

Materials and Methods

The study area, Bara tract is spread in Amod, Vagra and Jambusar talukas of Bharuch district of Gujarat. It lies between 21°40′ to 22°13′ N latitudes and 72°32′ to 72°55′ E longitudes at the reduced level of 16 ft (5.1 m) and 30 ft (9.14 m), located in Gulf of Khambhat in Gujarat state. This area is bounded by the rivers Narmada in the south and the Mahi in the north and forms a part of Mahi-Narmada Doab. This region occurs on nearly flat lands with slope gradient of 1:2800-4500 or more. It is also characterised by poor out fall and out flow conditions. The region experiences a tropical climate. The maximum temperature rises up to 45 °C in the month of May. The soil temperature regime is hyperthermic and soil moisture regime is ustic. The average annual rainfall is 737 mm.

Traversing of the entire Bara tract (Fig. 1) was done to select locations for studying the effect of

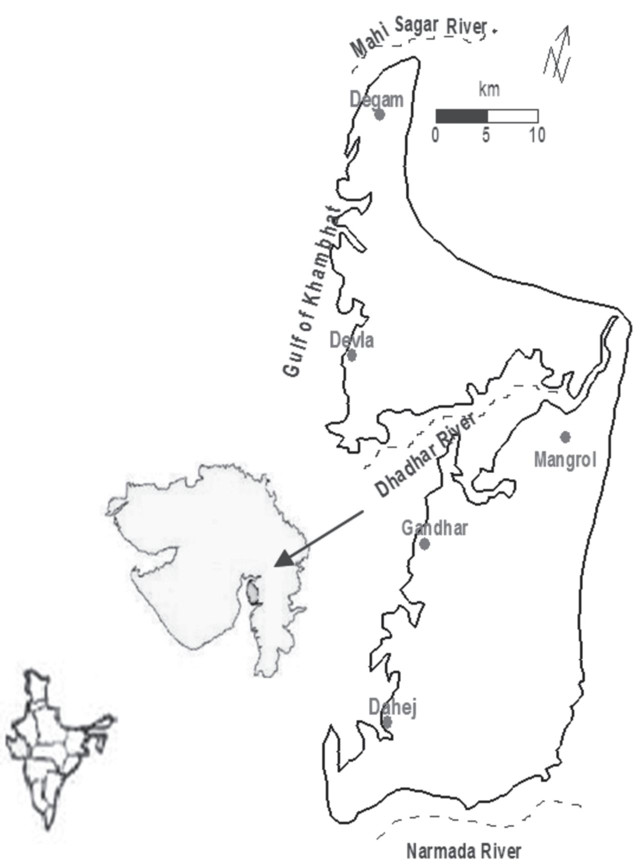

Fig. 1. Location map of the Bara tract

irrigation on soil properties. Soil profiles (15) from rainfed farming, tube well irrigated and canal irrigated farming were studied and auger hole soil samples up to a depth of 90 cm with an interval of 30 cm *i.e.* for 0-30, 30-60 and 60-90 cm depth was also done in about 40 locations representing rainfed and irrigated (tube well as well as canal) situations. Soil profiles were excavated to study field morphology (Table 1) of these soils and soil samples from profiles were collected horizon wise. Soil samples were processed for analysing different properties like pH and EC_e (Page *et al.* 1982), organic carbon (OC) by wet oxidation method (Nelson and Sommer 1982). Cation exchange capacity (CEC) was determined by 0.1 *N* NaOAc-0.4 *N* NaCl method (Gupta *et al.* 1985) with the help of a flame photometer and expressed the results in cmol(p^+)kg^{-1} of soil. Exchangeable sodium percentage (ESP) by the method given by Tucker (1971), particle size analysis was carried out by International pipette method (Jackson 1975), bulk density and hydraulic conductivity by the method given by Klute and Dirkson (1986). To know precise impact of irrigation on soil properties, soil profiles were studied (Annual Report 2002-03) during year 2001 at village Vagra was taken as base and soil profile at the same location was again studied during the year 2010.

Results and Discussion

The properties of soils earlier studied as published in the Annual report 2002-2003 of ICAR-CSSRI has been given in the table 2 which indicated that pH ranged from 7.6 to 8.7 and ECe ranged from 1.1 to 9.8 dS m^{-1}. The ECe of surface soils is 9.8 dS m^{-1} which is because of saline water irrigation to cotton crop. Soils of the study area *i.e.* Bara tract have significant concentration of soluble salt in lower horizons showing sub-soil salinity as had been reported by Chinchmalatpure *et al.* (2011). The ESP ranged from 2.6 to 7.8 which in general showed increasing trend with depth. The OC ranged from 2.1 to 4.1 g kg^{-1}. These soils were cultivated for cotton using saline water irrigation from tube well. The properties of soils (Table 3) as studied during the year 2010 revealed that pH ranged from 8.4 to 8.9 and ECe ranged from 0.6 to 8.0 dS m^{-1}. As these soils were cultivated for wheat using fresh canal irrigation since 2004 and due to leaching of soluble salts, the concentration of salts were reduced drastically. The ESP of these soils ranged from 3.5 to 17.2 which also showed increasing trend with depth. The OC varied from 2.8 to 3.4 g kg^{-1}.

Table 1. Morphometric features of the pedon

Hori-zon	Depth (m)	Colour	Boun-dary	Tex-ture	Struc-ture	Consis-tence	Roots	Cutans	Nodules Con Ca	Efferve-scences	Special feature
Ap	0.00-0.21	10YR3/1	c s	c	c3sbk	h fi ssps	f/m m	—	vf f	e	
Bw1	0.21-0.46	10YR3/1	c s	c	c3sbk	vh vfi sp	m m	—	f f	e	pf
Bw1	0.46-0.75	10YR3/1	a w	c	c3sbk	vh vfi sp	f f	Mn tn p	f f	e	pf
Bss1	0.75-1.05	10YR3/1	a w	c	c3abk	vh vfi sp	f f	Mn tn p	f f	e	ss
Bss2	1.05-1.31	10YR3/1	a w	c	c3abk	vh vfi sp	f f	—	f f	es	ss
BC	1.31-1.60	10YR3/ 110YR5/3	a w	gc	c3sbk	h fi ssps	vf f	—	m m	es	
C	1.60-2.00	10YR5/3		gcl	c3sbk	h fi ssps	—	—	c m	ev	

Table 2. Properties of saline Vertisols under cotton with tube well saline water irrigation at Vagra village in Bharuch district

Horizon	Depth (m)	pH_2	EC_e (dS m^{-1})	OC (g kg^{-1})	ESP (%)
Ap	0.00-0.21	7.8	9.8	2.1	4.0
Bw1	0.21-0.46	7.6	3.4	4.1	2.6
Bw2	0.46-0.75	8.0	2.4	2.3	3.3
Bss1	0.75-1.05	8.5	1.2	3.7	4.8
Bss2	1.05-1.31	8.6	1.1	3.7	5.1
BC	1.31-1.60	8.7	1.3	3.9	6.0
C	1.60-2.00	8.5	3.7	4.1	7.8

Source: Annual Report (2002-03), ICAR-CSSRI, Karnal

Table 3. Properties of saline Vertisols under wheat with canal irrigation at Vagra village in Bharuch district

Horizon	Depth (m)	pH_2	EC_e (dS m^{-1})	OC (g kg^{-1})	ESP (%)
Ap	0.00-0.31	8.5	0.6	3.1	3.5
Bw1	0.31-0.70	8.7	0.9	2.8	8.3
Bss1	0.70-1.09	8.9	0.9	2.9	11.2
Bss2	1.09-1.40	8.6	1.7	3.4	13.4
BC	1.40-1.73	8.4	8.0	3.2	17.2

In the study area, properties of Vertisols cultivated for rainfed cotton, saline water irrigated cotton and canal water irrigated cotton/wheat were compared and determined the changes in soil properties like ESP, EC, pH, OC content, bulk density, CEC and clay content. Canal water irrigated soils showed increase in ESP (ranging 2.27 to 18.5), and bulk density (1.4 to 1.8 Mg m^{-3}) as compared to ESP (ranging from 1.5 to 10.3) and bulk density (1.3 to 1.5 Mg m^{-3}) for soils under tube well irrigation and ESP (2.2 to 13.9) and bulk density (1.34 to 1.45 Mg m^{-3}) for soils under rainfed cultivation (Table 5). Continuous use of canal water for irrigation reduced surface salinity of these soils due to leaching of salts but at the same time soils are becoming potentially sodic, for which management may be difficult.

Accumulation of salts in surface horizon took place in soils which were irrigated with saline water having EC_{iw} of 10.6 dS m^{-1} (Table 6). Salt is likely to accumulate in the landscape due to salt from saline water of tube well (ECiw 10.6 dS m^{-1}), combined with the influence of climate *i.e.* high temperature and evaporation, upward flux and landscape features (ridge and furrow) and human activities like amount of irrigation water, fertilizer applications, *etc*. The development of secondary salinisation as groundwater salts contribute to secondary soil salinity through saline water irrigation from tube well which was observed in the soils studied in Vagra village during pre-canal irrigation (Table 5). For comparison, properties of soils under rainfed and tube well irrigated cotton cultivation in other locations in the study area are presented in the table 4. Desalinisation has been noticed when the same soils were irrigated with canal water *i.e.* wheat cultivation using canal water irrigation (since 2004) as obvious from the EC_e values in the surface layer reduced from 9.8 dS m^{-1} (Table 2) to 0.65 dS m^{-1} (Table 3) due to leaching of

Table 4. Properties of saline Vertisols under different land uses at Kalak and Samni villages for comparison

Horizon	Depth (m)	pH_2	EC_e (dS m^{-1})	OC (g kg^{-1})	ESP (%)
Village Kalak, Land use-Rainfed cotton					
Ap	0-0.30	7.28	0.5	6.2	2.16
A12	0.30-0.49	7.54	0.4	5.0	2.56
Bss1	0.49-0.74	7.90	0.5	6.5	8.41
BC	0.74-1.02	8.43	1.3	6.2	12.02
C	1.02-1.28	8.55	1.5	7.4	11.18
Village Samni, Land use-Tube well irrigated cotton					
Ap	0-0.20	7.9	1.4	4.3	2.52
Bw1	0.20-0.43	8.0	1.2	3.9	2.39
Bw2	0.43-0.71	7.8	5.4	3.0	2.49
Bss1	0.71-1.03	7.9	8.2	2.9	5.72
BC	1.03-1.35	8.1	10.5	2.9	6.42
C	1.35+	8.0	11.4	2.5	8.09

Table 5. Variation in properties of soils under rainfed cultivation/tubewell water irrigation and canal irrigation in Vagra Taluka of Bharuch district Gujarat

Soil properties		Tubewell irrigated (n=25)	Rainfed cultivated (n=15)	Canal irrigated (n=25)
Clay	Range	55.0-72.0	54.0-72.0	52.0-73.0
content	Mean	58.0	59.0	56.0
(%)	SD	0.56	0.45	0.59
CEC	Range	36.4-64.9	33.0-56.8	37.3-51.2
[cmol(p^+)	Mean	45.2	42.0	46.0
kg^{-1}]	SD	0.40	0.52	0.58
Organic	Range	2.4-4.8	1.2-5.1	2.4-4.3
carbon	Mean	2.8	2.6	2.8
(g kg^{-1})	SD	1.0	1.2	0.7
pH_2	Range	8.0-9.2	7.9-9.0	7.9-9.2
	Mean	8.2	8.4	8.6
	SD	0.42	0.39	0.40
EC_e	Range	0.6-3.3	0.52-1.76	0.26-1.72
(dS m^{-1})	Mean	1.98	0.86	0.80
	SD	1.02	0.45	0.35
ESP	Range	1.5-10.3	2.2-13.9	2.27-18.50
	Mean	4.56	4.62	5.12
	SD	4.01	3.88	4.21
Bulk	Range	1.3-1.5	1.34-1.45	1.4-1.8
density	Mean	1.40	1.40	1.56
(Mg m^{-3})	SD	0.04	0.04	0.06

Table 6. Quality of canal as well as tube well water from the study area

Parameters	Canal water	Tube well water
EC (dS m^{-1})	0.51	10.6
pH	8.4	7.4
Ca (me L^{-1})	2.5	17.0
Mg (me L^{-1})	3.0	28.0
Na (me L^{-1})	0.52	55.9
K (me L^{-1})	0.05	0.24
CO_3 (me L^{-1})	1.4	0.2
HCO_3 (me L^{-1})	2.6	1.8
Cl (me L^{-1})	3.5	92.5
SO_4 (me L^{-1})	0.91	10.7
SAR	0.31	11.8

salts from surface horizon and accumulated in the lower horizon of the soil profile.

Besides desalinisation, initiation of pedogenic process *i.e* sodification has been noticed as evident from increased ESP in the lower horizon from 7.8 (Table 2) to 17.2 (Table 3). These changes may be due to the low to moderate saline soils and expected to be potentially more sodic if irrigation water of low salt concentration (<3 me L^{-1}) like canal water is applied owing to their susceptibility of clay dispersion and resultant reduction in hydraulic conductivity (Oster and Schoer 1979; Shainberg *et al*. 1981) and because of the difference in osmotic potential between the bulk soil solution and the interior of soil aggregates. Besides, canal water (with low electrolyte concentration, EC = 0.5 dS m^{-1} and SAR = 0.31, table 6) is more likely to flow into the spaces (micropores) between clay platelets. If the bulk solution salinity becomes low relative to the salinity of the aggregates, this water migration may cause swelling and dispersion of clay particles. In the presence of fresh canal water, the sodic clays are hydrolysed and releases the Na^+ and OH^- ions, with rapid formation of Na_2CO_3 and the environment becomes alkaline

$$Na^+ \text{ clay} + H_2O \rightleftharpoons H^+ \text{ clay} + Na^+ + OH^-$$

But in presence of saline water (rich in NaCl) as soluble sodium in tube well water is 55.8 me L^{-1} and chloride is 92.5 me L^{-1}, this hydrolysis is prevented, for the equilibrium has a tendency to be displaced in reverse direction and alkalisation remains moderate. This condition was observed in the soils irrigated with saline tubewell water where soils are neutral to slightly alkaline. In addition, the excess Na^+ ions have a flocculating effect on the clays which maintain an aggregate structure as has been observed in term of lower bulk density (1.3 to 1.5 Mg m^{-3}). This is the situation of saline soils with sodic complex but under the influence of desalinisation, with application of canal water, sodic clays are able to be hydrolysed again which causes alkalisation and a dispersion of the aggregates. These are the irrigation induced changes and processes like migration of salts (salinization–desalinization, alteration of the chemical composition of soil salts, *etc*.), exchange reactions (adsorption and desorption of sodium, changes in the content and composition of exchangeable cations). It is observed that the rates of secondary irrigation-induced soil alkalization and salinization are more than those of the initial (natural) salinization and alkalization processes.

Conclusions

From the present investigation it is evident that saline water irrigation increases salinity of soils and use of canal water irrigation reduces soil salinity. But in these saline Vertisols of Bara tract, canal water having low electrolyte concentration increases the sodium concentration relative to calcium on soil colloid complex and thereby increasing the ESP of soils. Soils turn sodic and reclamation and management become difficult because of nature and properties of these black soils. Farmers of the region have to be suggested to use canal water in conjunction with tube well water on salt affected Vertisols. By mixing canal water with tube well water, a large area can be irrigated with this mixed water. This blending of water is helpful in avoiding the adverse impact of canal water on hydraulic conductivity of the soil (mixed water may have a higher EC value compared with the EC of canal water) and also reducing salinity hazards of tubewell water (mixed water may have lower EC value compared with the EC of tube well water) and the sodicity hazards (SAR of the mixed water may reduce by the square root of the dilution factor).

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