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Assessment of groundwater quality for irrigation of Kanina block of Mahendragarh district, Haryana

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ABSTRACT

Pressures on groundwater resources in semi-arid regions due to over irrigation can be released through the judicious use of this scarce resource by knowing the groundwater quality. Thus, a study has been carried out for the quality appraisal of the groundwater of Kanina block of Mahendragarh district in Haryana state, India by focusing on spatial variability of electrical conductivity (EC), pH, cationic and anionic composition of the groundwater. The study revealed that 85.2 per cent of the samples showed EC values less than 4 dS m^{-1} and the maximum value of EC (9.29 dS m^{-1}) was found in the village Dongra Ahir. Residual sodium carbonate (RSC) and sodium adsorption ration (SAR) varied from 0 to 13.0 me L^{-1} and 3.98 to 25.04 (m mol $l^{-1})^{1/2}$, respectively. According to All India Coordinated Research Project classification, the maximum samples (44.4%) were found in high alkali category followed by high SAR saline (20.4%). The per cent samples in good, marginally alkali, marginally saline, alkali and saline classes were 16.6, 7.4, 5.6, 3.7 and 1.9, respectively. The concentration of Na^+, Ca^{+2} and Mg^{+2} --ions generally increased with increase in EC of the water samples. Cl^- and HCO_3^- were found in appreciable quantities, whereas, CO_3^{-2} were in traces. Contour maps of EC, pH, SAR and RSC of groundwater used for irrigation in Kanina block were plotted to study spatial variability of these parameters. Contour map of EC revealed that quality of water is better in central part of the block in comparison to northern and southern parts.

Key words: groundwater, residual sodium carbonate, salinity, sodicity, sodium adsorption ration

Introduction

One of the main hurdles in boosting the agricultural production in arid and semi-arid areas of the world is the inadequate supply of good quality water for irrigation. In India, agriculture is the major user (89 per cent) of water resources but the estimates show that the growing demands from municipalities, industry and energy generation will claim about 22 per cent (24.3 m ha-m/year) of the total water resources (105 m ha-m $year^{-1}$) by the year 2025 AD, thereby, further reduce the good quality water supply for irrigation (Minhas and Tyagi, 1998). In Haryana state, out of the total cultivated area of 3.4 million ha, canal irrigated area is only 66%, whereas rest of the area is dependent either on rainfall or upon wells/tubewells of doubtful quality. The quality of ground water plays a key role in judging its suitability for crop production. Indiscriminate use of brackish water deteriorates the soil productivity by causing salinity, sodicity or toxicity effects and even sometimes the land eventually goes out of cultivation. Therefore, a prior appraisal of ground water quality is important to assess pressures on groundwater resources and for judicious use of this scarce resource.

Water resources in Mahendragarh district are currently under serious pressure. During 1978 the total useable recharge in the district was 379.70 million cubic metre (MCM) and out of it 451.78 MCM was being utilized which indicates that 119 per cent of the available groundwater was being used. Now in year 2010, according to Central Ground Water Board, utilizable groundwater resources in the district is 193 MCM and net groundwater draft is 262 which indicates that 136 per cent of the available groundwater was being used. This means over exploitation of groundwater has increased by 17 per cent in the last 32 years. In the district, shallow aquifers occur in the alluvial deposit down to a depth of 60 m to 100 m. Wells in these areas yield 30 to 50 m^3 hr^{-1} for moderate drawdown. In some parts of the district, aquifers in the weathered/fractured quartzites and cavernous limestone have yield potential of 5 to 50 m^3 hr^{-1} for moderate to high drawdown.

In the past, attempts have been made to establish groundwater quality zones of Haryana state (Manchanda, 1976), but a sea change has occurred over the years due to exhaustive water use and a shift in the cropping pattern in the western part of the state which led to change in water quality (Kumar *et al.,* 2009; Satyavan *et al.,* 2006). Therefore, a reappraisal on nature, properties and extent of groundwater quality of Kanina block of Mahendragarh district is essential for optimum irrigation planning of the area. This paper envisages to illustrate the spatial variability of various parameters of groundwater quality *i.e.* electrical conductivity (EC), pH, residual sodium carbonate (RSC) and sodium adsorption ration (SAR).

Material and methods

Kanina block lies between 28º10′20″ to 28º28′15″N latitude and 76º09′45″ to 76º22′00″E longitude. The occurrence, origin, quality and availability of groundwater in the block are related to the recent and sub-recent formations. These geological formations of the area do not contain groundwater in substantial quantity. Due to very limited canal network in the block, rainfall is the only source of groundwater. From the last seventeen years record, the highest annual rainfall (771.0 mm) of the block was observed in year 1996 and the lowest (82.0 mm) in year 2002 (Kumar *et al.,* 2011). The water table is going down due to the deficit in rainfall in recent years and over exploitation of groundwater. In the last decade, the annual water table decline rate was 93 cm per year in the block, whereas, in the district, it was 164 cm per year.

Water samples were collected randomly at an interval of three to four kilo meters by thorough covering the whole block (Fig. 1). The elevation, longitude and latitude angles of the sampling points were recorded by GPS system at each location. The samples were analyzed for EC, pH, CO_3^{-2}, HCO_3^-, Cl^-, Ca^{+2}, Mg^{+2} and Na^+ by following the procedures outlined in USDA Handbook No. 60 (Richards, 1954). Water samples were also categorized on the basis of criteria adopted by All India Coordinated Research Project (ACRIP) on Management of Salt Affected Soils and Use of Saline Water in Agriculture, through the values of EC, SAR and RSC of the samples (Gupta *et al.*, 1994). RSC and SAR were calculated as described by the following equations.

$$RSC\ (me / l) = (CO_3 + HCO_3) - (Ca + Mg) \qquad \text{... (i)}$$

$$SAR\ (m\ mol / l)^{1/2} = \frac{\text{Na}}{\left\{\dfrac{Ca + Mg}{2}\right\}^{1/2}} \qquad \text{... (ii)}$$

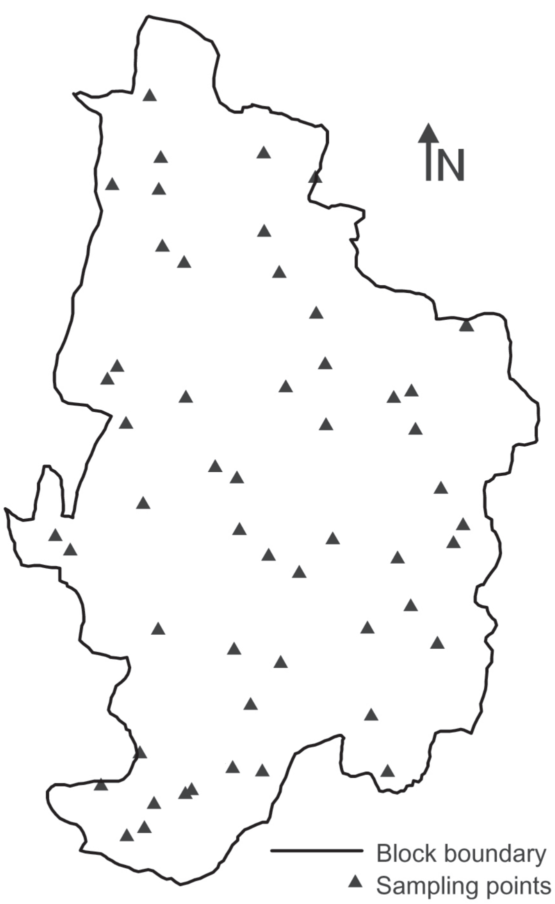


Fig. 1. Location map of the sampling points in Kanina block of Mahendragarh district

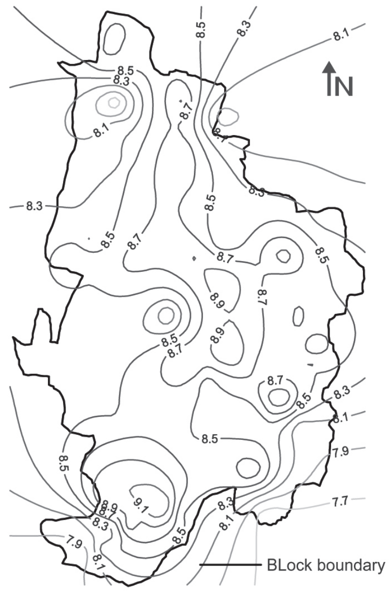
Results and discussion

In Kanina block, electrical conductivity (EC) ranged from 0.35 to 9.29 dS m^{-1} with a mean of 2.37 dS m^{-1} (Table 1). The lowest EC of 0.35 dS m^{-1} in water samples was observed in village Kakrla and its highest value (9.29 dS m^{-1}) was recorded in village Dongra Ahir. It is observed from the contour map (Fig. 2a) that the EC of groundwater is low in the central part of the block and high at two locations one in southern and other in northern boundary area. No particular trend in the variation of EC is present in the block but most part of the block is having EC less than or equal to 2 dS m^{-1}. The pH ranged from 7.53 to 9.37 with an average of 8.51 and the highest pH of 9.37 in water samples was observed in village Kharana. In central and southern parts of the block, pH is higher than other parts of the block (Fig. 2b). The pH in the whole block is more than 8.5 except some patches.The SAR ranged from 3.98 to 25.04 (m mol $L^{-1})^{½}$ with a mean value of 12.36 (m mol $L^{-1})^{½}$. The lowest SAR value was observed in village Unhani and its highest value was recorded in village Chhitroli. The variations in values of SAR of this block are shown by contour map

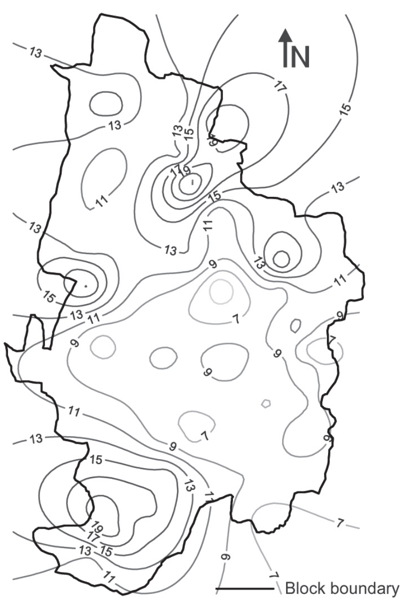
Table 1. Range and average of different water quality parameters in Kanina block of Mahendragarh district

Sr. No.	Parameters	Range	Average
1	EC (dSm^{-1})	0.35 – 9.29	2.37
2	pH	7.53 – 9.37	8.51
3	Na^+ (me l^{-1})	3.40 – 63.63	20.04
4	Ca^{+2} (me l^{-1})	0.50 – 12.20	2.40
5	Mg^{+2} (me l^{-1})	1.40 – 81.40	14.79
6	Cl^- (me l^{-1})	2.10 – 93.60	17.18
7	CO_3^{-2} (me l^{-1})	0.00 – 4.00	1.08
8	HCO_3^- (me l^{-1})	2.00 – 11.20	5.98
9	SAR (m mol $l^{-1})^{½}$	3.98 – 25.04	12.36
10	RSC (me l^{-1})	0.00 – 13.00	3.10

a) Contour map of EC of groundwater



b) Contour map of pH of groundwater



c) Contour map of SAR of groundwater

d) Contour map of RSC of groundwater

Fig. 2. Contour map of water quality parameters (EC, pH, SAR, RSC) of groundwater in Kanina block of Mahendragarh district

(Fig. 2c). In the central part of the block, the value of SAR is lower than the outer parts. Increasing SAR values reflect increase in sodicity of groundwater. The RSC varied from 0.0 to 13.0 me L^{-1} with an average value of 3.10 me L^{-1}. Maximum value of the RSC (13.0 me L^{-1}) was found in the village Kanina. The variations in values of RSC of this block are shown by contour map (Fig. 2d).There are three main patches of high RSC in the block on southern, eastern and northern boundaries. In the central part of the block, it was not observed.

Among cations, sodium was the dominant ion with values ranging from 3.40 to 63.63 me L^{-1} followed by magnesium (1.40 to 81.40 me L^{-1}) and calcium (0.50 to 12.20 me L^{-1}). Mean values for Na^{+}, Mg^{+2} and Ca^{+2} were 20.04, 14.79 and 2.40 me L^{-1}, respectively. Among anions, chloride was the dominant ion with maximum value of 93.60 me L^{-1} observed in village Dongra Ahir and the minimum value of 2.10 me L^{-1} recorded in village Kakrala. Bicarbonate (HCO_3^-) varied from 2.00 to 11.20 me L^{-1} and its highest value was found in the water samples of village Kanina and the minimum value in Kakrala village. Mean values for CO_3^{-2}, HCO_3^- and Cl^- and were found to be 1.08, 5.98 and 17.18, respectively. Shahid *et al.*, (2008) also reported similar results in Julana block of Jind

Table 2. Chemical composition of groundwater samples in different EC classes in Kanina block of Mahendragarh district

EC classes (dS/m)	% of samples	Na	Ca	Mg	CO_3	HCO_3	Cl	RSC	SAR (m mol l^{-1})$^{1/2}$
		....	....	....	....(me l^{-1})....	....	....	....	
0-1	16.67	8.24	0.88	1.47	0.71	4.93	3.78	3.30	7.88
1-2	40.74	15.45	1.26	2.18	1.26	6.57	8.71	4.39	12.42
2-3	20.37	19.38	2.21	3.10	1.27	6.88	14.64	3.64	13.34
3-4	7.41	23.01	4.08	5.40	0.70	5.10	25.30	0.08	11.50
4-5	5.56	32.51	5.47	9.67	0.33	4.13	42.80	0.00	12.00
5-6	3.70	49.60	3.95	5.30	2.60	6.30	40.50	0.30	23.16
6-7	1.85	53.67	6.80	11.70	1.00	5.60	54.00	0.00	17.65
7-8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8-9	1.85	63.63	10.00	10.50	0.00	5.00	83.20	0.00	19.87
9-10	1.85	48.92	12.20	29.30	0.00	2.40	93.60	0.00	10.74

district. It was further observed that cations and anions in groundwater followed the order $Na^+ > Mg^{2+} > Ca^{2+}$ and $Cl^- > HCO_3^- > CO_3^{-2}$, respectively. In arid and semi-arid regions, various workers have reported the dominance of sodium and chloride ions in irrigation waters (Sharma 1998; Shahid *et al.*, 2008).

The mean chemical composition and related quality parameters in different EC ranges for Kanina block are given in Table 2. Maximum per cent (40.74) of samples were in the EC range of 1-2 dS m^{-1}. The study revealed that 85.19 per cent of the samples showed EC less than 4 dS m^{-1}, 11.11 per cent had EC 4 to 8 dS m^{-1} and only 3.7 per cent samples had EC above 8 dS m^{-1}. Only two samples exhibited EC greater than 8 dS m^{-1}. Concentration of Na^+, Mg^{+2} and Ca^{+2} increased with increase in the EC of the water samples and the magnitude of increase in Na^+ and Mg^{+2} concentration was much higher than Ca^{+2}. Similarly, concentration of Cl^- anions increased with the increase in the EC of the water samples. HCO_3^- was also found to be in appreciable quantities, whereas, CO_3^{-2} was in low quantities, but the concentration of these two anions did not show any relation with EC of irrigation water.

According to AICRP classification, the maximum samples were found in highly alkali (44.4 per cent) category followed by high SAR saline (20.4 per cent) (Fig. 3). The per cent samples in good, marginally alkali, marginally saline, alkali and saline categories were 16.6, 7.4, 5.6, 3.7 and 1.9 per cent, respectively. Minhas *et al.* (1998) also reported that 32.84 per cent of running wells in India were of poor quality. Earlier studies conducted by Manchanda (1976) indicated that in Kanina block, 19, 58, 9 and 14 per cent of groundwater was under good, sodic, marginally saline and saline-sodic categories, respectively. During last three decades, minor groundwater quality degradation has been observed and good quality water percentage has deteriorated by 12.6 per cent approximately. But average watertable of the block has gone down drastically, even during the last decade, its average value in the block declined from 17.98 m to 27.28 m (Kumar *et al.*, 2011).

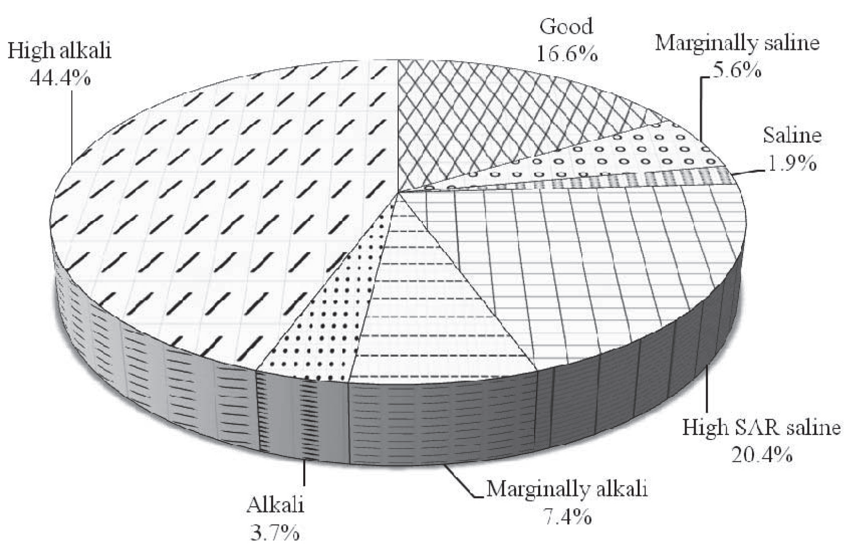


Fig. 3. Quality of groundwater (per cent) in Kanina block of Mahendragarh district

Conclusions

High alkali (sodic) water is the most predominant group of water accounting for 44.4 per cent of the total groundwater in the block and its indiscriminate and prolonged use will lead to the excessive build up of exchangeable sodium in soil resulting in dispersed and impermeable sodic soils. However, the extent of soil deterioration will depend upon the magnitude of sodium and RSC hazard in water, the type of soils to be irrigated and their drainage and permeability, the number of irrigations to be applied, management practices to be adopted, etc. So these waters can be used with special management practices depending upon the rainfall, crop to be grown and soil type. In light textured, well drained and permeable soils, farmers can add a good amount of farm yard manure (FYM). However application of gypsum along with FYM in light to medium textured soils will enhance the utility of these waters and helpful in arresting the decreasing trend in crop yields. Good quality and marginally saline waters can be successfully used for crop production without any hazardous effect on soil and plants. The waters rated as saline and high SAR saline is unfit for irrigation. Their indiscriminate use may cause secondary salinization and sodification of soil resulting in serious effects on crop growth. But in contingency, these waters can be used with special management practices depending upon the rainfall, crop to be grown and soil type.

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Comparison of drip and surface methods of irrigation for capsicum-okra crop rotation in saline water

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ABSTRACT

A field experiment was conducted during 2009-10 and 2010-11 to assess the salinity tolerance of capsicum-okra crops in drip and surface irrigation. The treatments comprised of three salinity levels (Control, EC_{iw} 4 and 8 dS m^{-1}) and three IW/CPE ratios (0.75, 1.00 and 1.25) for both drip and surface irrigation. The study revealed that the fruit yields of capsicum and okra were significantly decreased when irrigated with EC_{iw} of 4 and 8 dS m^{-1} as compared to control. On an average, the per cent reduction in capsicum fruit yield at EC_{iw} 4 and 8 dS m^{-1} over control was 28.8 and 39.1% in drip irrigation and 30.8 and 39.8% in surface irrigation, resoectively. Corresponding reduction in okra fruit yield was 52.9 and 73.8% in drip and 74.0 and 99.9% in surface irrigation, respectively. The IW/CPE ratios were found to be non-significant in both drip and surface irrigation, except in drip irrigation the okra fruit yield significantly increased with increasing IW/CPE ratio in both the years. The interaction effect between EC and IW/CPE ratio was found non-significant in both the crops and irrigation methods.

Key words: capsicum, drip irrigation, okra, saline water

Introduction

Micro irrigation is suited for undulated terrain, shallow soils and water scarce areas. Poor quality water can also be used with good filtration systems. The salt stress is kept minimum at the root zone of the crop with drip system as the salts are pushed to the periphery of the wetting zone. Hence, the salt injury is avoided. The spectacular advantages of micro irrigation as reported by Bucks *et al.* (1982) are increased water use efficiency (90-95%), higher yield (40-100%), decreased tillage requirements, high quality products, higher fertilizer use efficiency by fertigation saving fertilizers up to 30%, lesser weed growth, less occurrence of pest and diseases, reduced labour requirements etc. It is possible to apply water and fertilizer most precisely and uniformly to all plants by fertigation. Drip irrigation also enables reuse of poor quality waters like sewage effluents after proper filtration.

Material and methods

Studies were carried out at the experimental farm of R.B.S. College, Bichpuri, Agra during 2009-10 and 2010-11 on a sandy loam soil. Some of the physico-chemical characteristics of the soil are given in Table 1. The land at the experimental site is well drained and the water table always remained below 15 m during the study period. The field plots (2.5m x 2.5 m) were lined with polyethylene sheet down to a depth of 0.9 m to avoid lateral fluxes of salts and water. Capsicum (*Capsicum annuum*) and Okra (*Abelmoschus esculentus*) were grown in rotation on fixed plots irrigated with different waters. Treatments consisted of three salinity levels (Control, EC_{iw} 4 and 8 dS m^{-1}) and three IW/CPE ratios (0.75, 1.00 and 1.25) for both drip and surface irrigation. These waters were prepared by dissolving required amounts of $NaCl$, Na_2SO_4, $CaCl_2$ and $MgSO_4$ in the best available water. Each treatment was replicated four times in a randomized block design. Irrigation schedules were based on IW/CPE ratio. In drip irrigation, crops were irrigated at 4 days interval and the amount of water for irrigation was based on canopy size/area. In surface system, irrigation water was applied up to a depth of 4 cm.

Soil samples were collected at sowing and after the harvest of the crop at 0-10, 10-20, 20-30 and 30-60 cm depth. The soil samples for each treatments were air dried, ground to pass through a 2 mm sieve and analyzed for pH and the electrical conductivity of saturation extract (EC_e) following the method out lined in USDA Handbook No. 60 (Richards, 1954).

pH_2, EC_e, CEC, K and D_b denote pH of 1:2 Soil water, EC of saturation pest extract, cation exchange capacity, saturation hydraulic conductivity and bulk density, respectively. Agricultural practices followed for capsicum and okra are described in table 2.

Table 1. Some physico-chemical characteristics of the experimental soil

Horizon	Depth (m)	pH_2	EC_e (dS m^{-1})	CEC (cmol $_{(p+)}$/kg)	Textural Class	K (mm/ha)	D_b (Mg/m^3)
A1	0-0.2	8.5	1.0	8.6	Sandy loam	11.5	1.45
A3	0.2-0.45	8.5	2.6	8.8	Loam	6.5	1.52
$B_{2\text{-}1t}$	0.45-0.72	8.6	3.2	9.9	Clay loam	6.0	1.52
B2-2t	0.72-1.15	8.5	2.0	12.2	Clay loam	6.0	1.51
B3-ca	1.15-1.40	8.6	2.5	12.5	Sandy loam	8.1	1.44
C	1.40-1.80	8.6	4.5	14.7	Loam	18.2	1.42

Table 2

Operation	2009-10		2010-11	
	Drip irrigation	Surface irrigation	Drip irrigation	Surface irrigation
Capsicum				
Variety	Green Gold	Green Gold	Green Gold	Green Gold
Date of Transplanting/sowing	17.8.2009	17.8.2009	8.8.2010	8.8.2010
Doses of N:P:K	120:60:60	120:60:60	120:60:60	120:60:60
Total depth of irrigation (cm)				
IW/CPE 0.75	13.5	18.0	12.0	16.0
IW/CPE 1.00	18.0	24.0	16.0	20.0
IW/CPE 1.25	22.5	30.0	20.0	24.0
Date of harvest	24.1.2010	24.1.2010	20.1.2011	20.1.2011
Rainfall (mm)	297.7	297.7	403.9	403.9

Okra

Operation	2010		2011	
	Drip irrigation	Surface irrigation	Drip irrigation	Surface irrigation
Variety	Bhindi No.10	Bhindi No.10	Bhindi No.10	Bhindi No.10
Date of Transplanting/sowing	15.2.2010	15.2.2010	17.2.2011	17.2.2011
Doses of N:P:K	120:60:60	120:60:60	120:60:60	120:60:60
Total depth of irrigation (cm)				
IW/CPE 0.75	37.5	52.0	24.0	32.0
IW/CPE 1.00	50.0	68.0	33.0	44.0
IW/CPE 1.25	62.5	84.0	42.0	56.0
Date of harvest	29.5.2010	29.5.2010	21.6.2011	21.6.2011
Rainfall (mm)	29.4	29.4	121.3	121.3

Results and discussion

Fruit yield

The fruit yield of capsicum and okra decreased with increasing EC_{iw} levels in both the years (Table 3 and 4). The EC_{iw} of 4 and 8 dS m^{-1}, on an average, reduced the capsicum fruit yield by 28.8 and 39.1 per cent in drip irrigation and 30.8 and 39.8 per cent in surface irrigation, respectively. Corresponding, yield reductions in okra were 52.9 and 73.8 per cent in drip and 74.0 and 99.9 per cent in surface irrigation, respectively. In both crops, IW/CPE ratio treatments were found non-significant under drip and surface irrigations, whereas in drip irrigation okra fruit yield increased with increasing IW/CPE ratio. The average fruit yield increased by 48.2 and 75.3 per cent in IW/CPE ratio 1.00 and 1.25 over IW/CPE ratio 0.75, respectively. On an average, the increase in fruit yield of capsicum was about 69 per cent and in okra about 43 per cent under drip irrigation as compared to the surface irrigation. Our results are consistent with the finding of Sivanappan *et al*. (1976) that even at one sixth of the normal water intake (in the furrow system), the drip system of irrigation matched the former in total yields. Again, even at reduced level of water utilization, the early yields partly contributed by increase in the number of pods produced and partly due to increase in pod size were significantly increased in the new system.

Table 3. Effect of different treatments on fruit yield (t/ha) of capsicum in drip and surface irrigation

Treatments	Drip irrigation			Surface irrigation		
	2009-10	2010-11	Average	2009-10	2010-11	Average
			ECiw levels (dS m^{-1})			
Canal	19.49	14.00	16.74	12.51	13.05	12.78
4	12.64	11.21	11.92	7.52	10.16	8.84
8	10.22	10.16	10.19	6.19	9.18	7.69
CD at 5%	2.00	2.74	2.37	1.02	1.62	1.32
			IW/CPE ratio			
0.75	14.50	11.50	13.03	9.06	11.40	10.23
1.00	14.63	12.60	13.61	8.81	10.93	9.87
1.25	13.23	11.22	12.22	8.36	10.06	9.21
CD at 5%	NS	NS	NS	NS	NS	NS
ECxIW/CPE	NS	NS	NS	NS	NS	NS

Table 4. Effect of different treatments on fruit yield (t/ha) of okra in drip and surface irrigation

Treatments	Drip irrigation			Surface irrigation		
	2010	2011	Average	2010	2011	Average
			ECiw levels (dS/m)			
Canal	12.34	10.05	11.19	12.23	9.35	10.79
4	5.74	4.80	5.27	2.52	2.96	2.74
8	2.66	3.21	2.93	0.00	0.02	0.01
CD at 5%	0.86	1.67	1.26	1.39	0.89	1.14
			IW/CPE ratio			
0.75	4.94	4.22	4.58	5.12	3.89	4.50
1.00	6.88	6.71	6.79	4.52	4.10	4.31
1.25	8.92	7.14	8.03	4.52	4.34	4.43
CD at 5%	0.86	1.67	1.26	NS	NS	NS
ECxIW/CPE	3.15	NS	NS	NS	NS	NS

The interaction effect of EC and IW/CPE ratios were found non-significant in capsicum and okra crops in both the irrigation systems except in 2009-10 crop season when okra fruit yield was significantly higher under drip irrigation.

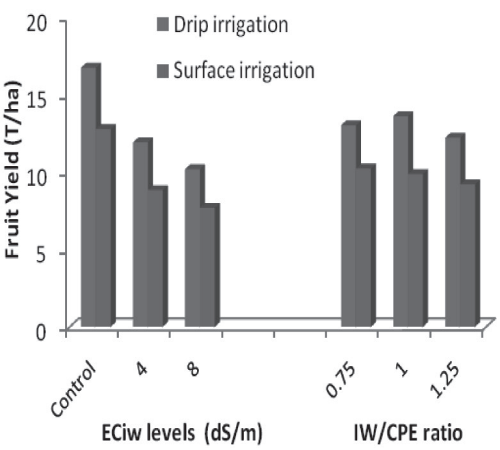

Fig. 1. Effect of different treatments on capsicum

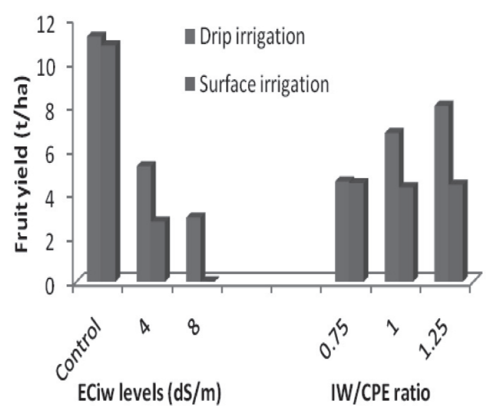

Fig. 2. Effect of different treatments on okra

Saving of irrigation water

Irrigation water was most efficiently used through drip irrigation system. It was observed that approximately 30 per cent irrigation water could be saved because of wastage of water through seepage in border and evaporation was minimum (Agarwal and Dixit, 1972).

Table 5. Interaction effect of EC and IW/CPE ratios on fruit yield (t/ha) of okra in drip and surface irrigation.

IW/CPE ratio	ECiw levels (dS m^{-1})					
	Drip irrigation			Surface irrigation		
	Canal	4	8	Canal	4	8
			2010			
0.75	9.04	3.80	1.98	12.88	2.62	0.00
1.00	11.15	6.65	2.86	12.45	2.76	0.00
1.25	16.83	6.77	3.15	11.38	2.17	0.00
CD at 5%		3.15			NS	
			2011			
0.75	7.84	3.66	1.15	9.17	2.349	0.00
1.00	9.02	5.48	5.62	9.44	2.81	0.06
1.25	13.3	5.27	2.87	9.43	3.38	0.00
CD at 5%		NS			NS	

The water use and water use efficiency in drip and surface irrigation are given in Table 6. On two year average basis, total water use by the okra crop varied from 32.8 to 57.6 cm in drip and 50.5 to 78.4 cm in surface irrigation system. The water use efficiency decreased with increasing EC_{iw} levels. The water use efficiency was higher in drip than surface irrigation. In control, EC_{iw} 4 and 8 dS m^{-1} treatments, the water use efficiency was 240.4, 176.0 and 71.0 (kg/ha^{-cm}) in drip and 166.7, 44.3 and 0.2 (kg/ha^{-cm}) in surface irrigation systems, respectively.

Salinity buildup

Salinity profiles, determined after harvest of capsicum and okra crops, are depicted in Figures 3 and 4. Higher salt accumulation with saline irrigations occurred in surface 0-10 cm soil. In drip irrigation, the salts accumulated at the wetting front on periphery of the wet zone. The salinity buildup was higher in IW/CPE ratio of 1.25 than 1.00 and 0.75 which seems to be due to amount of irrgation water. In okra crop, salinity buildup was higher in soil profile as compared to capsicum due to more utilization of water.

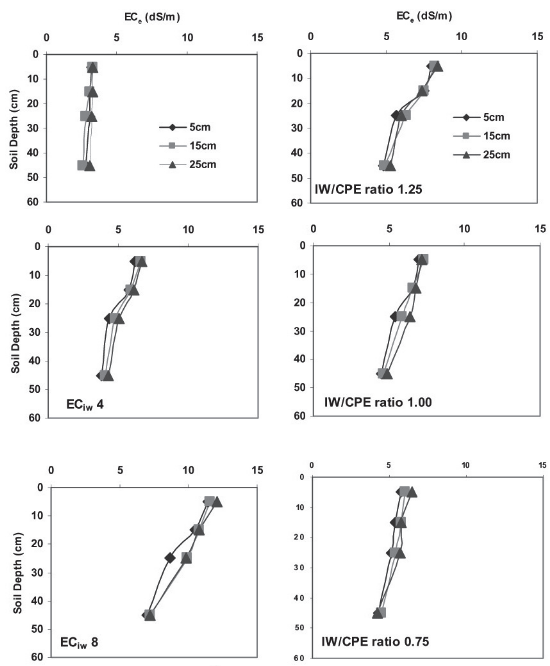

Fig. 3. EC_e (dS m^{-1}) in different ECiw levels and IW/CPE ratios at harvest of capsicum in drip irrigation

Table 6. Water use and water use efficiency under different treatments in okra (2010 and 2011)

Treatments	Drip irrigation						Surface irrigation					
	Water use (cm)			Water use efficiency (kg/ha/cm)			Water use (cm)			Water use efficiency (kg/ha/cm)		
	2010	2011	Av.	2010	2011	Av.	2010	2011	Av.	2010	2011	Av.
					ECiw levels (dS m^{-1})							
Control	53.9	39.9	46.9	228.9	252.0	240.4	75.1	54.8	64.9	162.8	170.6	166.7
4	52.0	39.5	45.7	110.4	121.6	116.0	74.7	53.9	64.3	33.7	54.9	44.3
8	51.8	35.4	43.6	51.3	90.8	71.0	74.6	53.4	64.0	0.0	0.4	0.2
					IW/CPE ratio							
0.75	39.2	32.7	32.8	126.1	129.0	127.5	58.4	42.7	50.5	87.6	91.0	89.3
1.00	53.0	42.7	47.8	129.8	157.1	143.4	75.3	54.4	64.8	67.5	75.5	71.5
1.25	64.2	51.1	57.6	138.9	139.8	139.3	90.9	66.0	78.4	49.7	65.7	57.7

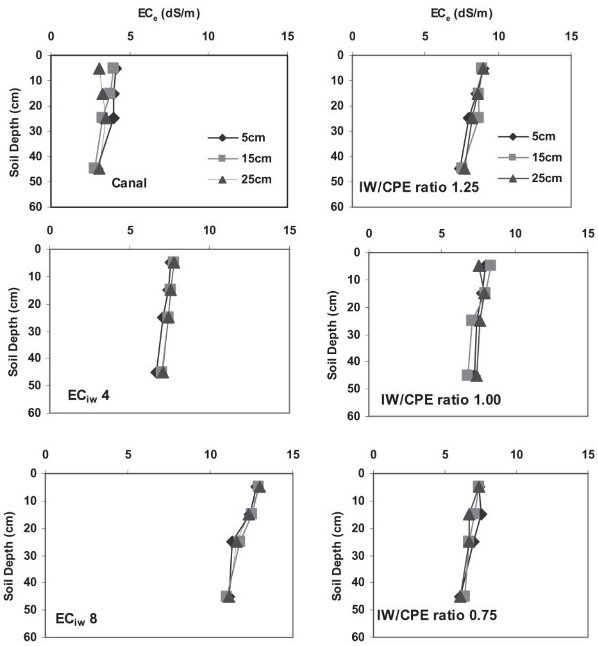

Fig. 4. EC_e (dS m^{-1}) in different ECiw levels and IW/CPE ratios at harvest of Okra in drip irrigation

In surface irrigation, the salinity buildup was higher in surface layer (0-10 cm) as compared to the lower depths (30-60 cm) (Table 7). At harvest of capsicum crop, the EC_e values in surface layer (0-10cm) were 3.6, 8.0 and 12.2 (dS m^{-1}) with canal, EC_{iw} 4 and 8 dS m^{-1}, respectively. Corresponding value for the lower depths (30-60cm) were 3.1, 5.1 and 6.1 dS m^{-1}, respectively. In case of okra crop, these values were 4.1, 9.2 and 13.2 dS m^{-1}in control, EC_{iw} 4 and 8 dS m^{-1} and in lower depths were 3.4, 8.4 and 11.8, dS m^{-1}, respectively. The ECe buildup was higher in higher IW/CPE ratio of 1.25 than either 1.00 or 0.75.

Conclusion

The salinity tolerance of capsicum-okra crop rotation was assessed under drip and surface irrigation systems. The capsicum and okra fruit yields declined significantly with increasing salinity and drastic yield reduction was noted at EC_{iw} 8 dS m^{-1} in both drip and surface irrigations. The IW/CPE ratios were found statistically at par in drip irrigation and surface irrigations of capsicum and okra, while okra fruit yield significantly increased with increasing IW/CPE ratio. In general, the crop yield potential was higher under drip method. The drip method also saved about 25 per cent irrigation water than surface irrigation and the net economic return was also higher than surface irrigation system.

Table 7. Salinity build-up in different EC_{iw} levels and IW/CPE ratios at harvest of capsicum and okra (Average 2009-10 and 2010-11) in surface irrigation

Treatments	Soil depth	EC_e (dS m^{-1})	
	(cm)	Capsicum	Okra
	Salinity levels (dS m^{-1})		
Control	0-15	3.6	4.1
	10-20	3.3	3.8
	20-30	3.1	3.3
	30-60	3.0	3.2
EC_{iw} 4	0-10	7.5	11.1
	10-20	6.5	9.7
	20-30	5.0	9.4
	30-60	5.0	8.6
EC_{iw} 8	0-10	12.0	19.1
	10-20	9.5	16.3
	20-30	8.7	14.4
	30-60	8.0	12.2
	IW/CPE ratio		
1.25	0-10	8.7	12.5
	10-20	7.5	10.8
	20-30	6.5	9.8
	30-60	5.8	8.8
1.00	0-10	7.7	11.5
	10-20	6.5	9.9
	20-30	5.8	9.0
	30-60	5.5	7.9
0.75	0-10	6.8	10.3
	10-20	5.5	9.2
	20-30	5.1	8.1
	30-60	4.7	7.2

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Land shaping for crop diversification and enhancing agricultural productivity in degraded lands of A&N Islands

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ABSTRACT

In Andaman and Nicobar (A&N) Islands, about 30,000 ha area is under plantation and spice crops in hilly lands and 8,800 ha area is under rice cultivation in low-lying land. In general, hilly lands face the problem of soil erosion during wet season and water scarcity during dry season whereas coastal low-lying lands are mostly waterlogged during wet season whereas no water is available for second crop during dry season. In addition, some of these low-lying lands also face the problem of soil and water salinity due to sea water ingress. With reference to A&N Islands, eroded hilly lands, saline/waterlogged areas fall in the category of degraded land and water areas. Therefore, these low-lying areas are generally mono-cropped with low yielding rice cultivation that gives low economic returns and limits the options of livelihood. In plantation crops on hilly areas, soil conservation measures, multi-tier cropping along with introduction of micro-irrigation system may help in improving the land and water productivity. In low-lying paddy areas, appropriate agricultural land drainage coupled with land shaping techniques and other supplementary activities such as introduction of salt tolerant/long duration high yielding rice varieties, vermi-composting may help these degraded areas for crop diversification and multiple cropping to increase the overall farm productivity, income and thus livelihood security.

Key words: agricultural productivity, crop diversification, land shaping, low lying land, soil salinity

Degraded Land and Water

Salt affected soils contain excessive concentration of either soluble salts or exchangeable sodium, which impair plant growth. Based upon pH of saturated paste (pHs), electrical conductivity (ECe) and exchangeable sodium percentage (ESP), these soils, as per Indian system, can be classified as given in Table 1.

The quality of irrigation water is another important parameter for successful crop cultivation. The amount and kind of salt present (using EC, RSC, SAR and specific ion toxicity namely B, Cl, Na) determines the suitability of water. Based on total dissolved salt and EC, SAR and RSC, the irrigation water is classified as given in Table 2-3.

Agricultural Land Drainage

In order to facilitate quick removal of excess rainwater and to stop the ingress of sea water in low-lying areas, construction of peripheral embankments with provision of one way sluice gates and construction of drainage network will be necessary. In general, a three-tier system of surface drainage is recommended for effective and economic view (Gupta *et al.*, 2006):

1. Rainwater is allowed to accumulate and remain in the fields till such time and extent as will not be harmful to crop.
2. Excess water from the fields is led to the dugout ponds of sufficient capacity. The stored water can be utilized subsequently during dry spells or for irrigating winter season crops.
3. Rainwater in excess of these two components of storage is taken out of the area to the creeks/sea through appropriately located one-way sluice gates/structures.

Land Shaping Interventions

Land shaping is nothing but articulation of land arrangement so as to overcome certain hydrologic problems in agricultural area for potential crop cultivation. Some of the land shaping techniques, which could be

Table 1. Classification of salt affected soils

Soil characteristics	Saline soil	Alkali soil
pHs	< 8.2	> 8.2
ESP	< 15	> 15
ECe	> 4 dS/m	Variable, mostly < 4 dS/m
Nature of salts	Neutral, mostly Cl and SO_4 of Na, Ca and Mg. HCO_3 may be present but CO_3 is absent	Capable of alkaline hydrolysis, prevalence of HCO_3 and CO_3 of Na

Table 2. Classification of water quality

Water quality	Total dissolved salt (mg/L)
Fresh	< 500
Marginal	500-1500
Brackish	1500-5000
Saline	> 5000
Brine	35000
Bitter	> 350000

Table 3. Classification of water quality as per EC, SAR and RSC ground waters

Water Quality	ECiw (dS/m)	SARiw	RSC (me/L)
A. Good	<2	<10	<2.5
B. Saline			
-Marginally saline	2-4	<10	<2.5
-Saline	>4	<10	<2.5
-High SAR saline	>4	>10	<2.5
C. Alkali waters			
-Marginally alkali	<4	<10	2.5-4.0
-Alkali	<4	<10	>4.0
-Highly alkali	Variable	>10	>4.0

followed in the A&N Islands, are pond based integrated farming, broad bed and furrow, rice-cum-fish, three tier land management and ridge and furrow systems.

Pond based integrated farming system (IFS)

Farm ponds, as one of the suitable options of land shaping, form the centre of integrated farming system. It may store *in situ* rainfall or harvest surface runoff from surrounding areas depending upon the available rainfall in a region. In high rainfall areas, like A&N Islands where average annual rainfall is about 3100 mm, even in-situ rainwater storage in farm pond serves the purpose. However, in areas where surface runoff is the main source of water, the contributing drainage area or watershed should be large enough to maintain desired water level in the farm pond. The requirement of expensive overflow structures may be avoided by optimising the catchment vs. storage area. The required catchment area depends on soil type, land use and land slope. Following steps should be made while planning, designing and constructing a farm pond: (i) rainwater availability, (ii) crop water requirements, (iii) design dimension of farm pond, (iv)location of the farm pond and (v) lining requirement for seepage control. A comprehensive work on rainwater management in Sundarban delta, West Bengal (Ambast *et al.*, 1998) suggested to convert 20% of the farm/watershed area into on farm reservoir (OFR) to harvest excess rainwater. Further, simulation of surface drainage improvement by rainwater harvesting with and without OFR indicated surface drainage improvement up to 75%, which provides scope for cultivation of high yielding rice varieties in rainfed humid rice lowlands. Optimal land and water allocation using linear programming model indicated benefit-cost ratio of 2:1 (excluding income from fishery and horticulture), and thus justified the investment in OFR.

For A&N Islands, Gupta *et al.*, (2006) suggested that excess rainwater available during May to December should be stored *in situ* in the dugout farm ponds to provide supplemental irrigation during dry spells in wet season and life saving irrigation for crop cultivation during dry season. Further, on the basis of crop evapotranspiration and water requirement of different crops (Table 4), the size of the pond was optimized as 15% of the land holding (Fig.1; Table 5) to irrigate the remaining 85% area for summer crops.

Broad bed and furrow system (BBF)

It involves making of broad beds and furrows alternatively in rice fields. The ideal location is the flat low lying area, where the floodwater stagnates and only rice crop can be grown. Broad beds are made in the shape of inverted trapezium by digging soil from either side of the broad bed and putting it in the bed area by cut and fills method (Ravisankar *et al.*, 2008). The proper time of starting the earthwork is summer season. In summer season, the soil can be easily manipulated. The excavated depressed area is used for rice cultivation and the raised broad bed area which is above the water level of the paddy fields are used for cultivating any seasonal vegetable or fodder crop during monsoon period. The beds of 4-5 m wide and furrows of 5-6 m wide were found suitable for this system of cultivation. The BBF system is shown in Fig. 2. Planting two rows of hybrid Napier on both sides of the bed stabilizes the broad beds. At the end of the furrow on descending side, a fish shelter or pond is to be excavated. In this pond, the fish farming can be along with rice. This is added to the profit as well as livelihood of the farmer. From the bund of the furrow, two PVC

Table 4. Evapotranspiration (ET), crop water requirement (CWR), effective rainfall (R_{eff}), gross and net irrigation requirement (GIR, NIR) for different crops

Crop	ET_{crop} (mm)	CWR (mm)	R(Eff.) (mm)	NIR (mm)	GIR (mm)
Rice (*Kharif*)	468	1300	1200	150	215
Rice (*Rabi*)	447	1280	691	589	840
Groundnut (*Rabi*)	478	478	554	-	-
Maize (*Rabi*)	442	442	436	-	-
Sorghum (*Rabi*)	361	361	403	-	-
Rabi veg (Cauliflower/tomato)	328	328	358	-	-
Pulses (Summer)	456	456	238	218	311
Summer veg1 (Brinjal/Bitterguard/ Cucumber/Pumpkin)	429	429	180	249	356
Summer veg2(Chilli/Watermelon)	358	358	112	246	351

Table 5. Estimation of available water in the pond for agriculture

Item	Details
Dimension of the pond	40 m x 40 m
Depth of pond	3 m
Dead storage	0.5 m
Water losses (@5 mm/d for 100 days)	0.5 m
Effective rainfall during summer	0.1 m
Available depth for agriculture	2.1 m
Available storage for agriculture	2700 m^3
Extent of irrigated area	0.85 ha

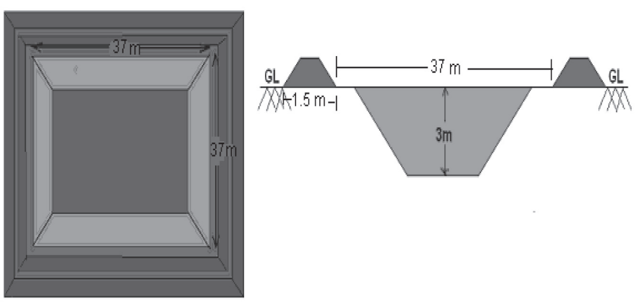

Fig.1. Plan and side view of the suggested farm pond for 1 ha land

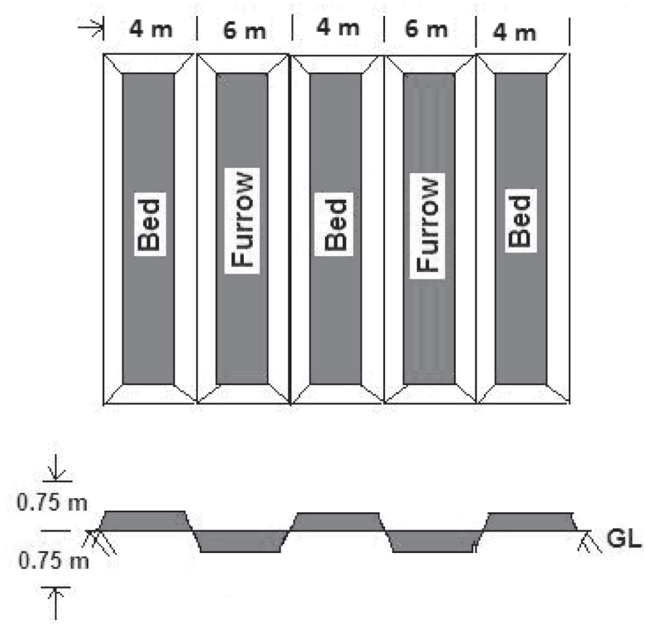

Fig.2. A typical sketch of broad bed and furrow system

pipes of 2 m length may be provided for draining out excess water. After the rice is harvested the rice area can be planted with medium duration vegetables in the month of December and can extend up to the end of March depending upon the stored moisture availability in the rice furrows. The broad bed area can be used for either 3 crops rotation of two medium and one short duration crop like bhindi-brinjal-radish from mid April to mid January or for single long duration crop like ginger or turmeric from May to January or perennial fodder crop like hybrid napier. On such beds vegetables like French bean, cowpea, tomato, capsicum, chillies, cluster bean etc. can be grown successfully. After harvesting of rice in the furrows, the area can be put under pulses or oil seed crops, besides vegetables. This technology being practised in rice fields provides bright sunshine for growing crops. The system also increases the cropping intensity from the present level of 100% in the rice to 300% in the beds and 200% in the furrows of the broad bed-furrow system. The initial cost of about Rs. 100,000/ha incurred on land manipulation is easily returned back from vegetables produced in one season. The technology helps in replacing 40% of the rice area with vegetables and fodder and also assures continuous supply of fodder and vegetables during peak monsoon period in these islands. This technology can also be extended to similar coastal plain areas in other parts of the country.

Paddy cum fish system (P-F System)

Integrating aquaculture with agriculture assures higher productivity and year round employment opportunities for farmers. The plots utilised for rice cum fish system (Fig.3) is mainly based on organic fertilisation

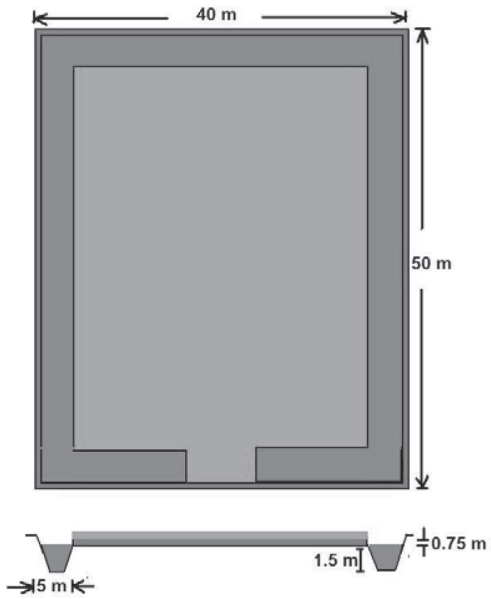

Fig. 3. A typical sketch of paddy-fish system

with a varieties of animals excreta such as poultry dropping, pig excreta, cow dung and wastes of plants such as rice husks and ashes from household burnt and remains of burnt straws after the harvest is over. Compost fertiliser like decomposed straws, weeds and stalks. The rice field can be utilized for fish culture in the following two ways. Fishes can be reared from the month of May to September when the paddy crops grow in the field. The fish culture can also be taken up from the month of November to February after harvesting of paddy crops is completed and transplantation for the next season begins. The culture of fishes in paddy fields, which remain flooded even after the paddy is harvested, may also serves as an occupation for the unemployed youths. Paddy field is suitable for fish culture because of having strong bund in order to prevent leakage of water, to retain up to desired depth and also to prevent the escape of cultivated fishes during floods. The bunds built strong enough to make up the height due to geographical and topographic location of the paddy field. Bamboo mating was done at the base of the bunds for its support.

Ridge and furrow system (R-F System)

In low lying areas, the paddy land is converted into ridges and furrows (Fig.4). This system is semi-permanent type, which could be lasted for 3-5 years. Regular maintenance is required for proper shaping of ridges. The paddy land is converted into ridges by cutting the soil and making the ridge. The width of the ridge and furrows are 1.0-1.5 m and height of up to 0.5 m. The earth cutting and filling operation could be accomplished manually by spade in the summer. At the time of filling the soil should be compacted. It will prevent the soil erosion. The ridges are used for plating of coconut, arecanut and banana. If possible vegetable crops could also be grown on the ridges.

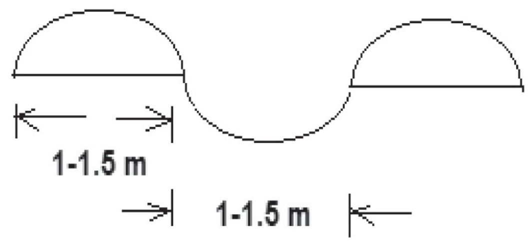

Fig. 4. A layout of ridge and furrow system

Three tier land farming system (TTLF)

It is another form of land shaping option so as to introduce crop diversification in the low-lying mono-cropped paddy area. In this, one third part of the land is dugged to a depth of 2 m or more depending upon the site specific condition and the dugged soil can be spread to the other extreme of the field so as to raise this part by at least 1 m whereas some soil can be used for making bunds around the pond. The middle part of the field remains at the original ground level. In the raised part, vegetables can be grown whereas in the middle part rice is grown. The rainwater can be harvested in the dugged part and fish can be integrated. This enhances the net return of the farms.

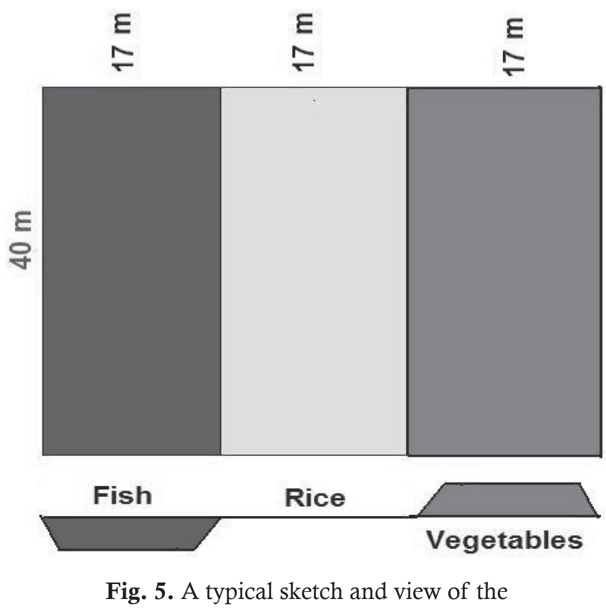

Fig. 5. A typical sketch and view of the 3-tier land farming system

Agronomic Strategies and Salt Tolerant Paddy Varieties

In the degraded low-lying waterlogged fields, farmers grow tall, extremely long duration traditional Burmese paddy cultivar, C 14-8. It covers about 60-70% of the rice-cultivated area. The farmers used to transplant the rice and revisit the farm only for harvest with virtually no management inputs in terms of nutrient application or pest/disease management. A yield of 1.8-2.2 t/ha

Table 6. Recommended rice varieties for different land situations

HYV for unaffected areas	Salt tolerant cultivars
For mono-cropping: IET 9188, IET 7991, IET 8021 For double cropping: IET 11754, IR 18350-229-3, IR 31851-6-3-3-2-2 (Short duration); Quing Livan 1, Taichung Sen Yu, Milyang 55, Nanjing 47161 (Medium duration)	CSR 10, CSR 23, CSR 30, CSR 36, Canning 7 (CSSRI) Vytilla 3, Vytilla 4, and Vytilla 5 (KAU) CO 43, TRY 1, Pokkali (TNAU); PSBRc 50, PSBRc 88, PSBRc 90 (IRRI); BTS 24, BRRI dhan40, BRRI dhan41 (BRRI)

Table 7. Vegetables and fruit crops with their salinity tolerance for coastal areas

Vegetable crops	Varieties	Salinity levels (dS/m)
Brinjal	Pusa Hybrid 6 and Pusa Uphar	8
Tomato	Pusa Ruby, Pusa 120 and Pusa Rohini	8
Chilli	CA 960, Suryamukhi and Pusa Jwala	7
Watermelon	Sugar sweet and Sugar Baby	6
Sapota	Badami, Cricket Ball and Kalipatti	10
Guava	KG, Kashi and L-49	6

provides livelihood in subsistence mode. On the other hand, modern long duration high yielding paddy varieties could produce about 4-5 t/ha, of course with management at semi-intensive scale. Based on evaluation of different varieties, CARI recommends Ranjeet and Varshadhan as the alternate high yielding long duration paddy varieties. In some areas after tsunami, rice cultivation became an uphill task owing to high salinity and associated nutritional problems. Moreover, there is a need to increase the cropping intensity, diversify from rice cropping and shift to some vegetable crops. In areas where soil salinity is between 4-8 dS/m, CSR-23 and CSR 36 have shown better performance and can be used for obtaining high yield. Some other salt tolerant rice cultivars are given in Table 6. Salt tolerances of some other common crops are given in Table 7.

Conclusions

Different types of land shaping techniques i.e. pond based integrated farming, broad bed furrow, paddy-fish, ridge and furrow and three tier cropping systems are discussed as effective means for crop diversification in low-lying degraded lands. The techno-economic evaluations of these systems were evaluated. Similar techniques may be adopted by the farmers of the Islands depending upon the specific farmer field location.

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Response of gypsum in calcareous sodic soils in Muzaffarpur district of Bihar

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ABSTRACT

A field experiment was conducted in farmer's fields in five villages *viz.* Birahima, Mathaiya, Tajpur, Babutola and Sirsia of Motipur block of Muzaffarpur district of Bihar (India), with six treatment combinations (T_1 = control, T_2 = 50% GR, T_3 = Pressmud (PM) @10 Mg ha^{-1}, T_4 = 50% of GR + PM @10 Mg ha^{-1}, T_5 = 50% of GR + *Dhaincha*, T_6 = 50% of GR + PM @10 Mg ha^{-1} + *Dhaincha*) to evaluate the response of FCI-Aravali mineral gypsum in calcareous sodic soils under rice-wheat cropping system. After levelling and bunding, different amendments were applied and after leaching the salts, rice (*cv. Usar Dhan*-3) was transplanted followed by wheat (*cv HD* 2824) during *rabi* season. The grain and straw yield of rice and wheat was found to increase significantly under all the treatments over control. The grain yield of rice and wheat increased from 2.0 to 3.6 and 2.0 to 4.5 Mg ha^{-1} under control and amendments, respectively. The per cent increase in grain yield of both rice and wheat was maximum (83% and 132%) in the treatment receiving all the amendments (T_6) over control. Besides improvement in crop production, the pH and electrical conductivity of soil were also found to decrease, while there was slight increase in organic carbon content. This was more pronounced in the treatments receiving sulphitation pressmud and/or *Dhaincha* along with gypsum.

Key words: gypsum, reclamation, rice, sodic soils, wheat

Introduction

In the state of Bihar, India about 89.5 per cent of the population resides in villages, and it is the second largest and one of the most densely populated states of India. In Bihar, out of total 92.83 lakh hectares, about 4.0 lakh ha arable area falls under salt-affected soils and are mainly distributed in the districts of Chhapra, Siwan, Gopalganj, East Champaran, West Champaran, Vaishali, Muzaffarpur, Banka and Samastipur. The development of salt-affected soil is secondary in nature; the area of such land is increasing year after year due to continuous use of poor quality water and faulty methods of irrigation along with water stagnation in low lying areas by restricted horizontal drainage.

In these soils, the preponderance of exchangeable sodium on colloidal complex reduces the availability of calcium and magnesium to plants. This exchangeable sodium causes the dispersion of colloidal particles and thus creating poor soil physical conditions which induces waterlogging and thus adversely affects root aeration. High pH also reduces the availability of nutrients and restricts crop growth. Due to faster oxidation of organic matter in sodic soils, the organic carbon content in these soils remains very poor resulting in poor soil physical conditions. Thus, these soils produce very poor or no yields at all. Therefore, it is necessary to improve the productivity of such soils by reclaiming them with the application of suitable amendments.

The occurrence of calcareous alkaline soils in Ganadak command and its adjoining areas in Bihar has been previously reported (Prasad, 1998; Sharma, *et al.,* 2008). For calcareous sodic soils, pyrites proved superior to gypsum both in respect of yield and improved soil properties (Choudhary, 1980). For reclaiming calcareous sodic soils having large amounts of $CaCO_3$, the use of sulphur or any other sulphur bearing or acid producing material is suggested. The sulphur on oxidation produces sulphuric acid, which ultimately react with $CaCO_3$ in soil to produce $CaSO_4$. Owing to the non availability of pyrite in Bihar, ~~so~~ gypsum can be used as a source of sulphur to reclaim the sodicity. Application of gypsum provides soluble calcium and sulphur. Application of gypsum not only directly supplies soluble calcium but also results in greater solublization of calcium carbonate of soils. Sharma *et al*. (2011) reported that the alkali soils in a part of Gandak command area of Bihar can be treated with gypsum at 4 Mg ha^{-1} to reduce alkalinity and improve productivity. Thus, in calcareous sodic soils, an experiment was conducted to evaluate the response of gypsum alone and in combination with pressmud and *Dhaincha* in rice-wheat cropping system in farmer's field in Motipur block of Muzaffarpur district (Bihar).

Material and methods

A field experiment was conducted in calcareous sodic soils in five villages (Birahima, Mathaiya, Tajpur, Babutola and Sirsia) of Motipur block of Muzaffarpur district (Bihar). The initial soil properties are depicted in Table 1. The different treatments T_1 – Control, T_2 - 50% of GR (gypsum requirement), T_3 – Sulphitation Press Mud (SPM) @10 Mg ha^{-1}, T_4 - 50% of GR + PM @10 Mg ha^{-1}, T_5 - 50% of GR + *Dhaincha* and T_6 - 50% of GR + PM @ 10 Mg ha^{-1} + *Dhaincha* were applied in randomized block design. In all treatments, recommended dose of fertilizers were applied as per the crop requirement. After levelling and bunding of fields, the gypsum was applied @ 4 Mg ha^{-1} (*i.e.*50% of gypsum requirement of soil), while, sulphitation pressmud @ 10 Mg ha^{-1} as per the treatments. After application, amendments were mixed in surface soil and fields were irrigated for leaching the salts followed by *dhaincha* cultivation. After leaching of salts with water, *Dhaincha* was sown as per treatment.

The salt-tolerant rice (*Usar Dhan*-3) was selected as first crop to grow after reclamation of soils. The rice nursery was raised by using paddy seeds @ 40 kg ha^{-1} in normal soils. Thirty five days old standing *Dhaincha* crop was incorporated in the soil with the help of rotavator/ cultivator. The recommended dose of fertilizers *i.e.* 100 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 40 kg K_2O ha^{-1} was applied through urea, di-ammonium phosphate (DAP) and muriate of potash (MOP), respectively. Half dose of N and full dose of P and K were applied at the time of rice transplanting and remaining half dose was applied as top dressing in two equal splits, one at tillering and other at panicle initiation stage.

The wheat crop (*HD 2824*) was sown after harvest of rice. The recommended dose of fertilizers *i.e.* 120 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 40 kg K_2O ha^{-1} was applied through urea, DAP and MOP, respectively. Half dose of N and full dose of P and K were applied at the time of wheat sowing and remaining half dose of nitrogen was applied as top dressing in two equal splits, one after first irrigation and other after second irrigation.

The grain and straw yields from each plot were recorded at maturity of crops. Initial as well as in final values of pH, EC, organic carbon, available P, available K, SAR and ESP in soils after harvest of each crop were analysed using standard procedures (Table 1).

Results and Discussion

Grain and Straw Yield of rice

Significant increase in the grain and straw yield of rice was recorded in all the treatments over control (Table 2). The rice (*Usar-Dhan-3*) yield in untreated plots was also good as the variety is salt-tolerant and shows better performance under salt-affected soils. This variety is semi-dwarf and crop duration is about 130 days. The grain yield varied from 1.98 to 3.63 Mg ha^{-1}, while the mean straw yield varied from 3.74 to 6.35 Mg ha^{-1} (Table 2). The maximum mean grain yield was recorded in treatment T_6 (3.63 Mg ha^{-1}) significantly followed by T_5 (3.13 Mg ha^{-1}), T_4 (2.81 Mg ha^{-1}), T_3 (2.57 Mg ha^{-1}), T_2 (2.34 Mg ha^{-1}) and T_1 *i.e.* control (1.98 Mg ha^{-1}). The same increasing trend in rice straw yield was also recorded. The maximum grain and straw yield was found to increase by 83 and 70 percent, respectively, over control (Fig. 1).

Such marked increase in grain yield might be due to improvement in physico-chemical properties of soil and also the salt tolerance of rice variety grown. According to Brady and Weil (2002), when the exchangeable Na^+ ions are replaced by Ca^{2+} in the form of gypsum, soil aggregation and improved water infiltration results. The neutral sodium salts (Na_2SO_4) formed during this replacement can then be leached from the soil, thereby reducing both salinity and sodicity. The reclamation effects of gypsum are greatly accelerated by plants growing on the soil. Crops that have some tolerance to saline and sodic soils can be grown initially. Their roots help provide channels through which gypsum can move downward and enhance the ameliorating effect.

Table 1. Initial soil properties of the experimental site

Parameter	Reference	Range	Mean
pH	Jackson (1973)	8.8-9.2	9.02
Electrical conductivity (dSm^{-1})	Jackson (1973)	1.49-2.8	2.14
Organic carbon (%)	Walkley and Black (1934)	0.42-0.51	0.46
Available P_2O_5 (kg ha^{-1})	Olsen et al. (1954)	14.8-31.99	22.15
Available K_2O (kg ha^{-1})	Jackson (1973)	175-210	189.00
Sodium Adsorption Ratio	-	68.5-74.3	71.10
Exchangeable Sodium Percentage	-	49.98-52.0	51.21

Table 2. Yield (Mg ha^{-1}) of rice (2010) and wheat crop (2010-11)

Treatment	Rice		Wheat	
	Grain	Straw	Grain	Straw
T_1	1.98	3.74	1.95	3.22
T_2	2.34	4.38	3.03	4.93
T_3	2.57	4.80	3.10	5.01
T_4	2.81	5.17	3.69	5.85
T_5	3.13	5.66	3.96	6.14
T_6	3.63	6.35	4.54	6.70
S.Em±	0.08	0.14	0.15	0.23
CD (P = 0.05)	0.22	0.41	0.43	0.67

T_1 control, T_2 50% of GR, T_3 PM @10 Mg ha^{-1}, T_4 50% of GR + PM @10 Mg ha^{-1}, T_5 50% of GR + Dhaincha, T_6 50% of GR + PM @10 Mg ha^{-1} + Dhaincha

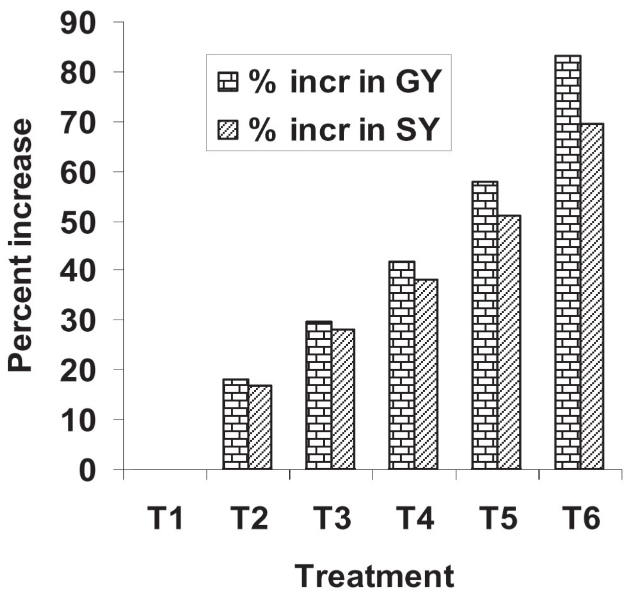

Fig. 1. Per cent increase in grain and straw yield over control in rice- 2010

Shukla and Pandey (1987) in a field trail in saline sodic soil found that the lone application of either organic (pressmud and green manure) or inorganic (pyrites and gypsum) amendments on paddy yield was less effective than their combined application.

Grain and straw yield of wheat

The residual effect of gypsum alone and in combination with other organic amendments significantly increased the grain and straw yield of wheat over control (Table 2). The wheat grain yield varied from 1.95 to 4.54 Mg ha^{-1}, while the straw yield from 3.22 to 6.70 Mg ha^{-1}. The maximum mean grain yield was recorded in treatment T_6 (4.54 Mg ha^{-1}) followed by T_5 (3.96 Mg ha^{-1}), T_4 (3.69 Mg ha^{-1}), T_3 (3.10 Mg ha^{-1}), T_2 (3.03 Mg ha^{-1}) and control (1.95 Mg ha^{-1}). The same increasing trend of wheat straw yield was also recorded. The maximum mean grain and straw yield was found to increase by 132 and 108 per cent, respectively, over control (Fig. 2).

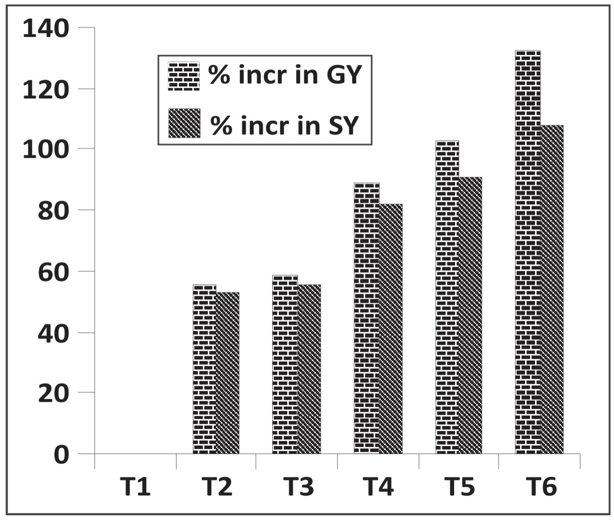

Fig. 2. Percent increase in grain and straw yield over control in wheat- 2010-11

Sinha *et al.* (1977) observed in a pot experiment with calcareous saline sodic soil of north Bihar that all the amendments *viz.* pressmud, neem cake, pyrite, organic manure and gypsum increased the grain and straw yield of rice and wheat significantly over untreated soil.

Thus, it appeared that the chemical amendments *i.e.* gypsum give more pronounced result in increasing grain and straw yield of both rice and wheat in presence of organic manures *viz.* pressmud and *Dhaincha*. Therefore, the combined use of chemical amendments and organic manures seems necessary for reclaiming the sodic soils for obtaining higher crop yields. For obtaining higher yield of crops as well as for improving the soil physico-chemical environment, application of organic amendments along with chemical amendments seems necessary.

Harvest index (HI) and grain: straw ratio

The HI and grain: straw ratio of rice and wheat increased in all the treatments receiving amendments over control (Table 3). The HI varied from 34.6 (no gypsum) to 36.36 (T_6, all amendments) and 37.75 (no amendments) to 40.39 (T_6 all amendments) per cent in rice and wheat, respectively, while the grain: straw ratio varied from 0.53 to 0.57 and 0.61 to 0.68. When the proportion of economic yield (grain) increases, it results in improved grain: straw ratio as well as harvest index.

Benefit cost ratio (B: C)

Benefit: cost ratio of amendment application represents the economic return of the crop per unit of additional investment in amendments. After rice, the benefit: cost ratio was found to be maximum in the

Table 3. Harvest Index (HI), grain: straw (G: S) ratio and benefit: cost (B: C) ratio of rice, wheat and rice-wheat cropping system

Treatment	Rice			Wheat			System
	HI	G:S	B:C	HI	G:S	B:C	B:C
T_1	34.60	0.53	0.42	37.75	0.61	0.44	0.52
T_2	34.79	0.53	0.00	38.11	0.62	1.23	1.35
T_3	34.84	0.53	0.18	38.26	0.62	1.28	1.41
T_4	35.21	0.54	-0.10	38.68	0.63	1.71	1.85
T_5	35.59	0.55	0.29	39.20	0.64	1.90	2.05
T_6	36.36	0.57	-0.06	40.39	0.68	2.29	2.47

T_1 control, T_2 50% of GR, T_3 PM @10 Mg ha^{-1}, T_4 50% of GR + PM @10 Mg ha^{-1}, T_5 50% of GR + Dhaincha, T_6 50% of GR + PM @10 Mg ha^{-1} + Dhaincha

untreated plots, while negative in the treatments T_4 (Gypsum @ 4 Mg ha^{-1} + PM @10 Mg ha^{-1}) and T_6 (Gypsum @ 4 Mg ha^{-1} + PM @ 10 Mg ha^{-1} + *Dhaincha*) (Table 3). Again after wheat, the ratio was found to increase in all the treatments over control. This might be due to increase in grain yield and decrease in input cost as no amendment was applied before cultivation of wheat.

After completion of one crop cycle *i.e.* rice-wheat, the B: C ratio was found to vary from 0.52 to 2.47 under control and treatment T_6, respectively. The increase of B: C ratio with gypsum alone and in combination with pressmud and/dhaincha may be attributed to the decrease in rate of inputs (residual effect of amendments) and increase in grain yield with successive increase in amendments (Table 3).

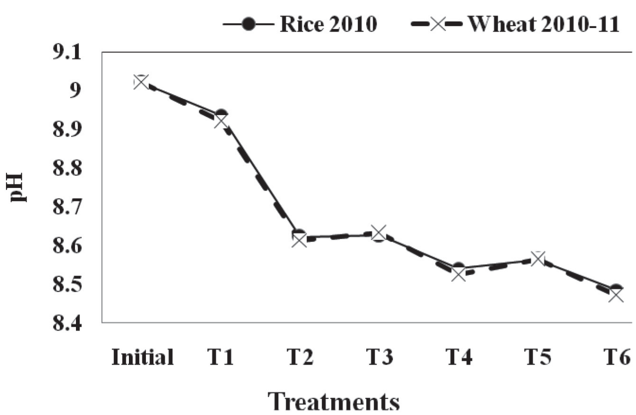

Fig. 3. Status of soil pH (after rice 2010 and wheat 2010-11)

Physico-chemical properties of after crop harvest

The changes in organic carbon and electrical conductivity due to application of different amendments are depicted in Table 4 and the pH in Figure 3. The data revealed that gypsum application alone as well as in combination with pressmud and *Dhaincha* improved the physico-chemical properties of soil after crop harvest. The improvement was more in the plots receiving gypsum along with the organic amendments.

After harvest of rice, the organic carbon content in soil increased significantly under all the treatments except untreated and treated with gypsum alone, while the increment was significant under all the treatments after wheat. The mean organic carbon build up after rice-wheat cropping system varied from 0.46 (initial content) to 0.53 percent, under the treatment receiving all the amendments. The EC was found to decrease significantly after rice and wheat. The mean EC after rice-wheat cropping system decreased from its initial content 2.14 to

Table 4. Changes in organic carbon and EC in post harvest soil after rice 2010 and wheat 2010-11

Treatment	Organic carbon (%)			Electrical Conductivity (dS m^{-1})		
	Rice	Wheat	Mean	Rice	Wheat	Mean
T_1	0.43	0.42	0.42	1.98	2.06	2.02
T_2	0.47	0.48	0.48	1.01	1.06	1.04
T_3	0.49	0.50	0.49	1.05	0.98	1.02
T_4	0.50	0.51	0.50	0.96	0.95	0.95
T_5	0.49	0.50	0.49	0.93	0.95	0.94
T_6	0.51	0.53	0.52	0.91	0.93	0.92
S.Em±	0.01	0.01	-	0.05	0.05	-
CD (P =0.05)	0.03	0.03	-	0.15	0.15	-

T_1 control, T_2 50% of GR, T_3 PM @10 Mg ha^{-1}, T_4 50% of GR + PM @10 Mg ha^{-1}, T_5 50% of GR + Dhaincha, T_6 50% of GR + PM @10 Mg ha^{-1} + Dhaincha

0.92 dS m^{-1}, in the treatment receiving all the amendments. The pH was also found to decrease from 9.14 to 8.69 after rice, while 9.12 to 8.67 after wheat (Fig. 3). The decline in pH and EC was more after rice due to leaching of salts with water. The decline in pH and EC was more under the treatments receiving gypsum along with organics due to production of acids and sodium sulphate. Kumar (1998) in a field experiment in farmers field in calcareous sodic soils in Muzaffarpur district (Bihar) found the improvement in rice yield and physico-chemical properties in soils after crop harvest with the application of pyrite alone and in combination with pressmud.

Conclusion

The improvement in crop yield and physico-chemical properties was more pronounced when the gypsum was applied along with organics than alone application. Thus, by following proper reclamation technology, the economic condition of farmers will improve due to enhancement in yield and supported by improvement in soil properties.

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Constraints in sustainability of rice-wheat cropping system in Haryana

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ABSTRACT

Among the cropping systems prevailing in the northern parts of the country, rice-wheat cropping system is the most important contributing significantly to the national food security. Stagnation in land productivity has been observed over the past few years in the northern and north western Indo-Gangetic Plains. A survey was undertaken in Haryana covering the rice-wheat system in Karnal, Kurukshetra, Ambala and Kaithal districts. Forty SMSs were selected randomly from these districts. Data were collected by using personal interview method during 2011. The experts perceived declining groundwater table, non availability of labour, non availability of seeds of recently released varieties, late sowing/transplanting, low organic matter in the soil and poor participation in kisan gosthi/field day/training/kisan melas as the major constraints in sustainability of rice-wheat cropping system. Rice and wheat productivity in Haryana can be increased by making some policy decisions like providing seeds of newly released varieties, good quality seed, fertilizers, pesticides and extension workers to encourage the farmers to participate in kisan gosthies/ field days/ trainings/kisan melas to know about the latest technologies.

Key words: constraints, productivity, rice-wheat cropping system, sustainability

Introduction

Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system in Indo-Gangetic Plains (IGP) has been showing signs of exhaustion and concerns are now being raised over the sustainability of this system. Continuous cultivation of rice and wheat is lowering soil fertility and organic matter, depleting groundwater resources in tubewell irrigated areas, exacerbating herbicide resistance in weeds and aggravating disease and pest problems. Even micronutrient deficiency started appearing in the IGP with the adoption and spread of intensive agriculture (Gupta, 2012). Rice and wheat have been grown as food crops from the time immemorial but the intensified rice-wheat system evolved rapidly since 1960s after the introduction of high yielding semi-dwarf varieties. Rice and wheat are the world's two most important cereal crops, contributing 45 percent of the digestible energy and 30 percent of total protein in the human diet and considerable contribution to feeding livestock (Evans, 1993). During last four decades, the growth rates of rice and wheat production in South Asia (2.5% and 5.2% per year, respectively) exceeded the population growth rate (2.22% per year), indicating an increase in the per capita availability of these two cereals that strengthened the food security, reduced rural poverty and increased affordability of food in the region (Pingali and Shah, 1999). This was possible due to introduction of high yielding varieties of rice and wheat and their intensive crop production and protection technologies. Demand for rice and wheat is expected to grow at 2.5% per year over the next two decades but it will be difficult to meet the target as the per capita rice-wheat growing area has already shrunk from 1200 m^2 in 1960 to less than 700 m^2 in 2001 (Singh *et. al.,* 2002). However, growth in the production of these two crops has decelerated.

Rice-wheat cropping system so far has maintained the balance between food supply and population growth but recent evidence shows that productivity and sustainability of this system is threatened as yields of both rice and wheat crops are either stagnant or decreasing and total factor productivity is declining for the following reasons: 1) inefficiencies in the current production system; 2) increasing shortage of resources, especially water and labor; 3) changing climate; and 4) socio-economic changes (such as urbanization, labour migration, preference of non agricultural work, rapid economic growth led increased labour requirement in non agricultural sectors) (Ladha *et. al.,* 2003; Mahajan *et. al.,* 2010). In Haryana, over-exploitation of groundwater, imbalanced fertilization, policy decisions, poor quality of inputs and lack of awareness among farmers have threatened the agricultural sustainability. Water is a major concern for sustainability of the rice-wheat production systems (Erenstein, 2009). In both Haryana and Punjab, groundwater has become the predominant irrigation source, placing tremendous pressure on groundwater supplies (Abrol, 1999; Ahmad *et. al.,* 2007). This is further aggravated by the increasing competition for water from the other sectors (Briscoe and Malik, 2006; Kijne *et. al.,* 2003; Meinzen-Dick and Rosegrant, 2005; Molden, 2007). However, water rights and institutional arrangements still do not provide congenial environment to enhance water productivity in rice-wheat systems. Indeed, despite a gradual increase in regional water scarcity, enhancing water productivity remains a secondary concern for most rice-wheat farmers (Ahmad *et. al.,* 2007). Farmers typically lack incentives to enhance water productivity as the scarcity value of water is not reflected in the prevailing water prices (Pingali and Shah, 2001). Initial sustainability concerns in rice-wheat systems were flagged two decades ago and have generated significant research and policy interest. Yet despite some progress, the intrinsic incompatibility of an aerobic wheat crop and anaerobic rice crop has not been altered. Perhaps the clearest exponent of this is that, compared to other wheat production systems, the lowest growth in productivity over the last decades took place in the rice-wheat system on both sides of the border (Ali and Byerlee, 2000; Murgai *et. al.,* 2001). This is contrary to the popular perception, but reflects that rice-wheat output growth was largely due to input growth and partly offset by resource degradation (Byerlee *et. al.,* 2003; Kumar *et. al.,* 2002). The root cause of land degradation in the rice-wheat system is not agricultural intensification *per se*, but rather the policy environment and associated incentives that encouraged inappropriate land use and injudicious use of water and other resources (Datta and Jong, 2002; Pingali and Shah, 2001). This study aims at identifying constraints in sustainability of rice-wheat cropping system through SMSs/experts perceptions.

Material and methods

The study was conducted purposively in Haryana state during 2011. Four districts of Haryana viz; Karnal, Kurukshetra, Kaithal and Ambala were puposively selected based on their crop productivity. A total of 40 SMSs/respondents including scientists from Indian Council of Agricultural Research (ICAR), State Agricultural University (SAUs), Krishi Vigyan Kendras (KVKs), Officials of State Departments of Agriculture such as Subject Matter Specialist (SMS) and Agriculture Development Officer (ADO) working under rice-wheat system were selected randomly from four districts of Haryana.

Constraints were operationalized as irresistible forces perceived by the SMSs impeding sustainability of rice-wheat cropping system. It was ascertained by asking questions to SMS/respondent using personal interview technique on various issues (bio-physical, socio-economic, technological, input and extension constraints) reflecting the productivity of rice and wheat crops. The constraints ascertained through interview were given score on the basis of severity i.e. very serious (3), serious (2) and least serious (1). Every constraint was given rank on the basis of weighted mean score by multiplication of frequency with the score of severity of the constraint then sums all the value of a particular constraint and divided the obtained value by number of respondents. For example, low organic matter had a frequency of 19, 19 and 2 under very serious, serious and least serious score, respectively. The score of very serious, serious and least serious is 3, 2 and 1, respectively then the total score of this particular constraint will be $(19x3 + 19x2 + 2x1) \div 40 = 2.43$ (weighted mean score). In this way, the total weighted mean score of all the constraints was calculated for ranking.

Results and discussion

An attempt was made to identify the constraints in sustainability of rice-wheat cropping system as perceived by the SMS/Experts. The constraints were classified into five major categories viz; bio-physical, socio-economic, input, technological and extension constraints. The results are described hereunder.

Bio-physical constraints

Amongst ten identified constraints, on the basis of rank, SMSs perceived that declining groundwater table depth ranked 1st followed by low organic matter, erratic power supply, erratic rainfall, low micro nutrients, poor soil microflora, poor soil fertility, poor quality of irrigation water, lack of canal irrigation water facility and poor drainage facility (Table 1). Singh (2010a) and Gupta (2012) reported declining water table in Haryana. Erenstein (2009) has also reported water as a major concern for the sustainability of the rice-wheat production systems. Abrol (1999) and Ahmad *et al.* (2007) have mentioned that prevailing irrigation sources are putting tremendous pressure on groundwater supplies in both Haryana and Punjab. In Punjab, rice-wheat system has showed an overall decline in water productivity from 1967 to 1994 (Ali and Byerlee, 2000). The root cause of land degradation in the rice-wheat system is policy decision, environment and associated incentives that encouraged inappropriate land use and injudicious use of water and other resources (Datta and Jong, 2002; Pingali and Shah, 2001). Exploitation of natural resources contributed to soil degradation (Murgai *et. al.,* 2001). Indiscriminate use of high analysis chemical fertilizers resulted in deficiency of nutrients other than the ones applied and caused decline in the organic carbon content (Singh *et. al.,* 1999). Decreasing soil fertility has been reported as one of the major reason for decline in yields (Sheoran, 2003).

Table 1. Bio-physical constraints perceived by SMS/experts in sustainability of rice-wheat cropping system

Constraints	Very serious	Serious	Least serious	Rank (Wt. mean score)
Declining groundwater depth	36 (90.00)	4 (10.00)	0	I (2.90)
Poor quality of irrigation water	3 (7.50)	25 (62.50)	12 (30.00)	VIII (1.78)
Lack of facility of canal irrigation water	3 (7.50)	25 (62.50)	12 (30.00)	VIII (1.78)
Poor soil fertility (NPK)	8 (20.00)	21 (52.50)	11(27.50)	VII (1.93)
Low organic matter	19 (47.50)	19 (47.50)	2 (5.00)	II (2.43)
Low micro-nutrients	5 (12.50)	30 (75.00)	5 (12.50)	V (2.00)
Poor soil microbial flora	9 (22.50)	21 (52.50)	10 (25.00)	VI (1.98)
Erratic rainfall	9 (22.50)	26 (65.00)	5 (12.50)	IV (2.10)
Erratic power supply	11 (27.50)	26 (65.00)	3 (7.50)	III (2.20)
Poor drainage facilities	2 (5.00)	17 (42.50)	21 (52.50)	IX (1.53)

Figures in parenthesis indicate percentage

Socio-economic constraints

Amongst four identified socio-economic constraints, the response of SMS/experts was higher for non availability of labour followed by proper marketing of the produce, non availability of farm machinery on hired basis at proper time and non availability of crop loan, as per the ranking (Table 2).

Input constraints

The data given in Table 3 indicated that amongst seven identified input constraints, the response of SMS/experts about non availability of seeds of recently released varieties (ranked 1st) was highest followed by the poor quality of seed, poor quality of herbicides, imbalanced use of fertilizers, poor quality of pesticides and fertilizers and non availability of nitrogen/phosphorus at desired time. Diagnostic surveys (Yadav *et. al.,* 2000) have indicated that rice-wheat farmers in the IGP seldom adopt recommended fertilizer doses and potassium fertilizers are rarely used. In a recent survey by Singh et al. (2010), Haryana farmers indicated that they used on an average 165.7 kg N ha^{-1} and 12.5 kg P ha^{-1} with wheat, and only 9.2% of the farmers surveyed used K-fertilizers. Fertilizer use pattern for rice-wheat system in the IGP varies greatly from one part to another. Kumar *et al*. (2007) also found

Table 2. Socio-economic constraints perceived by SMS/experts in sustainability of rice-wheat cropping system

Constraints	Very serious	Serious	Least serious	Rank (Wt. mean score)
Non availability of labour	19 (47.50)	14 (35.00)	7 (17.50)	I (2.30)
Non availability of farm machinery on hired basis at proper time	1 (2.50)	17 (42.50)	22 (55.00)	III (1.48)
Non availability of crop loan	0	17 (42.50)	23 (57.50)	IV (1.43)
Lack of proper marketing of the produce	5 (12.50)	19 (47.50)	16 (40.00)	II (1.73)

Figures in parenthesis indicate percentage

Table 3. Input constraints perceived by SMS/experts in sustainability of rice-wheat cropping system

Constraints	Very serious	Serious	Least serious	Rank (Wt. mean score)
Non availability of seeds of recently released varieties	15 (37.50)	14 (35.00)	11 (27.50)	I (2.10)
Poor quality of seed	10 (25.00)	21 (52.50)	9 (22.50)	II (2.03)
Non availability of nitrogen/ phosphorus at desired time	2 (5.00)	12 (30.00)	26 (65.00)	VI(1.40)
Poor quality of fertilizers	2 (5.00)	9 (22.50)	29 (72.50)	VII(1.33)
Imbalanced use of fertilizers	5(12.50)	24(60.00)	11(27.50)	IV (1.85)
Poor quality of herbicides	7(17.50)	22(55.00)	11(27.50)	III (1.90)
Poor quality of pesticides	2 (5.00)	15(37.50)	23(57.50)	V (1.48)

Figures in parenthesis indicate percentage

Table 4. Technological constraints perceived by SMS/experts in sustainability of rice-wheat cropping system

Constraints	Very serious	Serious	Least serious	Rank (Wt. mean score)
Poor plant population	3 (7.50)	28(70.0)	9(22.50)	IV (1.80)
Late sowing/transplanting	10(25.00)	30(75.00)	0	I (2.25)
Increasing incidence of insect, pest and diseases	13(32.50)	23(57.50)	4(10.00)	II (2.23)
Faulty tillage method	2 (5.00)	15(37.50)	23(57.50)	VI (1.48)
Faulty irrigation methods	5(12.50)	16(40.00)	19(47.50)	V (1.65)
Lack of land leveling	4 (10.00)	31(77.50)	5(12.50)	III (1.98)

Figures in parenthesis indicate percentage

Table 5. Extension constraints perceived by SMS/experts in sustainability of rice-wheat cropping system

Constraints	Very serious	Serious	Least serious	Rank (Wt. mean score)
Lack of knowledge among farmer about newly released technologies	6(15.00)	22(55.00)	12(30.00)	II (1.85)
Poor information supply by extension worker	3 (7.50)	19 (47.50)	18(45.00)	IV (1.63)
Training programme not as per need	1(2.50)	19 (47.50)	20(50.00)	VI (1.53)
Lack of extension literature	1(2.50)	21 (52.50)	18(45.00)	V (1.58)
Poor participation in exposure visits arranged by various deptts	2 (5.00)	23(57.50)	15(37.50)	III (1.68)
Poor participation in kisan gosthi/ field day/ training/ kisan melas	6(15.00)	25(62.50)	9(22.50)	I (1.93)

Figures in parenthesis indicate percentage

shortage of quality seed and adulteration of fertilizers as major constraints in wheat production in eastern India.

Technological constraints

The data given in Table 4 indicated that amongst six identified technological constraints, response by SMS/experts was highest for the late sowing/transplanting followed by increasing incidence of insect, pest and diseases, lack of land leveling, poor plant population, faulty irrigation and tillage practices. Gupta (2012) reported that late planting of cereals as the production system constraint.

Extension constraints

Amongst six identified constraints, SMS response was highest for the poor participation in *kisan gosthi*, field day, trainings and *kisan melas* followed by lack of knowledge among farmers about newly released technologies, poor participation in exposure visits arranged by various departments, poor information supplied by extension worker, lack of extension literature and training programmes not as per need (Table 5). Investments in agricultural research and extension are needed to make South Asia's irrigated production systems more sustainable (Erenstein, 2010). Murgai *et al.* (2001) also suggested policy decisions that promote agricultural productivity and sustainability through public investments in education, research and extension.

Overall constraints

In order of rank, amongst five identified major constraints, bio-physical constraints ranked 1st followed by technological, input, socio-economic and extension constraints (Table 6). Further analysis indicated that input and socio-economic constraints had the same score.

Table 6. Overall constraints perceived by SMS/experts in sustainability of rice-wheat cropping system

Constraints	Very serious	Serious	Least serious	Rank (Wt. mean score)
Bio-physical constraints	11(27.50)	21(52.50)	8(20.00)	I (2.08)
Socio-economic constraints	6(15.00)	17(42.50)	17(42.5)	III (1.73)
Input constraints	6(15.00)	17(42.50)	17(42.50)	III (1.73)
Technological constraints	6(15.00)	24(60.0)	10(25.00)	II (1.90)
Extension constraints	3 (7.50)	22(55.00)	15(37.50)	IV (1.70)

Figures in parenthesis indicate percentage

Conclusions

Amongst the constraints perceived by the Subject Matter Specialists, declining groundwater depth, non-availability of labour, non availability of seeds of newly released varieties, late sowing/transplanting and poor participation in kisan gosthi/ field day/ training/ kisan melas were found to be the major constraints in sustainability of rice-wheat cropping system in the studied districts of Haryana. To increase wheat and rice productivity in Haryana, the State Department of Agriculture should ensure good quality of seeds, fertilizers and pesticides apart from the quality information about the newly released technologies to the farmers to sustain the rice-wheat cropping system.

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Effect of various levels of zinc and sulphur on the rice in partially amended Typic Natrustalf of Uttar Pradesh

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ABSTRACT

Individual and interactive response of different levels of zinc and sulphur on the yield, yield attributes, nutrients uptake and statistical relationship between various factors of rice variety 'Sarjoo-52' were studied. Application of 8 kg zinc ha^{-1} significantly enhanced grain and straw yields along with yield attributing characteristic and zinc uptake. Similarly, significant response of rice to sulphur addition was also recorded up to 8 kg ha^{-1}. Increasing levels of zinc and sulphur significantly increased their uptake by rice crop. The interaction effect of zinc and sulphur was non-significant and the highest grain and straw yields were recorded with the combined application of each zinc and sulphur @ 8 kg ha^{-1}. The uptake of nitrogen and phosphorus by rice crop enhanced markedly with zinc and sulphur addition. The uptake of nutrients and yield attributes along with quality parameter of grain were found to be significantly correlated with each other.

Key words: rice, sodic soil, sulphur, zinc

Introduction

Salt-affected soils are wide spread in Uttar Pradesh, Haryana and Punjab states of India. A vast chunk of productive agricultural lands in these states have gone out of cultivation due to the problem of sodicity. The sodic soils are characterized by high pH throughout the soil profile, high exchangeable sodium, low soil organic matter content and sparse vegetation. Sodic soils pose many limitations to crop growth due poor physical conditions, low soil fertility and the toxic effects of exchangeable sodium. Alkali soils can be identified by the presence of white or dull white crust of sodium bicarbonate, sodium carbonate, or both salts on the surface. They have low permeability and poor physical conditions caused by deflocculation of the sodium ion. Due to excess exchangeable sodium, the soil tends to become more dispersed which results in the breakdown of soil aggregates and lowers the permeability of the soil to air and water. A second effect of excess exchangeable sodium on plant growth is that it frequently results in lowering the availability of some essential plant nutrients (Abrol *et al*., 1988). In sodic soils, the availability of N, Zn and S to plants is extremely poor. Rice crop is preferably grown on sodic soils because it is tolerant to sodicity and has reclamation effect. Zinc deficiency has been recognized as an important and wide spread nutritional disorder of rice. Sulphur availability is also a serious problem in plant nutrition in soils poor in organic matter. The response of combined application of zinc and sulphur had been studied by several researchers on various crops but the information gathered on interactions between Zn and S on upland rice in partially amended sodic soils is scanty. Therefore, the present study was undertaken to evaluate the effect of various levels of zinc and sulphur on the rice in partially amended Typic Natrustalf of Uttar Pradesh.

Material and methods

A field experiment was conducted for two consecutive kharif seasons of 2005 and 2006 as a fixed layout with partially amended sodic soil of Regional Research Station, Dalipnagar, C.S. Azad University of Agriculture and Technology, Kanpur using high yielding rice cultivar 'Sarjoo-52'. The soil was classified as Typic Natrustalf. The initial physico-chemical characteristics of the soil were pH-9.8, EC- 6.75 dSm^{-1}, ESP- 45%, CEC-13.25 C mol (p+) Kg^{-1} and organic carbon- 0.25 mg kg^{-1} soil. The hydraulic conductivity was 0.28 cm ha^{-1}. The soil was clay loam having available NP&K-132, 8.55 and 290 kg ha^{-1}, respectively. Available S and DTPA-Zn were 0.18 & 0.32 mg kg^{-1}, respectively. The treatments consisted of four levels each of Zn & S (0, 4, 8 and 12 kg ha^{-1}) through zinc sulphate and elemental sulphur, respectively. N, P_2O_5 and K_2O were applied @ 120, 60 and 60 kg ha^{-1}. Initially full dose of P_2O_5 and K_2O were applied at the time of transplanting of 35 days old seedling through DAP & MOP, respectively and half dose of N through DAP &

Urea. Remaining half dose of N was applied in two equal splits at maximum tillering and pre-flowering stages of rice crop. At maturity, grain and straw yields were recorded. Grain and straw were analyzed for N content by modified Kjeldahl's method and phosphorus content by Vanado-molybdate yellow colour method. Sulphur was determined turbidimetrically and zinc was estimated by Atomic Absorption Spectrophotometer (Lindsay and Norvell, 1978).

Results and discussion

Data pertaining to yield, yield attributing characteristics and dry matter accumulation at various growth stages of rice 'Sarjoo-52' are presented in Tables 1 and 2. Increasing levels of zinc significantly increased the average grain yield of rice from 42.45 to 52.92 q ha^{-1} in first year and from 44.95 to 55.47 q ha^{-1} in second year of the experimentation. The average grain yield of rice was statistically at par at 8 and 12 kg zinc ha^{-1}. Hence, 8 kg zinc ha^{-1} may be suitable dose for enhancing the grain yield of rice 'Sarjoo-52'. The straw yield under the influence of various doses of zinc varied from 53.05 to 64.60 q ha^{-1} in the first year and 56.17 to 67.62 q ha^{-1} in the second year. The average grain and straw yield response at 8 kg zinc level was 10.49 and 11.50 q ha^{-1} with corresponding per cent yield response 24.01 and 21.05, respectively. Increasing level of zinc sulphate up to 50 kg ha^{-1} enhanced the yield and yield attributes of rice cultivars significantly in partially reclaimed sodic soil (Sing *et al*., 1995). Singh and Triapthi (2005) also reported that basal addition of zinc sulphate up to 50 kg ha-^{1} significantly increased the yield and nutrient uptake in comparison to control and broadcasting application. Application of varying levels of sulphur in partially amended sodic soil exhibited beneficial effect on grain as well as straw yield of rice 'Sarjoo-52'. The grain and straw yield increased progressively with increasing levels of sulphur up to 8 kg ha^{-1} during both the kharif seasons. The average grain and straw yield response due to sulphur application varied from 4.17 to 8.47 and 5.14 to 10.38 q ha^{-1}, respectively. However, the corresponding percentage yield response of zinc was more pronounced than that of sulphur. Corresponding percentage of yield response due to sulphur addition ranged from 9.30 to 18.80 and 9.76 to 19.34 in grain and straw, respectively. The findings of experiment conducted by Singh and Singh (2002) and Jena *et al*. (2006) also revealed that application of various levels of zinc and sulphur markedly increased the yield and yield components and nutrient uptake by rice cultivars in partially amended sodic soil. The response was more pronounced at 8 kg ha^{-1} of zinc and sulphur both.

Table 1. Response of zinc and sulphur on the grain and straw yield of rice 'Sarjoo-52'

Treatments	Kharif 2005					Kharif 2006					Average yield response		Corresponding percentage yield response	
Zinc levels kg ha^{-1}	Sulphur levels (kg ha^{-1})					Sulphur levels (kg ha^{-1})								
	0	4	8	12	Mean	0	4	8	12	Mean	Zn	S	Zn	S
						Grain yield (q/ha^{-1})								
0	37.6	41.0	45.3	45.9	42.45	40.2	43.5	47.7	48.4	44.95	-	-	-	-
4	42.0	46.0	50.9	51.2	47.52	45.0	49.3	53.9	54.4	50.65	5.38	4.17	12.32	9.30
8	47.6	52.0	56.4	55.8	52.92	50.3	54.8	58.6	58.2	55.47	10.49	8.47	24.01	18.88
12	46.8	51.6	56.1	55.2	52.42	49.7	54.3	58.0	57.0	54.75	9.88	8.37	22.62	18.65
Mean	43.47	47.65	52.17	52.02	48.82	46.30	50.47	54.55	54.50	51.45	8.58	7.60	19.66	15.61
CD at 5%														
Zn						1.436					1.512			
S						1.432					1.507			
Zn x S						1.957					1.978			
						Straw yield (q/ha^{-1})								
0	47.0	51.20	56.6	57.4	53.05	50.2	54.4	59.6	60.5	56.17	-	-	-	-
4	51.2	56.1	62.1	62.5	57.97	54.9	60.1	65.7	66.3	61.75	5.25	5.14	9.61	9.76
8	57.9	63.4	68.8	68.3	64.60	61.3	66.8	71.4	71.0	67.62	11.50	10.38	21.05	19.34
12	56.66	62.6	67.9	66.8	63.47	60.1	65.7	70.1	68.9	66.20	10.22	10.31	18.72	19.22
Mean	53.17	58.32	63.85	63.75	59.77	56.62	61.75	66.70	66.67	62.93	8.99	8.61	16.46	16.10
CD at 5%														
Zn						1.635					1.820			
S						1.639					1.826			
Zn x S						2.387					2.427			

Table 2. Response of zinc and sulphur levels on the yield components and dry matter accumulation of rice 'Sarjoo-52'

Treatments	Productive tillers/m^2			Number of filled grains/panicle			Test weight of 1000-grains (g)			Dry matter accumulation (g/m^2) Tillering stage			Dry matter accumulation (g/m^2) Flowering stage		
	2005	2006	Mean	2005	2006	Mean	2005	2006	Mean	2005	2006	Mean	2005	2006	Mean
Zinc levels (kg ha^{-1})															
0	230	245	237.5	72	92	82.0	23.2	25.5	24.3	540	550	545.0	582	591	586.5
4	265	277	271.0	95	120	107.5	28.7	31.0	29.8	585	602	593.5	620	630	625.0
8	290	309	299.5	128	155	141.5	35.2	39.3	37.2	618	638	628.0	649	665	657.0
12	305	320	312.5	134	160	147.0	37.3	41.4	39.3	630	645	637.5	656	673	664.5
Mean	272.5	2877	-	107.2	131.7	-	31.1	34.3	-	593.2	616.7	-	626.7	639.7	-
CD at 5%	12.3	13.4	-	3.6	4.5	-	NS	NS	-	26.3	27.5	-	28.0	29.3	-
Sulphur levels (kg ha^{-1})															
0	242	254	248.0	68	85	76.5	25.3	26.7	26.0	532	540	536.0	575	583	579.0
4	269	278	273.5	98	117	107.5	29.9	31.6	30.7	580	595	587.5	616	635	625.5
8	309	323	316.0	133	167	150.5	34.7	38.7	36.7	623	636	629.5	661	670	665.5
12	320	331	325.5	138	171	154.5	36.1	40.8	34.4	635	643	639.0	672	684	678.0
Mean	28.7	296.5	-	109.0	135.0	-	31.5	34.4	-	529.5	603.5	-	631.0	644.2	-
CD at 5%	13.0	14.2	-	3.9	4.7	-	NS	NS	-	26.8	27.7	-	28.8	30.8	-

Yield attributing characteristics

Variability in the yield attributing characteristics *viz*., productive tillers/m^2, number of filled grains/panicle, dry matter accumulation and test weight of grains are very important for improving the yield since these contribute directly to grain yield. The maximum productive tillers/m^2, number of filled grains/panicle and test weight of 1000 grains were noticed in the plot treated with 8 kg zinc ha^{-1} followed by 12 and 4 kg zinc ha^{-1} during both the kharif seasons. Increasing levels of sulphur significantly increased these attributing characteristics up to 8 kg S ha^{-1}. These characters did not differ significantly at 12 kg S ha^{-1}. Response of sulphur levels was more pronounced than that of zinc levels. The average values of both the year of productive tillers/m^2, number of filled grains/panicles and test weight ranged from 248.0 to 325.5, 76.5 to 154.5 and 26.0 to 38.4 g, respectively due to various levels of sulphur application. Although each levels of zinc and sulphur significantly enhanced the dry matter accumulation in plants up to 8 kg, ha^{-1}, application of each zinc and sulphur @ 12 kg ha^{-1} did not differ significantly from that of 8 kg ha^{-1}. The accumulation of dry matter in plants of rice 'Sarjoo-52' at flowering stage under the influence of each level of zinc and sulphur were more than that of tillering stage of crops. These results corroborate with the findings of Dwivedi *et al*. (2002).

Uptake of nutrients

It is evident from the data in Table 3 that increasing levels of zinc application increased the uptake of nitrogen, phosphorus, sulphur and zinc by grain and straw during both the seasons of experimentation. Uptake of nitrogen by grain and straw under the influence of zinc application varied from 90.7 to 118.4 and 30.0 to 39.8%, respectively during first year and 97.8 to 123.2 and 33.6 to 42.2 kg ha^{-1}, respectively during second year of experiment. Phosphorus uptake by grain ranged between 14.3 to 18.9 and 15.0 to 19.2 during first and second year, respectively. The sulphur uptake also increased due to zinc application. It varied from 16.8 to 25.7, 13.2 to 28.0 kg ha^{-1}during first year and 10.8 to 26.3, 13.9 to 28.9 kg ha^{-1}during second year, respectively. The maximum sulphur uptake was observed when it was applied @ 12 kg ha^{-1} during both the seasons. Increasing zinc level increased its uptake by grain up to 12 kg zinc ha^{-1} during both the years. On the other hand, uptake of Zn by straw was highest at 8 kg Zn ha^{-1}. These findings are in accordance with the reports of Dubey and Chauhan (2002) and Singh and Tripathi (2005). Application of zinc enhanced the total uptake of N by rice during both the years. This increase in N uptake may be attributed to increased N content in grain and straw yield. The phosphorus uptake by grain was also increased with zinc application up to 8 kg ha^{-1} level during both crop season but it decreased at higher level which might be due to antagonistic effect of zinc.

Increasing levels of sulphur significantly increased the uptake of nitrogen, phosphorus, zinc and sulphur by grain and straw of rice Sarjoo-52. The increase in sulphur uptake may be attributed to enhanced sulphur content in rice plants along with dry matter accumulation. The uptake of sulphur was also affected markedly by the addition of zinc sulphate. The uptake of sulphur by grain and straw increased up to 8 kg zinc ha^{-1} and decreased at higher level due to antagonistic effect of zinc on sulphur. The increase in nitrogen and phosphorus uptake might be attributed to increase in N and P content in plant and

Table 3. Response of zinc and sulphur on the uptake nutrients by rice 'Sarjoo-52'

Treatments	N uptake (kg ha^{-1})				P uptake (kg ha^{-1})				Zn uptake (g ha^{-1})				S uptake (kg ha^{-1})			
	Grain		Straw		Grain		Straw		Grain		Straw		Grain		Straw	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
Zinc levels (kg ha^{-1})																
0	90.7	97.8	30.0	33.6	14.3	15.0	6.0	6.8	104.2	107.2	73.8	78.3	16.8	18.0	13.2	13.9
4	103.0	109.7	34.7	37.8	17.4	18.6	7.5	7.8	133.7	137.6	100.2	108.8	23.8	24.2	22.2	23.7
8	115.5	120.0	38.9	43.8	18.9	19.2	7.7	8.2	153.8	159.6	132.5	139.8	25.7	26.3	28.0	28.9
12	118.4	123.2	39.8	44.2	17.4	17.9	8.0	8.3	182.5	188.4	127.3	132.9	20.0	20.8	27.3	28.0
Mean	106.90	112.67	35.85	39.85	17.0	17.7	7.3	7.8	143.5	148.2	108.4	114.9	21.6	22.3	22.7	23.6
CD at 5%	1.90	2.8	0.43	0.48	0.22	0.26	0.16	0.18	2.23	2.62	1.81	1.93	0.30	0.40	0.25	0.32
Sulphur levels (kg ha^{-1})																
0	92.0	96.2	31.0	34.2	15.0	15.8	6.7	6.9	144.2	148.0	112.2	114.7	15.0	16.8	9.3	10.0
4	13.7	108.8	32.5	37.8	17.8	18.7	7.0	7.3	147.3	150.4	118.5	122.6	22.3	22.9	14.6	14.8
8	116.5	121.7	35.6	34.4	18.2	19.1	7.5	7.9	152.5	155.7	122.4	127.2	27.0	28.0	20.2	21.0
12	119.0	125.4	39.0	46.6	17.8	17.6	7.7	8.0	150.6	153.0	119.0	124.3	29.5	30.2	21.4	21.9
Mean	107.8	113.0	34.5	39.2	17.2	17.8	7.2	7.5	148.6	151.8	118.0	122.2	23.4	24.5	16.4	16.9
CD at 5%	1.90	2.08	0.43	0.42	0.22	0.26	0.16	0.18	2.23	2.62	1.81	1.93	0.30	0.40	0.25	0.32

Table 4. Integrated response of zinc and sulphur levels on the statistical relationship between yield and yield attributes alongwith chemical characteristics of rice 'Sarjoo-52"

S. No.	Relationship between	Correlation coefficient (r)		Regression equation (y)	
		2005	2006	2005	2006
1.	Nos. of productive tillers (χ) and grain yield (y)	0.785**	0.789**	Y=1.34 χ+5.50	Y=1.37 χ+5.20
2.	Ear bearing tillers (χ) and grain yield (y)	0.799**	0.81**	Y=1.68 χ+6.5	Y=1.71 χ+7.22
3.	Nos. of filled grains (χ) and grain yield (y)	0.887**	0.890	Y=0.32 χ+7.21	Y=0.39 χ+7.17
4.	Test weight of grains (χ) and grain yield (y)	0.962**	0.969**	Y=0.27 χ+7.31	Y=0.33 χ+7.70
5.	Total uptake of N (χ) and grain yield (y)	0.865**	0.870**	Y=102.30 χ -30.39	Y=105.10 χ-34.0
6.	Total uptake of P (χ) and grain yield (y)	0.890**	0.897**	Y=108 χ-18.7	Y=1.10 χ-22.7
7.	Total uptake of Zn (x) and grain yield (y)	0.852**	0.860**	Y=78.2 χ+6.70	Y=80.1 χ+8.10
8.	Total uptake of S (χ) and grain yield (y)	0.877**	0.884**	Y=85.3 χ+9.20	Y=87.7 χ+10.27
9.	Grain yield (χ) and straw yield (y)	0.967**	0.972**	Y=20.2 χ+16.20	Y=22.5 χ+17.3
10.	Percentage of protein (χ) and percentage of starch (y)	-0.625**	-0.630**	Y=39 χ+20.2	Y=39.9 χ+23.0
11.	Percentage of protein (χ) and mineral matter (y)	0.957**	0.962**	Y=0.70 χ+9.20	Y=0.79 χ+10.30
12.	Percentage of protein (χ) and Nitrogen content (y)	0.972**	0.978**	Y=2.37 χ+12.0	Y=3.0 χ+13.5

grain of rice 'Sarjoo-52' due to rising sulphur levels. Such type of synergistic relationship among N, P and S have been observed by Singh and Singh (2002) and Jena *et al*. (2006).

Data presented in Table 4 revealed that grain and straw yields of rice were significantly correlated with number of tillers, ear bearing tillers, filled grains and test weight of grains etc. during both the years. Nitrogen, phosphorus, zinc and sulphur uptake by rice grain and straw also showed positive correlation during both the crop seasons. However, protein and nitrogen content in grain exhibited positive correlation but starch and protein were negatively correlated. Application of zinc and sulphur had positive response on the content of protein, starch and mineral matter of rice grain, probably because of their role in synthesis of these constituents (Tripathi and Tiwari, 2002) and Nayyar (1999).

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Saturated hydraulic conductivity of saline–sodic soils as influenced by microbial application with gypsum

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ABSTRACT

Microbial application for the amelioration of sodic and saline-sodic soils may reduce the economic and environmental costs of chemical amendments. The effect of microbial application on saturated hydraulic conductivities of four different saline-sodic soils which were being ameliorated with gypsum was stud- ied. Suspensions of three fungal isolates (*Aspergillus spp.* FS 9, 11 and *Alternaria spp.* FS 8) and two bacterial strains (*Bacillus subtilis* OSU 142 and *Bacillus megaterium* M3) at 10^4 spore/ml and 10^9 CFU/ml, respectively, were mixed with leaching water and applied to the soil columns. The measured saturated hydraulic conductivities of soil columns after the treatment indicated that saturated hydraulic conductivity of saline-sodic soils increased significantly ($P< 0.01$) by application of the microorganisms. Average increase for all soils was 68%. The data suggest that microorganisms tested in the present study may have potential to help improve water movement through saline-sodic soils.

***Key words*:** microorganisms, remediation, saline-sodic soils, saturated hydraulic conductivity

Introduction

Soil degradation resulting from salinity, sodicity, or a combination of both, is a major impediment to optimal utilization of land resources. Salt-affected soils exist mostly under arid and semi-arid climates, in more than 100 countries, and on all the continents except Antarctica (Qadir and Oster, 2002). Currently, at least 20% of the world's irrigated land is salt-affected. Among those affected by salt, about 60% are sodic (Qadir *et al.*, 2006).

Sodic and saline-sodic soils are characterized by reductions in hydraulic conductivity and inûltration rate. These soils contain large amounts of exchangeable sodium. Soil dispersion is the primary physical process associated with high sodium concentrations. Dispersed clay particles cause plugging of the soil pores resulting in impeded water flow and inûltration into the soil (Warrence *et al.*, 2002).

Over the past 100 years, different site specific approaches-involving the use of chemical amendments, tillage, crop diversification, water, and electrical currents-have been used to ameliorate sodic and saline-sodic soils. Of these, chemical amendments have been used most extensively (Oster *et al.*, 1999; Qadir and Oster, 2002; Qadir *et al.*, 2006).

Chemical amelioration of sodic and saline-sodic soils is done by providing a source of calcium to replace excess sodium from the cation exchange sites. The replaced sodium is leached from the root zone through excess irrigation, a process that requires adequate ûow of water through the soil (Qadir and Oster, 2004; Qadir *et al.*, 2006).

Chemical reclamation has become costly for subsistence farmers in developing countries. Amendment costs have increased because of greater usage by industry and reductions in government subsidies to farmers (Qadir and Oster, 2002). Gypsum, an economical alternative for replacing sodium with calcium (Gharaibeh *et al.*, 2009; Oad *et al.*, 2002), has low solubility which can limit its efficiency. In order to provide more active Ca from gypsum amendments and other non-soluble compounds, the possibility of exploiting plants and microorganisms is under investigation. The use of plant metabolites as a strategy to ameliorate saline-sodic soils was reviewed by Qadir *et al.* (2001), Qadir and Oster (2002) and Qadir *et al.* (2003). Although some plants were screened for their potential to be used in amelioration, little information is available on the possible effects of microbial-based treatments. Syed *et al.* (2003) reported successful trials on amelioration of saline-sodic soils where a mixture of different microorganisms was applied to soil without gypsum. Furthermore, experiments conducted with blue-green algae resulted in augmented solubility of gypsum which provided better amelioration for the sodic soils (Subhashini and Kaushik, 1981). In another trial, contrary

Table 1. Some physical and chemical properties of the soils studied

Properties	Soil type			
	Soil I	Soil II	Soil III	Soil IV
Clay (%)	23.6	29.8	30.7	20.8
Silt (%)	39.0	41.9	38.0	40.1
Sand (%)	37.4	28.3	31.3	39.1
Texture	Loam	Clay loam	Clay loam	Loam
pH	9.0	9.5	9.9	8.8
EC (dS m^{-1})	5.3	42.8	36.3	23.7
CEC (cmol $_{(p+)}$ kg^{-1})	36.2	41.3	39.1	27.5
ESP (%)	47.5	55.5	59.3	24.7
$CaCO_3$ (%)	5.6	9.6	8.3	4.8
Organic matter (%)	0.6	0.5	0.4	0.9

results to that study were attributed to inability of the transferred bacteria to colonize in the soil (Rao and Burns, 1991).

The aim of this work was to study the effect of microbial mixtures, including fungi and bacteria transferred by leaching water in gypsum ameliorated conditions, on saturated hydraulic conductivities in four different saline-sodic soils.

Material and methods

Soils

Four samples from 0 to 30 cm top layer of soils with different salinity and sodicity levels (Typic Natrargids) were collected from the Igdir plain in northeast Turkey. This is an important agricultural production area that covers 68,000 ha of irrigated land at a mean slope of 0.1%. The mean elevation is 850 m. About 36% of these soils (25,000 ha) suffer from some degree of salinity and/or sodicity (Ardahanlioglu *et al.*, 2003). Soil humidity and temperature regimes are defined as Aridic and Thermic (Soil Survey Staff, 1999).

Selected soil properties were determined (Table 1). The particle size analysis was done using hydrometer method (Gee and Bauder, 1986). Soil pH and electrical conductivity (EC) were measured in saturation extracts (Mc Lean, 1982; Rhoades, 1982a), cation exchange capacity (CEC) by sodium acetate method (Rhoades, 1982b), carbonates by calcimeter method (Nelson, 1982), and organic matter by wet combustion method (Nelson and Sommers, 1982). Exchangeable sodium percentage (ESP) was calculated as the percentage of exchangeable sodium in total cation exchange capacity (Knudsen *et al.*, 1982).

Packing of soil columns

Air-dried soil that had been sieved through a 1 cm mesh was packed into twenty-four drainage type chrome columns (60 cm in length×10 cm in diameter) to a depth of 30 cm (Fig. 1). The bottom of each column was padded with a 5cm layer of gravel and sand to facilitate leaching. The soil columns were tapped 25 times after each 10 cm soil was added. The bulk densities of the columns were 1.36, 1.31, 1.32 and 1.41 g cm^{-3} for soils I, II, III and IV, respectively. The particle size of gypsum used was smaller than 0.5 mm (Hira and Singh, 1980; Sahin *et al.*, 2003). Gypsum was incorporated into the surface 2-3 cm of soil at rate equivalents to 41.28, 56.53, 58.99 and 9.70 Mg ha^{-1} for soils I, II, III and IV, respectively. Calculations of the gypsum requirement were made considering the cation exchange capacity, exchange efficiency, and the initial and

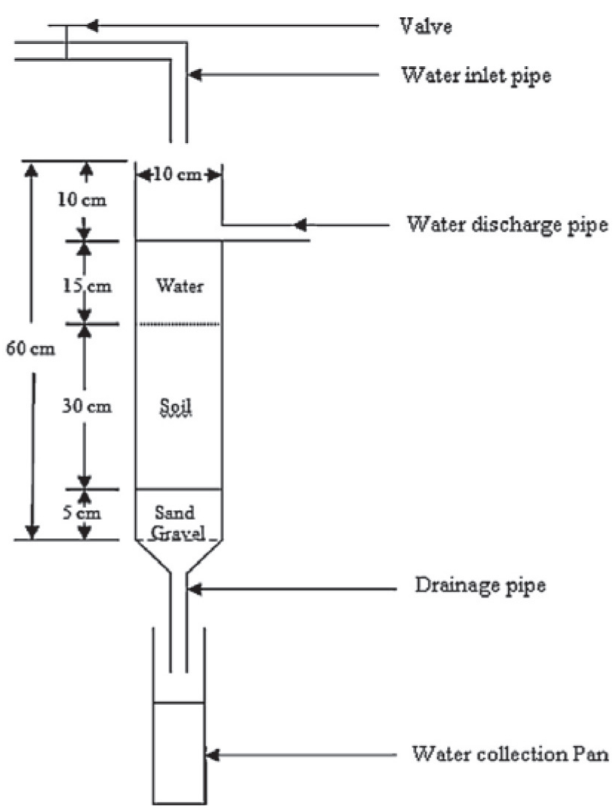

Fig. 1. Vertical section of a column used in experiment

final exchangeable sodium percentage (ESP) using the gypsum requirement equation described by Oster and Jayawardane (1998) and applied by Lebron *et al.* (2002):

$$GR = 0.0086 \times F \times D \times \gamma_s \times (CEC) \times (ESP_i - ESP_f)$$

where GR is the gypsum requirement, F is a Ca–Na exchange efficiency factor and for this case was considered equal to 1, D is the depth of the soil to be reclaimed, γ_s is the soil bulk density, CEC is the cation exchange capacity, and ESP_i and ESP_f are the initial and final exchangeable sodium percentage.

Preparation of microorganisms

Two bacterial strains (*Bacillus subtilis* OSU-142 and *Bacillus megaterium* M3) and three fungal isolates (*Aspergillus spp.* FS 9, 11 and *Alternaria spp.* FS 8) were obtained from the microorganism culture collection unit in the Department of Plant Protection at Atatürk University, Erzurum, Turkey. These microorganisms have been reported as plant growth promoting bacteria and/or potential bio-control agents against a wide range of bacterial and fungal pathogens that cause economically important problems in agriculture (Aslantas *et al.*, 2007; Cuppels *et al.*, 1999; Esitken *et al.*, 2003, 2006; Kotan *et al.*, 1999; Orhan *et al.*, 2006; Turan *et al.*, 2006). Bacteria were grown on nutrient agar (NA) for routine use, and maintained in nutrient broth (NB) with 15% glycerol at -86 ^{0}C for long-term storage. For each experiment, a single isolated colony was transferred to 500 mL flasks containing NB, and grown aerobically in flasks on an orbital shaker (150 rpm) for 48 h at 27 ^{0}C (Merck KGaA, Germany). The bacterial cells were first centrifuged at 20,800×g for 5min, and then re-suspended in sterile distilled water to a final concentration of 109 CFU/mL. The fungal isolates were cultivated on PDA (potato dextrose agar) for 3 days at 27 ^{0}C. At the time of fructification, spores were harvested by gently washing of PDA plates on 45µm sieve, and then spore suspensions of each isolate were prepared at a density of 104 spores/ml in sterile distilled water.

Treatments

Two main treatments, leaching water with microorganisms (MLW) and without microorganisms (LW), were conducted. A total of 45 cm leaching water as an intermittent ponding (3×15 cm) was applied to each column (Sahin *et al.*, 2002). The soils were air-dried prior to the first slice leaching water application. Water with 0.27 dS m^{-1} electrical conductivity and 0.30 sodium adsorption ratio was used as leaching water. Microorganisms (109 CFU/ml bacterial suspension + 104 spore/ml fungi) were applied to the soil columns by mixing them in the first 15 cm of leaching water for MLW treatments. Second and third slice leaching waters were applied without the addition of microorganisms 24 h following the previous application.

Saturated hydraulic conductivity measurements

A constant head method was used to measure the saturated hydraulic conductivity. The constant head of water above the surface of the soils was 15 cm. A constant head was maintained with continuous water flow from the water inlet pipe to the columns. Excess water was drained by the water discharge pipe (Fig. 1). By measuring infiltration over time, saturated hydraulic conductivity was calculated when steady state flow had been reached. Water was at atmospheric pressure at the boundary between the soil and the sand in the bottom of the columns. Outflow volumes drained from the bottom of the soil columns were used in the Darcy equation to calculate the saturated hydraulic conductivity (Ks):

$$Ks = \frac{V}{At}\left(\frac{L}{L+H}\right)$$

where V is outûow volume, A is cross sectional area of soil column, t is time, L is length of soil column, and H is height of ponded water above the surface of the soil.

Statistical analysis

Experiments were conducted in three replications using four saline sodic soils with or without the addition of microorganisms. Analysis of variance (ANOVA) was performed for data on saturated hydraulic conductivity. For the comparison of the saturated hydraulic conductivity, Duncan's tests were used.

Results and discussion

The saturated hydraulic conductivity (Ks) values of soils after leaching are shown in Fig. 2. There were significant ($P < 0.01$) changes among the soil's Ks values. According to Fig. 2, soil III with high ESP and clay content (Table 1) had a low Ks value (in agreement with Mamedov *et al.*, 2001). Soil IV, which had lower ESP and clay content (Table 1) had the highest Ks value. The higher EC and $CaCO_3$ values of soils II and III with high ESP could have had a positive effect on the Ks value. For a given sodium adsorption ratio value, the adverse impacts on soil physical properties are reduced with increasing salinity (Suarez *et al.*, 2006). Many researchers reported that water conductivity of soils decreases with increasing ESP and decreasing total electrolyte concentration of soil solution (Moutier *et al.*, 1998; Oster *et al.*, 1999; Sahin and Anapali, 2005). Soils with high ESP but with low electrolyte concentrations are unstable and show weak aggregate stability. For all of the soil columns, Ks values increased significantly ($P < 0.01$) after leaching water treatments with microorganisms (MLW, Fig. 2). Average Ks values for MLW treatments and leaching water treatments without microorganisms (LW) were 0.101 cm h^{-1} and 0.060 cm h^{-1}. Ks values of MLW treatments were higher than LW treatments at 1.3, 3.4, 2.4 and 1.6 times for soils I, II, III and IV, respectively (Fig. 2).

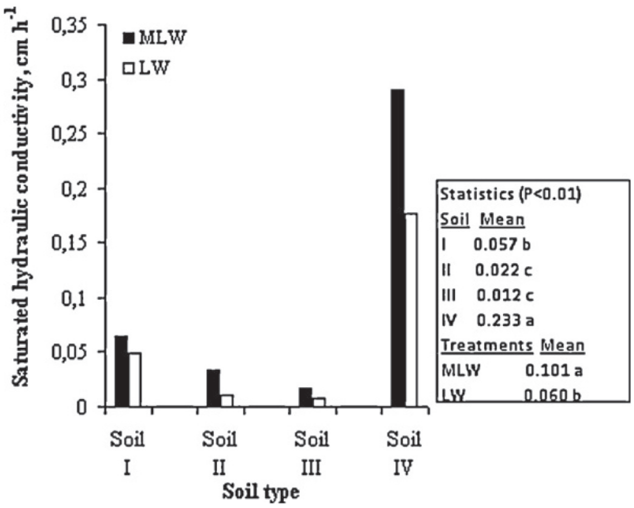

Fig. 2. Saturated hydraulic conductivities of the soils treated by leaching water with microorganism (MLW) and without microorganisms (LW)

Increase in gypsum and other calcium salts solubility via microorganisms may lead to this result. If electrolyte concentration of the percolating solution is adequate to reduce clay swelling, the permeability of the soil remains high (Abu-Sharar *et al.*, 1987; Diamantis and Voudrias, 2008; Gharaibeh *et al.*, 2009; Oster *et al.*, 1999; Quirk, 2001; Sahin and Anapali, 2005), because the concentration of calcium electrolyte maintained in the soil solution prevents the disruption of aggregates and the occlusion of pores by dispersed clay particles (Greene *et al.*, 1988). The higher ratio of Ks value of the MLW treatments compared to the LW treatments for soil II and soil III could be related to higher $CaCO_3$ contents of these soils which can be served as Ca reservoirs. A recent study showed that some of the microorganisms used in the mixture helped dissolve $CaCO_3$ (Eroglu *et al.*, 2009). The increase in the Ks values may be related to organic acids secreted by the microorganisms. Previous studies suggested that microorganisms can secrete large amounts of organic acids when confronted with stress (Ullman *et al.*, 1996). Dissolution of gypsum and $CaCO_3$ by microbial metabolics, may increase the dissolved and exchangeable calcium in the soil, facilitating replacement of sodium by calcium as assumed for a phytoremediation study (Qadir *et al.*, 2001).

Conclusions

The data of the present study demonstrated for the first time that application of a microbial mixture (three fungi isolates *Aspergillus spp.* FS 9, 11 and *Alternaria spp.* FS 8, and two bacterial strains *B. subtilis* OSU 142 and *B. megaterium* M3) other than cyanobacteria may increase Ks values of saline-sodic soils in amelioration with gypsum. The effect of microorganisms on the Ks value was most dramatic in soils with high ESP, EC and $CaCO_3$. Further field studies are needed to develop microbial application strategy for better amelioration of saline-sodic soils with gypsum.

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Socio-economic impact of reclaiming salt affected lands in India

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ABSTRACT

The salt-affected lands cover about 6.73 million ha area in India, consisting of 3.77 million ha sodic and 2.96 million ha saline soil. About half of the total sodic land has been reclaimed so far, out of which 0.8 million ha was located in Punjab, 0.6 million ha in U.P., 0.3 million ha in Haryana and remaining 0.13 million ha in other states of the country. Similarly, about 60 thousand ha of saline, waterlogged lands have been reclaimed so far. This paper reviews reclamation and rehabilitation trends of salt affected lands, technologies available for reclamation, economic feasibility and socio-economic impact of these technologies and major constraints and policy issues relating to the reclamation of sodic and saline lands in India. The study highlighted that the capital required for reclamation of sodic land is around Rs 45000 per ha, whereas it was estimated Rs 55000 per ha in case of saline soils. On an average, benefit-cost ratio of reclamation was 1.5, internal rate of return 20 percent and net present worth Rs 56000 per ha, indicating economic feasibility of the technology. The salt affected soil reclamation resulted in to 15 million tonne additional food grains production and 250 million man-days employment every year in the country as a whole. The salt affected land reclamation technology has remarkable impact on crop yield, farm income, capital formation and employment which ultimately lead to positive socio-economic changes in the salt affected areas. The major socio-economic and policy constraints affecting land reclamation were small and scattered land holdings, cost intensive reclamation technologies, defective irrigation methods and inadequate water pricing policy. A well-defined and strong integrated natural resource management system, particularly for soil and water should be evolved to prevent, monitor and rehabilitate degraded salt affected soils for sustainable agriculture.

***Key words*:** environmental benefits, saline soil, sodic soil, land reclamation, socio-economic impact,

Introduction

Man is the main culprit for degradation of our natural resources like land and water as he uses these as per their utility and capability to meet his immediate needs and wants. Preserving, protecting and defending land resources have been part of our age-old culture. There are innumerable examples of the traditional practices and systems of conservation, which still survive and are effective. But, with the advent of new forces of consumerism, a predominantly materialistic value system, short-term profit-driven motives and the greed of the users the tradition of conservation is deteriorating. As a result, land has degraded, soil fertility depleted, the rivers polluted and the forests destroyed. The ultimate sufferer is the common man, especially in the developing and underdeveloped countries. On global scale, degradation is equally striking. The world's population has doubled in the last forty years and is now more than 6 billion. At this rate it will cross 10 billion in the coming fifty years. The current growth rate of the global economy is a mere 3 percent. Even if this rate expands five times over, there will be a critical gap between supply and demand of food, energy and other related services. Keeping in view the role of degraded and salt affected lands in food security and numerous socio-economic benefits, it is worthwhile to examine the pattern, practices and policy implications relating to rehabilitation of these problematic lands. The main concern of this paper is to review the reclamation trend of salt affected land, technology available for reclamation, economic feasibility, socio-economic impact of these technologies and major constraints and policy issues in reclaiming these lands.

Material and methods

Results and findings of this paper are based on primary as well as secondary data collected from different sources. An intensive enquiry was made to collect primary data on various aspects of sodic and saline land reclamation during the year 2003-04 to 2007-08. The information was collected through direct personal interviews with the selected respondents on establishment cost required for sodic and saline soil reclamation, use of farm inputs, crop yields and farm returns obtained during and after reclamation of sodic land. The secondary data on technology available for sodic and saline land reclamation, package of practices and crops and crop rotations recommended for effective land reclamation have been collected from the research reports and official publication of the Central Soil Salinity Research Institute (CSSRI) and other research organizations.

The time series data on salt affected lands reclaimed during the period 1975-76 to 2006-07 has been collected from the Land Reclamation and Development Corporations and State Agriculture Department of Punjab, Haryana and Uttar Pradesh to find out long-term trends in sodic land reclamation. The triennial average and index number of sodic land reclaimed from 1975-76 to 2006-07 have been worked out using suitable statistical tools. The compound growth rates of the sodic land reclaimed have been calculated from the triennial averages with the help of exponential equation: $Y = a * b^t$. Where Y is the dependent variable, i.e. sodic land reclaimed (in ha); b is the value of regression coefficient for time variable t; t is the time variable and a is the constant term. The average annual growth rate 'r' was obtained as [exp (b) – 1] and multiplied by 100 for expressing in percentage. Thus, the calculated growth rate was an average rate representing the available observations over the period under analysis, not necessarily match the actual growth rate between any two periods.

Results and discussion

Present status of land resources

Global Assessment of Soil Degradation (GLASOD), based on a formal survey, was the first world wide comparative analysis to focus specifically on soil degradation (Oldeman, 1994). GLASOD was designed to provide continental estimates of the extent and severity of degradation from World War II to 1990. The study concluded that 1.97 billion ha (23 percent) of globally used land had been degraded (Table 1). Fourteen percent of the globally used land was seriously degraded. Thirty-eight percent of all agricultural land, along with 21 percent of permanent pasture and 18 percent of forests and woodland, had become degraded. Nine percent of all crop land, pasture and woodland was lightly degraded in 1990; 10 percent was moderately degraded, implying a large decline in productivity; and 4 percent was strongly degraded, implying a virtual loss in productive potential (FAO,1990). The regional analysis of the degraded land revealed that the largest percentage of the total land area is degraded in Central America (32%), followed by Africa (30%) and Asia (27%).

The cumulative productivity loss for cropland from soil degradation over the past 50 years is estimated to be about 13 percent and for pasturelands 4 percent. Crop yield losses in Africa from 1970 to 1990 due to water erosion alone were estimated to be 8 percent. Sub-regional studies have documented large aggregate declines in crop yields due to degradation in many parts of Africa, China, South Asia, and Central America. A global agricultural model has been suggested a slight increase in degradation relative to baseline trends could result in 17–30 percent higher world prices for key food commodities in 2020 and increased malnutrition.

According to the nine-fold land-use classification, out of 304 million ha of land in India, 40 million ha is considered unfit for vegetation as it is either under urban and non-agricultural uses such as roads and rivers or is under permanent snow, rocks and deserts. The remaining 264 million ha of land that has potential for growing vegetation is presented in Table 2. It is evident from the break up analysis that 53.79 % of the total culturable land was under cultivation and 25.38% under forest whereas 20.83% land was fallow, culturable waste, pastures, etc., which is considered as degraded culturable land.

The estimate of total degraded lands in India made by of the Ministry of Agriculture (Table 3) reveals that the largest area (61.70%) is affected by water erosion followed by degraded forest lands (11%) and wind erosion (10%). It is obvious that wind and water erosion constitute

Table 1. Estimates of degraded land in the world

Region	Total land area (million ha)	Degraded land (million ha)	% degraded to total land area	Seriouslydegraded land(million ha)	% degraded to total land area
Africa	1663	494	30	321	19
Asia	2787	747	27	453	16
South America	1516	244	16	139	9
Central America	198	63	32	61	31
North America	1131	96	9	79	7
Europe	796	218	27	158	20
Oceania	644	104	17	6	1
World	8735	1966	23	1216	14

Source: FAO 1990.

Table 2. Details of the culturable land available in India

S.N.	Particulars of the land	Area(million ha)	Percentage to total culturable land
1.	Cultivated land	142	53.79
2.	Forest land	67	25.38
3.	Fallow/ culturable waste/ pastures etc.	55	20.83
	Total Culturable Land	264	100.00

Table 3. Estimates of degraded lands in India as per assessment of the Ministry of Agriculture

S.N.	Types of degradation	Area (million ha)	% to the total degraded land
1.	Water erosion	107.12	61.70
2.	Wind erosion	17.79	10.24
3.	Ravines	3.97	2.28
4.	Salt affected	7.61	4.38
5.	Waterlogging	8.52	4.90
6.	Degraded land due to shifting cultivation	4.91	2.82
7.	Degraded forest lands	19.49	11.22
8.	Special problems	2.73	1.57
9.	Coastal sandy areas	1.46	0.84
	Total	173.64	100.00

Source: Ministry of Agriculture, 1985.

a large proportion of degraded land, which needs immediate attention of the planners and policy makers to rehabilitate these lands by formulating effective strategy for preventing further damage.

Extent of loss due to sodicity and salinity

No crop can be grown on severely salt affected soils without proper treatment. Some wild grasses such as *sporobolus* and trees like *Acacia arabica*, *Caparis apphylla*, etc. can be seen in patches. The yield loss on these salt affected soils varies from 40 percent to 80 percent (Table 4), which clearly underlines importance and necessity of reclamation and management of these problematic soils. Studies made by the CSSRI in Sarda Sahayak Irrigation Project (U.P.), Indira Gandhi Irrigation Project (Rajasthan), Kakarapar Right Bank Canal (Gujarat) and Western Yamuna Canal and Bhakhara Canal System (Haryana) revealed that the average loss of rice yield was 45 percent when grown under salt stress situation over the yield obtained in normal soils whereas it was 40 percent in the case of wheat crop. The yield loss was as high as 63 percent in case of cotton and 48 percent in sugarcane over yield of these crops received on normal soils. Apart from crop yield, there are other numerous losses caused by sodicity and salinity (Table 5). It is obvious from these facts that the salt affected soil reclamation helps in food production not only at the farm level but also enhances food security of the country at the national level.

Extent of salt-affected lands

On the basis of nature, characteristics and profile, the salt affected soils may be broadly grouped in to two main classes- Sodic Soils and Saline Soils. Nearly 50 percent of the irrigated lands in the arid and semi-arid regions have some degree of soil sodicity or soil salinity, indicating the magnitude of the problem that needs be

Table 4. Grain yield of major crops under various environments (tonne per ha)

Crops	Normal soils	Salt affected soils	Waterlogged soils
Rice	3.99	2.18 (45)	2.30 (42)
Wheat	2.59	1.57 (40)	1.85 (38)
Cotton	1.63	0.61(63)	0.37 (77)
Sugarcane	63.68	33.02 (48)	24.74 (61)

Figures in parentheses indicate percentage loss over normal soil.

Table 5. Losses due to soil sodicity, salinity and waterlogging

Particulars	Extent
Crop yield decreased (%)	40 – 80
Employment lost (man days/ha)	50 – 80
Production infrastructure lost (Rs per farm)	5000–15000
Human health problem increased (in %)	20 – 40
Animal health problem increased (in %)	15 – 50

Table 6. Sodic and saline land (ha) in different states of India

Name of state	Sodic soil	Saline soil	Total salt-affected soil
Gujarat	541430	1680570	2222000
Uttar Pradesh	1346971	21989	1368960
Maharashtra	422670	184089	606759
West Bengal	0	441272	441272
Rajasthan	179371	195571	374942
Tamil Nadu	354784	13231	368015
Andhra Pradesh	196609	77598	274207
Haryana	183399	49157	232556
Bihar	105852	47301	153153
Punjab	151717	0	151717
Karnataka	148136	1893	150029
Orissa	0	147138	147138
Madhya Pradesh	139720	0	139720
Andaman & Nicobar Islands	0	77000	77000
Kerala	0	20000	20000
Total	3770659	2956809	6727468

Source: NRSA & Associates, 1996.

tackled on priority. The extent of total salt affected area is 6.73 million ha in India, out of which nearly 56 percent is sodic and 44 percent saline land (NRSA, 1996). The state-wise distribution of these lands is given in Table 6, which highlights that acute problem of sodicity and salinity prevails in Gujarat, Uttar Pradesh, Maharastra, Bengal, Rajasthan, Tamil Nadu, Andhra Pradesh, Haryana, Bihar and Punjab. Three important states of the Indo-Gangetic Plains- Punjab, Haryana and Uttar Pradesh, who are major rice and wheat producing states of the country are facing severe problems of sodicity and salinity.

Rehabilitation of salt affected land

Sodic land reclaimed

About 1.8 million ha sodic soils have been reclaimed in India during the last 4 decades, constituting nearly 50% of the total sodic lands. So far, efforts are confined to reclaim the salt affected soils located in Indo-Gangetic plains where underground water quality is good and watertable is controlled by extensive tube well operations. Technology adopted for reclamation programmes proved technically feasible and economically viable. It is appropriate to review and take stock of the current status of knowledge and technologies available for managing sodic lands on a sustained basis.

Sodic soil reclamation technology has been adopted in Haryana, Punjab, Uttar Pradesh and some other states of the country. The largest proportion of the sodic land reclaimed was in Punjab by the year 2006-07 being 44 percent of the total area reclaimed, followed by U.P. (35%) and Haryana (17%). The information relating to the sodic land reclamation (Table 7) portrays that sufficient progress has been made by various agencies involved in reclamation of lands in the major sodicity affected states of the country. The Punjab Land Development and Reclamation Corporation (PLDRC) was set up in Punjab in 1965 as a nodal agency for reclamation of sodic land in Punjab state. The Corporation succeeded to reclaim 0.80 m ha of land till 2006-07 over a period of 3 decades. When reclamation of alkali soil was started in Punjab, 0.7 m ha area was affected from sodicity. Even after reclaiming 0.80 m ha in Punjab, there is still about 0.15 m ha sodic land to be reclaimed in the state as some fresh land became sodic. The Haryana Land Reclamation and Development Corporation (HLRDC) is the nodal agency in Haryana for distribution and supply of gypsum to the farmers in the state. Total sodic land reclaimed in Haryana was 0.30 m ha by the year 2006-07, while 0.18 m ha land remained un-reclaimed.

In U.P. 0.64 m ha sodic land was reclaimed with the help of Uttar Pradesh Land Development Corporation (UPLDC) by the year 2006-07 and 1.34 m ha sodic land remains to be reclaimed. The sodic land reclaimed in the other states, namely Gujarat (38300 ha), Rajasthan (22400 ha), Tamil Nadu (5100 ha), Karnataka (2900 ha), etc. is reported to be 0.13 million ha. The sodic land reclamation programme provided additional food grains, particularly in Haryana, Punjab and Uttar Pradesh valued between Rs 13000 million and Rs 15000 million per annum and employment nearly 250 million man-days every year.

The sodic soil reclamation technology has been tested and demonstrated on the farmer's fields successfully by CSSRI, State Agricultural Universities and Development Departments of various states. In addition to technical

Table 7. Progress of sodic land reclaimed in different states of India up to 2006-07

State	Alkali land reclaimed (ha)	% of total reclaimed area
Gujarat	38300	2.12
Haryana	303000	16.80
Karnataka	2900	0.16
Madhya Pradesh	100	0.01
Punjab	797000	44.18
Rajasthan	22400	1.24
Tamil Nadu	5100	0.28
Uttar Pradesh	635000	35.20
Total	1803800	100.00

Source: Estimates based on information provided by HLRDC, PLDRC, UPBSN, CSSRI, Department of Agriculture and cooperation (http://agricoop.nic.in/dacdivision/RAS.pdf (2005-06) and other reports, publications, websites and official correspondence.

guidance, subsidy ranging from 50 to 75 % on amendment and custom hiring services were also given to the farmers to adopt the land reclamation technology. Progress of sodic land reclamation has been much faster in Punjab as compared to Haryana and Uttar Pradesh (Fig. 1).

Waterlogged saline land reclaimed

No systematic data is available on waterlogged saline soil reclamation in India. However, estimates made by CSSRI Karnal on the basis of various plans and projects executed in various parts of the country showed that nearly 50,000 ha saline land have been reclaimed in the country as a whole. The progress of saline land reclaimed in different states of India up to 2006-07 is presented in Table 8. It is evident from the data that the largest saline area (16,000 ha) has been reclaimed in Rajasthan followed by Haryana (6,300 ha), Bihar (6,000 ha), Punjab (4250 ha) Orisa (4000), Madhya Pradesh (3050), Gujarat (3000 ha) and Maharastra (3000 ha). The progress made by these states for saline soil reclamation is appreciable,

Table 8. Progress of saline land reclaimed in different states of India up to 2006-07

State	Saline land reclaimed (ha)	% of total reclaimed area
Gujarat	3000	6.01
Uttar Pradesh	50	0.10
Maharashtra	3000	6.01
West Bengal	50	0.10
Rajasthan	16000	32.06
Tamil Nadu	3000	6.01
Andhra Pradesh	500	1.00
Haryana	6300	12.63
Bihar	6000	12.02
Punjab	4250	8.52
Karnataka	500	1.00
Orisa	4000	8.02
Madhya Pradesh	3050	6.11
Kerala	200	0.40
Total	49900	100.00

Source: Estimated by CSSRI Karnal based on reclaimed waterlogged saline area under subsurface drainage projects and other drainage schemes.

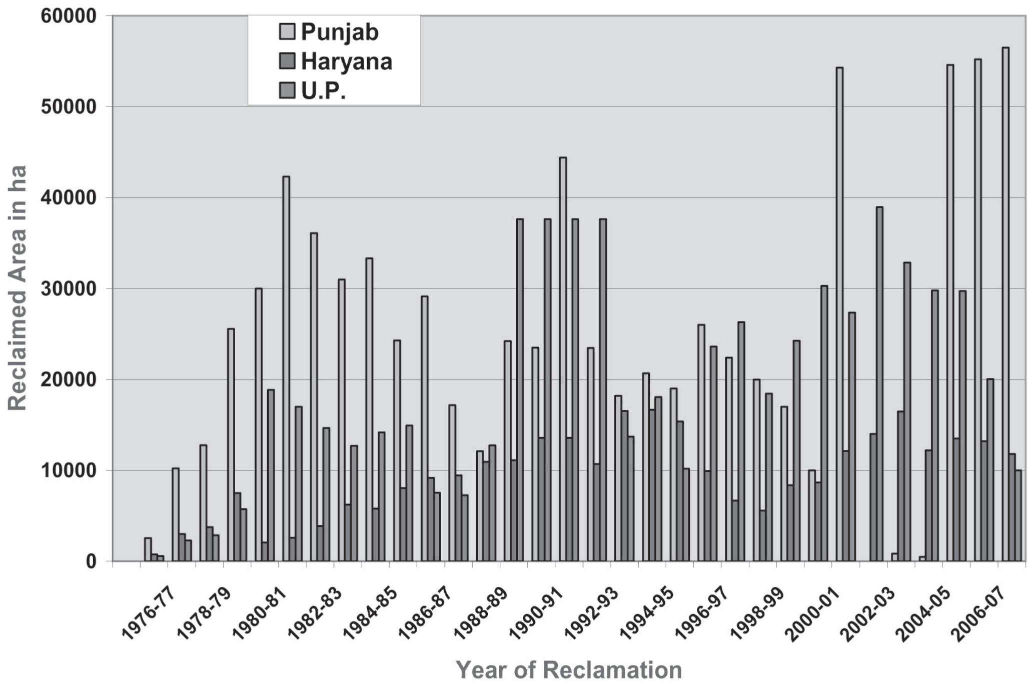

Fig. 1. Progress of sodic land reclaimed in Punjab, Haryana and U.P. from 1075-76 to 2006-07

whereas it was the worst in Uttar Pradesh, West Bengal, Andhra Pradesh, Kerala and Karnataka.

Trend of sodic land reclamation

The trends of sodic land reclamation and its annual average as well as compound growth rate have been estimated for Punjab, Haryana and Uttar Pradesh. It is evident from the analysis that the progress in growth rate of sodic soil reclamation was good enough in Punjab and Haryana but in case of Uttar Pradesh progress was not satisfactory. The state-wise trends of sodic land reclamation are as follows.

Trend of sodic land reclamation in Punjab

The triennial average and index number of sodic land reclamation in Punjab from 1975-76 to 2006-07 have been worked out and are presented in Table 9, which indicate that maximum sodic land was reclaimed in Punjab state during 1978 to 1986 where the rate of reclamation was between 23,000 ha and 36,000 ha per year. During 1992 to 2004, rate of reclamation was quite slow in the state, although it tended to increase at an increasing rate. The reclamation process slowed down again in 2002 to 2004 but after that it took momentum and achieved the level of 55433 ha per year in 2005-07.

The index number calculated from the triennial average of sodic land reclamation in Punjab revealed that the highest index number was in the year 2005-07 being 170 as against the base year 1979-81, followed by 2004-05 (113), 1981-83 (112) and 1980-82 (111). The index number was the lowest in 2002-04. Analysis showed that the progress of sodic land reclamation in Punjab was at

Table 9. Triennial average and their index numbers of sodic land reclaimed in Punjab, Haryana and Uttar Pradesh from 1975-76 to 2006-07

(Base year 1979-81 = 100)

Year	Punjab		Haryana		U.P.		Total	
	Triennial average	Index No.	Triennial average	Index No.	Triennial average	Index No.	Triennial average	Index No.
1976-78	8519	26	2500	62	1908	14	12927	26
1977-79	16186	50	4750	117	3625	26	24561	49
1978-80	22779	70	4434	110	9146	66	36359	72
1979-81	32619	100	4045	100	13859	100	50522	100
1980-82	36130	111	2835	70	16837	121	55802	110
1981-83	36463	112	4230	105	14790	107	55484	110
1982-84	33470	103	5301	131	13847	100	52619	104
1983-85	29533	91	6696	166	13933	101	50162	99
1984-86	28917	89	7675	190	12212	88	48804	97
1985-87	23537	72	8890	220	9914	72	42341	84
1986-88	19477	60	9852	244	9189	66	38517	76
1987-89	17827	55	10501	260	19217	139	47545	94
1988-90	19933	61	11881	294	29336	212	61151	121
1989-91	30700	94	12755	315	37634	272	81089	161
1990-92	30454	93	12614	312	37634	272	80702	160
1991-93	28691	88	13595	336	29661	214	71946	142
1992-94	20781	64	14629	362	23140	167	58550	116
1993-95	19293	59	16194	400	13988	101	49475	98
1994-96	21890	67	13992	346	17288	125	53171	105
1995-97	22467	69	10659	264	20033	145	53159	105
1996-98	22800	70	7381	182	22788	164	52970	105
1997-99	19800	61	6864	170	23005	166	49668	98
1998-00	15667	48	7532	186	24330	176	47528	94
1999-01	27100	83	9723	240	27303	197	64126	127
2000-02	21433	66	11605	287	32200	232	65238	129
2001-03	18380	56	14208	351	33060	239	65649	130
2002-04	443	1	14227	352	33864	244	48535	96
2003-05	18643	57	14059	348	30784	222	63486	126
2004-06	36763	113	12966	321	26505	191	76234	151
2005-07	55433	170	12838	317	19914	144	88186	175

Table 10. Average annual growth rate of sodic land reclamation in Punjab, Haryana and Uttar Pradesh from 1975-76 to 2006-07

State	Annual growth rate	Statistical significance
Punjab	1.18	Non-significant
Haryana	3.55	Significant at 1 percent level
Uttar Pradesh	3.53	Significant at 1 percent level
Total	2.45	Significant at 1 percent level

peak during 1979-81 to 1982-84. Further the increase in area reclaimed over previous years was the maximum in 2004-06 and 2005-07, being 113 and 170. Thus, the progress in land reclamation was remarkably high during these years as compared to the previous year's reclaimed area. The notable setback to the reclamation effort was noticed in 2002-04 where average annual area reclaimed was only 443 ha. The declining trend in reclamation was mainly due to reduction in subsidy on gypsum cost from 75 to 65 percent in 1993-94, 56 percent in 1994-95 and again to 50 percent 1995-96 onward.

The average annual growth rate of the sodic land reclamation in Punjab state was calculated from 1975-76 to 2006-07 (Table 10). It is evident from the table that the average annual growth rate of sodic land reclamation in Punjab state as a whole was 1.18 percent during a period of 3 decades from 1975-76 to 2006-07. The growth rates of reclamation of sodic soils in selected districts of Punjab, estimated with the help of logistic and linear equations which showed that the adoption process in six districts of Punjab namely Amritsar, Ferozepur, Jalandhar, Kapurthala, Patiala and Sangrur recorded a linear trend. The salt affected area has been reclaimed at faster rates in Sangrur and Kapurthala districts of Punjab but progress of reclamation was slow in Amritsar and Ferozepur districts. The progress in Jalandhar and Patiala was moderate. It was observed that demand for land in these states was growing rapidly and met through external land augmentation, i.e. utilizing sodic and saline soils.

The compound growth rate of sodic land reclamation in Punjab state was calculated from 1975-76 to 2006-07 and presented in Table 11, which indicates that the compound growth rate of sodic land reclamation for the state as a whole was 79.36 percent during 1975-76 to 1979-80, whereas it declined during the period of 1981-82 to 1989-90 (-6.23 %) and 1991-92 to 1999-2000 (-2.26).

The compound growth rate of reclamation was 1.73 percent per year when estimated for the period from 2001-02 to 2006-07. The compound growth rate of reclamation was -9.31 percent per year for the entire period of the sodic land reclamation from 1975-76 to 2006-07 in Punjab state. The compound growth rates were significant for the period from 1975-76 to 1979-80 and 1981-82 to 1989-90 but non-significant for the period 1991-92 to 1999-2000 and 2001-02 to 2006-07. It is obvious from these results that there was remarkable increase in growth rate of sodic land reclamation in the state due to concerted and favourable policy intervention and involvement of all stakeholders during 1975-76 to 1979-80 by providing subsidy on amendment, custom hiring services as well as active participation of the farmers. However, the declining trend after 1981-82 was mainly due to reduction in subsidy on gypsum from 75 percent to 50 percent in the state.

Trend of sodic land reclamation in Haryana

The triennial average and index number of sodic land reclamation in Haryana indicated that maximum sodic land was reclaimed in Haryana state during 1985 to 1997 where the rate of reclamation was between 8,890 ha and 16,194 ha per year. During 1996 to 2000, rate of reclamation was comparatively slow in the state, although it tended to increase at an increasing rate. The reclamation process took momentum again from 2001 and achieved the level of 14,227 ha per year in 2002-04.

The index number calculated from the triennial average of sodic land reclamation in Haryana revealed that the highest index number (400) was in the year 1993-95 against the base year 1979-81, followed by 1992-94 (362), 2002-04 (352), 2001-03 (351) and 1994-96 (346). The index number was in the lowest level in the initial stage 1976-78 and 1980-82. Analysis showed that the progress of sodic land reclamation in Haryana was at peak during 1993-95. The notable setback to reclamation was noticed from 1996-98 to 1998-2000 where average

Table 11. Exponential trends of sodic land reclamation in Punjab, Haryana and Uttar Pradesh from 1975-76 to 2006-07

Period of reclamation	Punjab	Haryana	Uttar Pradesh	Total
1975-76 to 1979-80	79.36**	34.03 NS	120.46***	83.41**
1981-82 to 1989-90	-7.74*	14.62***	10.7 NS	2.12 NS
1991-92 to 1999-2000	-2.26 NS	-5.71*	0.22 NS	-1.62 NS
2001-02 to 2006-07	1.73 NS	-3.97 NS	-21.08**	13.69 NS
1975-76 to 2006-07	-9.31 NS	5.43***	6.42***	3.73***

*Significant at 10 percent level of significance; ** Significant at 5 percent level of significance; *** Significant at 1 percent level of significance; NS Non-significant.

annual area reclaimed was around 7000 ha. The declining trend in reclamation was mainly due to reduction in subsidy on gypsum.

The average annual growth rate of the sodic land reclamation in Haryana state was 3.55 percent during the period from 1975-76 to 2006-07 (Table 10). The average annual growth rate was highly significant at 1 percent level of significance which underlines remarkable progress of sodic land reclamation in the state. The growth rates for reclamation of sodic soils in selected districts of Haryana estimated with the help of logistic and linear equations, showed that the adoption process was much faster in three districts of Haryana namely Karnal, Kurukshetra and Jind and it followed a S-shaped growth curve. The growth rate was as high as 67 percent in Kurukshetra whereas it was 66% in Jind and 33% in Karnal. During 1974 to 1984, about one-fourth and one-fifth of the total salt-affected area in Kurukshetra and Karnal districts of Haryana have been reclaimed and utilized for crop production.

The compound growth rate of sodic land reclamation in Haryana was calculated from 1975-76 to 2006-07 (Table 11), which indicated that the compound growth rate of sodic land reclamation for the state as a whole was 34.03 percent during 1975-76 to 1979-80 and 14.62 during 1981-82 to 1989-90. The growth rate was remarkably high for this period and was significant at 1 percent level of the significance for the segment 1981-82 to 1989-90. The compound reclamation rate declined during the period of 1991-92 to 1999-2000 (-5.71 %) and from 2001-02 to 2006-07 (-3.97). The compound growth rate of reclamation in Haryana was 5.43 percent per year for entire period of the sodic land reclamation from 1975-76 to 2006-07. The positive and highly significant compound growth rate indicated a remarkable increase in sodic land reclamation in the state mainly due to favourable policy intervention and active involvement of farmers and other stakeholders.

Trend of sodic land reclamation in Uttar Pradesh

No substantial efforts could be made in Uttar Pradesh during 1975-76 to 1986-87 for reclamation of salt affected land. Although various trails and experimentation were initiated in U.P. by Central Soil Salinity Research Institute (ICAR) and Uttar Pradesh Bhumi Sudhar Nigam to reclaim sodic land with the help of chemical amendments like gypsum, pyrites in combination with leaching and flushing of soluble salts, the process of reclamation did not exhibit momentum in early seventies and even till mid eighties. A number of schemes and programmes have been launched in different districts of the state by the state government for reclamation of sodic land. As a result of various efforts made, total sodic land reclaimed in U.P. was 0.42 ha by 1998-99, which increased to 0.51 million ha by 2001-02. Further, the total sodic land reclaimed under different schemes in the state was 0.64 million ha by the year 2006-07.

The triennial average and index number of sodic land reclamation from 1975-76 to 2006-07 have been worked out and are presented in Table 9. The triennial average and index number of sodic land reclamation in Uttar Pradesh indicated that maximum sodic land was reclaimed in Uttar Pradesh state during 1988-90 to 1992-94 where the rate of reclamation was between 19,217 ha and 37,634 ha per year. During 1993-95 to 1999-01, rate of reclamation was comparatively slow in the state, although it tended to increase at an increasing rate. The reclamation process took momentum again from 2000-02 and achieved the level of 33,864 ha per year in 2002-04.

The index number calculated from the triennial average of sodic land reclamation in Uttar Pradesh revealed that the highest index number was in the year 1989-91 and 1990-92 being 272 as against the base year 1979-81, followed by 2002-04 (244), 2001-03 (239), 2000-02 (232) and 2003-05 (222). The index number was the lowest in the initial stage 1976-80 and during 1984-86 to 1986-88. Analysis showed that the progress of sodic land reclamation in Uttar Pradesh was at peak during 1989-92. The notable setback to reclamation effort was noticed from 1984-88 where average annual area reclaimed was between 9,000 and 12,000 ha. The declining trend in reclamation was mainly due to non availability of gypsum in the state.

The average annual growth rate of the sodic land reclamation in Uttar Pradesh state was 3.53 percent during the period from 1975-76 to 2006-07 (Table 10). The average annual growth rate was highly significant at 1 percent level of significance which underlines the remarkable progress of sodic land reclamation. The compound growth rate of sodic land reclamation in Uttar Pradesh was calculated from 1975-76 to 2006-07 (Table 11), which indicated that the compound growth rate of sodic land reclamation for the state as a whole was 120.46 percent during 1975-76 to 1979-80 and 10.70 during 1981-82 to 1989-90. The growth rate was remarkably high for 975-76 to 1979-80 indicating highly significant value at 1 percent level of the significance. The compound reclamation rate declined during the period of 2001-02 to 2006-07 (-21.08%). The compound growth rate of reclamation in Uttar Pradesh was 6.42 percent per year for the entire period of the sodic land reclamation from 1975-76 to 2006-07. The positive and highly significant compound growth rate indicated a remarkable increasing trend of sodic land reclamation in the state mainly due to initiation of reclamation schemes with financial support from various international funding agencies and active involvement of Uttar Pradesh Bhumi Sudhar Nigam, farmers and other stakeholders.

Economic viability of salt affected land reclamation

The sodic and saline land reclamation technologies are technically viable, economically feasible and socially acceptable by all the categories of farmers. The land reclamation programme has proved a boon both to the farmers as well as to the country. However, the programme has not made uniform progress in all the states. For example, Punjab and Haryana have made tremendous efforts to reclaim their sodic soils but in U.P., reclamation process has not taken the desired speed. On the whole, however, it can be summed up that sodic land reclamation programme progressed well during the last 30 years and its impact has been quite appreciable. It is in the interest of both the farmers and the nation that this programme should be given more encouragement and support in years to come.

Capital required for sodic land reclamation

The capital required for sodic land reclamation ranges from Rs 45000 to Rs 50000 per ha. The items of cost consist of bunding and levelling of field, gypsum and its application, installation of tube well and flooding of field and flushing the salts. The details of initial cost and its breakup on farmer's field (Table 12) revealed that the total establishment cost required for sodic land reclamation was Rs 45000 per ha on farmers field at an average farming situation. The annual cost of rice and wheat cultivation was Rs 30,000 and Rs 27,000 per ha, respectively, excluding family labour and rental value of land (Cost B1). The gross income in terms of crop yield was Rs 62,300 in 1st year, Rs 77,500 in 2nd year and Rs 83,000 in 3rd year of the reclamation. Thus, the total cost on reclamation including crop cultivation estimated to be Rs 2,16,000 per ha during the 3 years of reclamation whereas gross income received was Rs 2,22, 500 per ha from the crop production on farmer's field at average farming situation. This analysis explained the fact that total cost involved on reclamation of sodic land could be recovered fully within a period of 3 years after commencement of the reclamation programme.

For complete and better understanding on the economic viability of sodic land reclamation technology, it is necessary to analyze cost and return of the technology at least for a period of 10 years or more. Considering this fact in view, the cost-benefit analysis of sodic land reclamation at farmer's field was done for a period of 10 years in an average farming situation. The results of the analysis (Table 13) indicated that net present worth of the sodic land reclamation at farmer's field was Rs 56,000/ ha without subsidy. The benefit-cost ratio was 1.52 and internal rate of return 21.40 percent during 10-year economic life of land reclamation project. Payback period was estimated 3 years for sodic soil reclamation in the farmer's field. These results clearly highlight economic viability of the sodic land reclamation technology.

Table 12. Capital required for sodic land reclamation

Particular	Cost (Rs/ha)
Bunding and levelling	5000
Tube well installation*	16000
Cost of gypsum	18000
Gypsum application	2500
Flooding and flushing	3500
Total	45000

*One-fourth cost is taken in to account as one tube well covers 4 ha land for irrigation.

Table 13. Economic viability of sodic land reclamation

Particulars	Amount (in Rs)
Net Present Worth (Rs/ha)	56000.00
Benefit-Cost Ratio	1.52
Internal Rate of Return (%)	21.40
Pay Back Period (years)	3

Estimates are based on 10-years economic life of project and 10% rate of discount.

Capital required for saline land reclamation

The sub-surface drainage system cost is incurred on two major components: (i) earth work and (ii) drainage materials. The earthwork cost changes with soil type and depth of excavation. The cost also varied with the wages of labour in specific locations. The material cost varies with the type of materials used. This depends mainly on the quality of material used and its existing market prices. It is essential to identify and select the material so meticulously that the cost is kept to minimum without affecting the efficiency of the drainage system. The installation cost of the system varies from Rs 55,000 to 60,000 per ha. An additional amount of Rs 5000 per ha is required as an annual operational cost for pumping water. The break up of cost incurred on installation of sub-surface drainage in Haryana at lateral drain spacing of 60 m in 1.75 m depth is summarized in Table 14. The total cost of the system was Rs 55,000 per ha. The cost of drainage material and its installation in the form of lateral and collector drains was the highest being 45% of the total cost of the system, followed by excavation of drainage trenches by labour (36%).

The cost-benefit analysis of saline land reclamation was done considering 30 years economic life of the subsurface drainage system and results are presented in Table15. The analysis revealed that net present worth of the land reclamation at farmer's field was Rs 52,000 per ha. The benefit-cost ratio was 1.46 and internal rate of return 17% during 30 years economic life of land

Table 14. Capital required for installing subsurface drainage system

Particular	Cost (Rs/ha)
Land development	5000
Drainage material	25000
Labour charges for system installation	20000
Drainage disposal and operational cost	5000
Total cost	55000

Table 15. Economic viability of sub-surface drainage in reclamation of saline lands

Particulars	Cost (Rs/ha)
Net Present Worth (Rs /ha)	52000.00
Benefit-Cost Ratio	1.46
Internal Rate of Return (%)	17.00
Pay Back Period (years)	5

Estimates are based on 30-years economic life of project and 10% rate of discount

reclamation system. The pay back period estimated 5 years for saline soil reclamation technology. These results clearly explain economic viability of the saline land reclamation programme at the farmer's resource situation.

It is obvious from the foregoing discussion that the sodic and saline land reclamation technologies are sound technically and viable economically in rehabilitation and management of salt affected lands. Keeping in view the success of the technology and its favourable input-output ratio, banks and other financing agencies are advancing loan to the farmers for reclamation of their salt affected land, which covered the cost of reclamation and crop cultivation for the 1st year of reclamation. It was observed that most of the farmers who got loan for reclamation returned it within prescribed time. The banks are also advancing medium term loans to poor and resource poor farmers for reclaiming degraded sodic and saline land. The impact assessment analysis of the technology revealed that sodic soil reclamation technology has remarkable impact on capital formation, factor productivity, crop yield, decision making capacity and standard of living of the farmers which ultimately leads to a positive socio-economic change in the society and integrated rural development.

Socio-economic benefits of land reclamation

The social impact of sodic and saline land reclamation is quite visible in terms of food grain production, farm income, resource use efficiency, farm assets, capital formation, land value, improvement in soil properties, employment and improvement in quality of life and environment (Tripathi, 2004; Tripathi, 2009). It helps in eliminating poverty and inequity in the rural society. The social indicators can also be identified as literacy levels, health care, poverty eradication, empowerment of women and weaker sections of the society. Salt affected soil reclamation has emphasized social aspects to ensure stakeholders commitment in sustaining the activities to manage degraded lands. The brief account of socio-economic benefits of sodic and saline land reclamation is as follows.

Additional food grain production

During later sixties and seventies, various districts of Haryana and Punjab states witnessed a sharp spurt in rice production ranging between 14.4 % and 23.9 % per annum. The rapid increase in production was mainly due to introduction of high yielding varieties of rice and wheat, on one hand and acreage expansion under these crops by reclamation of sodic lands, on the other. Additional annual food production of rice and wheat on sodic lands after reclamation was estimated to be 5 and 2.5 t/ha, respectively, after 3rd year of reclamation under farmer's resource constraints. It indicates that reclamation of sodic land played important role in augmenting the agricultural production in these states and food security of the country.

If the package of practices for sodic land reclamation technology is adopted to the full extent, 4 t/ha yield of rice can be achieved in the 1st year of land reclamation which increases to 5 t/ha in the second year onwards from almost negligible yield in the sodicity affected lands. The yield of wheat harvested from the reclaimed sodic lands was to the tune of 2, 2.5 and 3 t/ha in the 1st, 2nd and 3rd year of the reclamation, respectively. Yield of rice and wheat due to adoption of reclamation technology at full extent at farmer's field in Haryana is presented in Table 16. The annual gross income received from both the crops ranged from Rs 62,000 per ha in the first year to Rs 83,000 per ha in third year onwards of reclamation.

About 1.8 million ha sodic and 50,000 ha saline lands have been reclaimed and brought under crop cultivation in India, which are producing nearly 15 million tonne food grains annually. It is estimated that land reclamation has contributed 26.7 percent to the total increase in rice production in Punjab, 13.8 percent in Haryana and 11.5 percent in Uttar Pradesh. The social benefits of sodic land

Table 16. Yield obtained in sodic land after reclamation in selected farms of Haryana

Reclamation year	Rice yield (t ha^{-1})	Wheat yield (t ha^{-1})	Total yield (t ha^{-1})
1st year	4.0	2.0	6.0
2nd year	5.0	2.5	7.5
3rd year	5.0	3.0	8.0

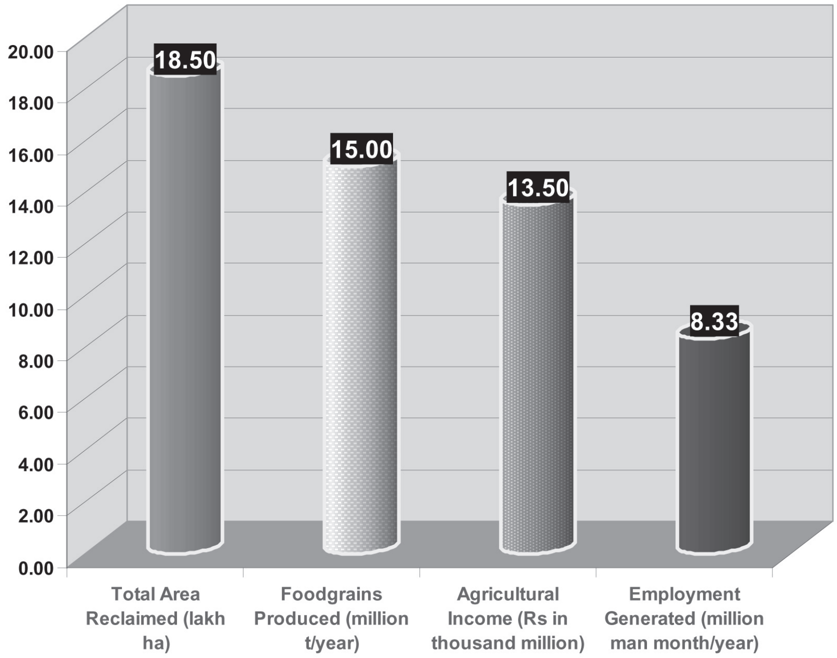

Fig. 2. Socio-economic benefits of salt affected land reclamation in India

reclamation at country level are numerous in terms of food grains, employment, etc. (Fig. 2).

Employment generation

The reclamation of sodic soils has generated productive employment for the marginal farmers as well as landless labourers in rural sector. Roughly 165 man-days per ha employment could be generated in the first year of reclamation. The employment potential through reclamation of sodic lands, shown in Table 17, was estimated to 30 man-days per ha in bunding, levelling and gypsum application whereas 94 and 41 days per ha in rice and wheat cultivation, respectively. In subsequent years, nearly 135 man-days per ha would be employed for rice-wheat cropping system at farmer's field. The total employment in the 1st year of reclamation at full-fledged level of technology was estimated to 214 and 160 man-days per ha for the subsequent years. It is indeed encouraging that the land once characterized as barren and lying uncultivated would generate tremendous employment opportunities after reclamation in the rural areas.

Enhancement in farm income

The land reclamation programme has not been limited to merely treatment of salt affected soils but also emphasized on proper soil and water management practices with the objective to develop a sustainable reclamation and production system. Post-project changes triggered significant increases in family income. Annual household income of erstwhile landless households has increased more than 100 %. Income from reclaimed land constitutes about 44 percent of incremental income for those households who did not have access to a productive land before reclamation. Their non-farm income confined mostly to wages, which has also gone up due to combined effect of rise in employment days and wage rate. Indian Institute of Management Lucknow reported that productivity of rice has increased from 1.5 t/ha to 3.0 t/ha and wheat productivity from 1.7 t/ha to 2.6 t/ha in

Table 17. Potential and achieved labour employment due to reclamation of sodic soils

Particulars	Estimated man-days (per ha)	
	Potential at full-fledged level of technology	Achieved at farmer's field
1. Labour demand for reclamation	54	30
2. Rice cultivation	99	94
3. Wheat cultivation	61	41
4.Toal employment in 1st year	214	165
5.Employment in subsequent years	160	135

reclaimed sodic lands of U.P. It is noteworthy that due to project intervention, C-class barren lands have come under double crop from no-crop level and B-class mono-cropped lands turned to double cropped.

Farm assets and capital formation

The farm assets and capital formation increased remarkably even on partial adoption of the technology. The farm assets and gross capital formation at different levels of technology adoption for the selected farms of Haryana are presented in Table 18. The data reveal that total capital formation on technology adopter farms was Rs 4.71 Lakh per farm, out of which 48 percent was on farm building, 28 percent on farm machinery, 14 percent on irrigation structures and rest on livestock (Tripathi, 2009). Gross capital formation was highest on highest level of technology adoption being Rs 5.03 Lakh per farm and lowest on the lowest level of adoption (Rs 3.52 lakh). The capital assets showed an increasing trend with increase in the level of technology adoption. The farm machinery got maximum emphasis at high level technology adopter group of farms (31% of the total assets). It is obvious from the data that sodic land reclamation has remarkable favourable impact on capital formation. The situation of farm assets increases which ultimately helps in enhancing farm production because of better input resource efficiency and improved investment capacity of the farming community.

Enhancement in value of land

The value of land, besides giving a prestige in society to the owner, decides credit worthiness of the farmer and plays an important role in many decision making processes on the farm. The reclamation of sodic lands substantially increases value of the land due to increased production potential and source of income. It is observed that average value of sodic lands increased from Rs 10,000 to Rs 2,00,000 per/ha depending on the location and availability of infrastructures in and around the area. The U.P. Sodic Lands Reclamation Project executed in ten districts of U.P. showed tremendous increment in value of land over a period of 7 years from 1993 to 2000. Figure 3 shows that the value of reclaimed land has gone up by about 48 per cent on B^+ class land whereas value of B and C class lands has risen by 108 and 317 per cent, respectively, with C class land recording maximum growth in value.

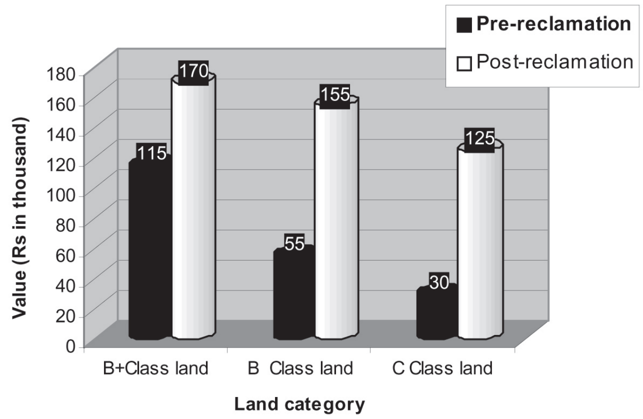

Fig. 3. Enhancement in land value after reclamation

Poverty alleviation

The sodic land reclamation programme has provided unique opportunity for alleviation of poverty of the rural people, particularly marginal and small farmers, who were bound to struggle for their livelihoods and were delimited by the vicious circle of poverty, i.e. low investment-low output-low savings. Project interventions in U.P. resulted in decline of participant households below poverty line on an average from 80% to 55% during a period of 8 years from 1993 to 2001 whereas 39% small and 43% big farmer crossed the poverty line after reclamation (Table 19). Thus, a sizable number of participants have crossed the poverty line and some households moved upwards. The sodicity reclamation programme developed exemplary models of poverty alleviation, environmental protection and improved agricultural production.

Empowering womenfolk

The sodic land reclamation programme has contributed to women empowerment through Woman Self Help Groups (WSHGs). This has provided a boost to the socio-economic upliftment of women. Women in rural areas had almost nil savings earlier but they have

Table 18. Capital formation at different levels of reclamation technology adoption

Levels ofTechnology	Gross capital (Rs in lakh/farm)	Percentage of total capital			
		Building	Machinery	Irrigation	Livestock
Very low	3.52	49	25	15	11
Low	4.73	47	28	15	10
Medium	4.94	47	28	14	11
High	5.03	48	31	13	8
Overall average	4.71	48	28	14	10

Table 19. Status of households before and after adoption of sodic land reclamation

Category of households	Percentage households below poverty line	
	Before project	After project
Landless	88	76
Marginal	84	67
Small	72	33
Big	69	26
Overall	80	55

Source: U.P. Sodic Lands Reclamation Project (UPSLREP).

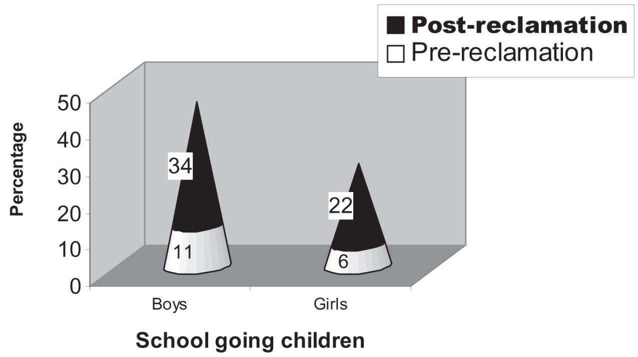

Fig. 4. Educational status after land reclamation

their own savings after getting their problematic lands reclaimed. Besides, the groups have been helpful in enabling their members to support the agriculture and allied activities by the way of micro financing. It is obvious from these facts that the sodic land reclamation has strong and favourable correlation with the women empowerment.

Betterment in quality of life

The intervention through land reclamation has increased cropping intensity, employment and crop yield. These all have a positive impact on economic and quality of life of the participant farmers. The literacy has improved remarkably over the years in the selected villages of U.P. after execution of reclamation project. It was higher among big and small farmers than among landless and marginal farmers. Male literacy was invariably more than female literacy irrespective of category of household and period. Rise in literacy ratio was higher among scheduled caste and landless and marginal farmers. The project has provided maximum benefits to such people. Male literacy improved by 7 percent and female literacy by 9 percent. It is attributed to the increased awareness among people about education. The number of children enrolled at school registered remarkably high as compared to the number registered before reclamation in those areas where reclamation project has launched. The children aged less than 7 years enrolled at school registered three-fold increase over a period of 7 years after execution of the reclamation project (Fig. 4).

Improvement in environment

One of the important social benefits of the sodic and saline lands reclamation is improved quality of the environment. Utilization of rainwater by reducing surface runoff and soil erosion during rainy season is the brighter aspect of sodic lands reclamation as about 40 percent of the total irrigation requirement of the newly reclaimed areas of rice and wheat is met from the rainwater conservation. It is ultimately resulting in increased ground water recharge and improvement in the soil quality. It further helps in controlling flood hazards by reducing peak runoff during the heavy rainstorms. Another important environmental benefit is the change in landscape after reclamation of these unproductive barren, undulated and unmanaged lands. The properly managed soil, water, road, path, vegetation and landscape improve the overall microclimate of the area.

Constraints in sodic land reclamation

There are several socio-economic and political factors, which affect reclamation of salt-affected soils. Field studies showed that there are a number of constraints, which need to be effectively overcome so as to provide fillip to the reclamation programme at the farm level. These are economy used by the farmers in use of soil amendment, land levelling, disposal of drainage water and increased cost of fertilizers and plant protection chemicals. Difficulties and inhibitions on the part of farmers to get credit, fears that sodic lands after reclamation would attract the provision of land ceiling acts, lack of specialized extension staff earmarked to take up land reclamation in the State Departments of Agriculture and frequent transfer of extension personnel even after attending specific land reclamation training programmes which need to be effectively overcome so as to provide fillip to the reclamation programme at the farm level. Socio-economic and political considerations often become extremely important in accentuating the problems of land degradation through sodification and related processes. Such factors are often beyond the control of individual farmer and for this reason appropriate policy decisions and corrective measures become the responsibility of respective governments. Some of the important constraints relating to sodic land reclamation in India are discussed below (Tripathi *et al.*, 2004).

Small and scattered land holdings

In India, land holdings are small and scattered over a wide area. The average size of the holdings is varying from 0.05 ha to 3 ha and individual plot sizes are as less as 0.01 ha. As a result, the attention of service agencies is diffused and much time and effort has to be concentrated on encouraging proper management of inputs by farmers. Land fragmentation and associated differences in cropping and management help the spread of secondary salinization. Differences in cropping patterns and irrigation regimes between adjacent farmers will cause migration of salts from high to low spots, from crop areas with more frequent irrigations to those with less frequent and from relatively wet soils to relatively dry soils. Consolidation of small land holdings although beset with many difficulties, is one practical way of improving technical, economic and social efficiency and also ease water management and other agricultural operations. When the holdings are fragmented, small and irregular shaped, on-farm development without land consolidation is difficult, inefficient and expensive. Furthermore, the supply of water to each farmer and draining the land after rainfall and irrigation poses problems. Besides efficient water distribution and land shaping, land consolidation simplifies land use planning and helps cut down the time required for water to travel among plots. It also reduces length of watercourses and drains as the land used in boundaries is reduced when there is consolidation.

Unfavorable land tenure system and absentee land holders

The land tenure systems also play an important role in spreading sodicity and salinity. Cultivators, who are share-tenants either on produce or cash payment basis to lease-in land each year, often move around landlords to get field for crop cultivation. As a result, such farmers have little interest in protecting the soil from degradation. On the other hand, long-term tenancy or private ownership of land will offer incentives for conservation measures including control of sodicity problem. Therefore, effective steps should be taken by the government and planners to reduce population pressure from agricultural land by improving land tenure system.

Cost intensive reclamation technology

Conventionally, the sodic soils are reclaimed by chemical amendments that either supply calcium externally or increase solubility of native lime available with in the soil (calcium carbonate) having very low solubility. Over the years, this method of soil reclamation has become cost-intensive because high capital input is required to start a reclamation programme. There has been a need to sort out some materials capable of soil reclamation at a low initial cost. Some evidences show that cultivation of certain salt tolerant forage plants on sodic soils may substitute the chemical approach. Some field studies indicated that cultivation of sesbania (Sesbania aculeate) or Kallar grass (Leptochloa fusca) for about two seasons caused a significant soil improvement. The reclamation efficiency of these plant species was found comparable with the conventional method, which needs a good initial investment to purchase chemical amendments.

Transfer of half baked technologies

The same package of reclamation technology cannot be suitable to all the situations. For example, the Punjab and Haryana farmers have adopted the existing alkali soil reclamation technology very well but the extent of adoption is limited and comparatively slow in U.P. because of differences in socio-economic and agro-ecological situations. Therefore, technology for reclamation and management of salt-affected soils must be evolved and tested separately for different agro-ecological and socio-economic environments on a pilot project scale before being transferred on a large scale to the farmer's fields. The objectives of such a pilot project should include testing and demonstration of the new or existing technologies on the farmer's fields, modification of the technologies to suit the local conditions, critical calculation of the profitability and economics of the new technologies and identification of technological, socio-economic and administrative bottlenecks in the transfer of technology. Only well tested technology with proven benefits should be passed on to the farmers after ensuring infrastructural support at appropriate cost.

Inadequate water pricing policy

Existing water laws and water pricing policy in India are important factor in determining the efficiency of on-farm water use. The surface irrigation waters are available almost free of charge, although some taxes are levied to mobilize resources for financing irrigation works. The farmers who operate their own pumps or buy water from pumps owned by others must pay for the amount of water they use. The water use efficiency of such farmers is therefore, much higher than that of those who do not pay for water. In the later case, farmers use water in excess of that required to meet the crop consumptive use causing the problems of water logging and salinization particularly in rice–wheat cropping system. The rational change in policy to charge for the water used will increase overall water-use efficiency and control soil degradation.

Low level of literacy and lack of people participation

Irrigated farming calls for particular skills in application of irrigation water and environment friendly production practices to get increased productivity and sustainable farm income. The efficiency of irrigation and drainage schemes rests on the individual cultivator who is the most important link in the chain of production. When irrigation is introduced in a new area the farmers of the region have had little or no experience in handling large quantities of water on the farm. Since the cultivator may be tradition bound and poorly literate, effort and ingenuity must be applied to convert him into an efficient irrigator. To ensure steady application of new irrigation methods to improve water use efficiency, the farmer must be kept informed of new ideas through organization of appropriate training and other extension programmes. The people participation in salt affected land reclamation programmes, particularly in subsurface drainage system is extraordinary poor almost in all the projects installed in various locations of Haryana state, which causing non-functional drainage systems and wastage of time and money.

Inadequate extension network

The extension network of the country needs strengthening in such a way that scientific knowledge is transferred quick and efficiently to the farmer's field. Well-designed and effectively operating irrigation and drainage systems right down to the farmer's field can increase productivity of irrigated agriculture. The individual farmer must understand importance of land shaping and uniform water application, the need and desirability of irrigating crops based on available scientific information, the importance and best ways of maintenance of field channels including proper lining procedures and drainage channels etc. A continuous effort to elevate the level of education of the cultivator will result in enhanced capability to manage the land and water resources with minimum degradation through sodification, salinization and related phenomena.

Future strategy

The following strategies are suggested for sustainable management of salt affected land, the most fragile and non-renewable natural resource, and preventing further damage to precise heritage of mankind.

Monitoring and long-run strategies

Continuous monitoring of soil degradation including sodicity and salinity is important for formulating long run strategic plans and timely action to overcome the problems. This will require strengthening of statistical reporting the land resources database and preparing long-run strategic plans to take timely action for rehabilitating degraded lands.

Role of institutions

The role of institutions is not identified and defined, so far, for controlling soil degradation in general. It is an important aspect to fix the accountability of various organizations and institutions working for sustainable use of natural resources. A well-defined and integrated resource management system including role of institutions is needed to reclaim and manage degraded lands.

People participation

People cooperation is important for managing degraded lands. Decisions on irrigation particularly canal development should be done with full consultation and cooperation of the farmers. Farmers should agree with land rehabilitation programmes being sponsored by the government and other external agencies. Local practices used by farmers to reduce the adverse effect of land degradation should be considered. In this regard, farmer organizations would be useful instruments to achieve this common goal. People participation in sodicity and salinity control activities could be encouraged through subsidies and farmer education and training.

Irrigation and drainage management

Excessive irrigation should be controlled to prevent the watertable from rising downstream. This can be achieved through institutional changes with close cooperation between the management agency and the farmer organization. Prevent excessive irrigation by suitable water pricing. More emphasis should be given for drainage in the canal command areas. It will help in minimizing the loss caused by soil salinity and sodicity. As a short-term measure, farmers could practice drainage improvement- cleaning, deepening and prevention of blockage of drainage outlets.

Agronomic practices improvement

Application of organic matter is necessary to prevent the soil degradation and improve fertility and water holding capacity of the agricultural lands. During the off-season, fields should be kept under salt and drought tolerant crops such as sesbania, sunflower, small millets etc. as plant cover retards salinization and alkalinization.

Afforestation of canal sides and low lying barren lands

There is considerable scope for growing trees and shrubs to deplete the groundwater table and reduce the salt problem under irrigated conditions. Biological drainage using salt tolerant and fast growing tree species is less expensive and people-centered than a capital-intensive technological solution.

Conclusions

Remarkable progress has been made in reclamation of salt affected land in Punjab and Haryana during the last 3-4 decades. But progress of reclamation in Uttar Pradesh, where a large proportionate of the affected area exists, is quite slow. As a result of various efforts made for rehabilitating sodic, saline and waterlogged lands about 1.85 million ha salt affected lands have been reclaimed in the country. Although suitable package of practices and varied technological options are available for amelioration and productive uses of degraded lands, there is an urgent need to evolve low cost reclamation technology suitable to the resource poor small and marginal farmers under various socio-economic and agro-ecological environments. The sodic and saline land reclamation technologies have been proved technically feasible and economically viable. The reclamation technology showed tremendous scope for producing additional food grains and generating employment opportunities in rural sector. The salt affected land reclamation has favourable impact on farm assets and capital formation, resource use efficiency, crop yield, farm income and standard of living of the farming community. Small and scattered land holdings, unfavourable land tenure system, cost intensive reclamation technology, inadequate water pricing policy, low literacy and inadequate extension network are the major hurdles coming in the way of salt affected land reclamation. It is a high time for restoring degraded lands by keeping it on priority in agenda of the state and central governments, research and extension institutions, policy planners and financing agencies engaged in the land reforms and agricultural production. Solutions must be result oriented, cost-effective, affordable, fast-working, income increasing and improving quality of life of the people and above all sustainable to the land management practices.

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Conjoint use of NPK briquette and trash manure for sugarcane ratoon in a slightly saline Inceptisol

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ABSTRACT

A field experiment was conducted on *Inceptisol* to study the efficiency of NPK briquette along with trash manure for sugarcane ratoon at Central Sugarcane Research Station, Padegaon, in Satara district of western Maharashtra. The experiment was carried out for three years (2009-10, 2010-11 and 2011-12) in a randomized block design with eight treatments. The application of 75 per cent recommended dose of NPK fertilizer through briquette was found beneficial in terms of yields of sugarcane ratoon (107.02 t ha^{-1}) and commercial cane sugar (14.81 t ha^{-1}). The fertilizer applied through straight fertilizers @ 100 per cent NPK RD either by conventional or by crow bar methods and fertilizer applied through briquette @ 75 per cent NPK RD by crow bar were found equally effective in terms of cane and commercial cane sugar yields indicating the 25 per cent saving of recommended dose of NPK fertilizer for sugarcane ratoon. The higher status of available N, P and K in soil at harvest recorded only in briquette treated plots might be due to deep placement as well as the slow release of N, P and K from briquette form of fertilizer. Further briquette applied along with trash *in-situ* management practice saved the cost of cultivation with better soil fertility. The differences in case of per cent commercial cane sugar under different treatments were found to be non significant. In general, the per cent use efficiency of briquette form of fertilizer is higher than the straight fertilizers in sugarcane ratoon crop.

Key words: briquette, yield, commercial cane sugar, nutrient use efficiency, sugarcane ratoon.

Introduction

The deep placement of fertilizers and use of slow release as well as nitrification inhibitors is recommended for improving the nutrient use efficiency in field crops. The use of urea super granules, urea briquette and urea-DAP briquette are the recent developments in this direction. The efficiency of briquettes for low land transplanted rice crop under anaerobic condition is amply proved (Savant *et al.*, 1992). Manuring and fertilization are costly propositions in sugarcane cultivation. The higher fertilizer costs can be significantly reduced by minimizing the present recommended dose of NPK fertilizer through the use of alternative nutrient sources such as NPK briquette and sugarcane trash. The trash is kept as mulch between rows which upon degradation adds organic matter in soil and thus raises the soil fertility without sacrificing the ratoon cane yield. Considering 40 to 45 per cent area under ratoon crop, it is necessary to test NPK briquette for sugarcane ratoon. The long duration of sugarcane crop as it stands in the field for 12 to 18 months coupled with the fact that it is a heavy feeder of nutrients, it would be logical to use sugarcane ratoon as a test crop. Keeping these facts in mind, the present investigation was carried out to assess the possibility of saving of NPK fertilizers as well as to increase the fertilizer use efficiency in sugarcane ratoon crop through the use of NPK briquette with in-situ trash organic manure. Significant improvement in all growth characters and yield of sugarcane were observed with the application of briquette form over non briquette form of NPK fertilizers (More *et al.*, 2004). The experiment was laid out in randomized block design (RBD) with three replications. The treatments consisted of T_1- Control (No fertilizer), T_2-100% NPK RD straight fertilizer by conventional method, T_3-100% NPK RD straight fertilizer by crow bar (50:50), T_4-100% NPK RD Briquette (50:50), T_5-75% NPK RD straight fertilizer by crow bar (50:50), T_6-75% NPK RD Briquette (50:50), T_7-50% NPK RD straight fertilizer by crow bar (50:50) and T_8-50% NPK RD Briquette (50:50).

Material and methods

A field experiment was conducted at Central Sugarcane Research Station, Padegaon in Satara district of Maharashtra (18° 12' N latitude, 74° 10' longitude with an altitude of 556 m above mean sea level) during 2009-

12 for three sugarcane ratoon crops grown on *Inceptisol*. The area receives 417 mm average annual rainfall. The experiment was laid out in randomized block design with eight treatments and three replications. The sugarcane harvesting was done and three successive ratoon crops were taken in three seasons. In 2009-10, sugarcane rationing date was 02/01/2009 and the harvesting was done on 29/02/2010. During 2010-1,1 second ratoon crop was taken on 25/01/2010 and its harvesting was done on 30/02/2011. In 2011-12, third ratoon crop was taken on 25/01/2011 and it was harvested on 26/02/2012.

Fertilizer application

a) Straight fertilizers

The recommended dose (RD) of N, P_2O_5 and K_2O were applied at the rate of 300:140:140 kg ha^{-1} through straight fertilizer *viz.* urea, single super phosphate and muriate of potash, respectively by conventional method (line method) of application in three split doses of 30 per cent N, 50 per cent P_2O_5 and 50 per cent K_2O at first irrigation, 30 per cent N at 60 days and 40 per cent N, 50 per cent P_2O_5 and 50 per cent K_2O at 135 days for Treatment 1. For the treatments T_3, T_5 and T_7, straight fertilizers were given with three levels of 100, 75 and 50 per cent of NPK RD in two splits of 50 per cent at first irrigation at 10 cm depth, 10 cm apart from stool on one side with keeping distance of 30 cm in between two spots, then the holes were closed with the soils and remaining 50 per cent at 135 days on opposite side by same method of application as described above.

b) Briquette form

The NPK fertilizer briquette containing N: P_2O_5: K_2O in ratio of 2.14:1:1 (same as the recommended dose of 300:140:140) were mechanically prepared by mixing of commercial grade urea, diammonium phosphate and murate of potash, with the help of briquetter using high pressure. For the treatments of briquette plots (T_4, T_6 and T_8) with three levels of 100, 75 and 50 per cent of RD, 50 per cent of RD dose of NPK were applied at first irrigation and remaining 50 per cent dose at 135 days.

The briquettes were applied at optimum moisture conditions at 10 cm depth, 10 cm apart from stool on one side with keeping distance of 30 cm in between two spots of briquette application by crow bar method, then the holes were closed with the soil. In one plot of 10 x 6 m^2 size, 180 stools were maintained giving 30,000 stools ha^{-1}. The fertilizers (urea, diammonium phosphate and murate of potash) to supply 50 % dose of RD NPK for 180 stools were calculated which was 3.75 Kg. As the briquettes were to be applied for one stool (two plants), the required quantity of fertilizers were calculated which was 20.83g. As the one briquette weight is 2.6g, the number of briquettes for one stool (two plants) was calculated which was 8 for 100 per cent, 6 for 75 per cent and 4 for 50 per cent dose of briquette. The remaining 50 per cent dose of briquette was given at 135 days by same method of briquette application as described above.

Soil samples at the beginning of experiment and after harvest of each crop were collected and used for determination of available N, P and K and other chemical properties using standard procedures. Soil samples were analyzed for pH and EC in 1:2.5 soil suspension ratio, organic carbon was estimated as per Nelson and Sommers (1982), available N by alkaline permanganate method of Subbiah and Asija (1956), available P as per method Olsen et. al.(1954) and available K was determined by flame photometer method as described by Knudesn et.al (1982). Plant samples were analyzed for total nutrient uptake as per the method given by Parkinson and Allen (1975). Cane juice quality was determined by the method of Spencer and Meade (1964) and commercial cane sugar (CCS) was calculated. The data obtained on chemical properties of soil, nutrient uptake by plants, juice quality and yield of sugarcane were analyzed statistically by using procedure laid down by Panse and Sukhatme (1995).

Results and discussion

Yield parameters

The treatment of 100 per cent NPK RD through briquette recorded significantly higher cane yield (112.41 t ha^{-1}) and CCS yield (15.70 t ha^{-1}) and it was statistically at par with 75 per cent NPK RD through briquette (107.02 and 14.81 t ha^{-1}, respectively). Whereas in case of average cane weight, the treatment of 100 per cent NPK RD briquette in two equal splits (1.11), 75 per cent NPK RD briquette in two equal splits (1.13), 100 per cent NPK RD straight fertilizer by conventional method (1.08 t ha^{-1}) and 100 per cent NPK RD straight fertilizer by crow bar in two equal splits (1.06) were statistically at par and significantly higher than rest of the treatments. While in case of number of millable canes per hectare, the treatment of 100 per cent NPK RD through briquette in two equal splits (101.06 "000" ha^{-1}) was found significantly superior over all other treatments. The fertilizer applied through straight fertilizers @ 100 per cent NPK RD either by conventional or by crow bar methods and fertilizer applied through briquette @ 75 per cent NPK RD by crow bar were found equally effective in terms of cane and commercial cane sugar yields. From the results, it is seen that considering cane and commercial cane sugar yields the application of fertilizer through briquettes can save 25 per cent recommended dose of NPK. There was better survival of plants in briquette treated plots which can be attributed to the better and longer availability of N, P and K due to deep placement (10 cm) of NPK briquettes in soil along with organic manures derived from *in situ* trash management in ratoon crop. These results are in agreement with the findings of Kadam (1986) and Bangar and Sharm (1992) in case of application of USG for sugarcane. Similarly, Jadhav et al. (2000) observed that keeping trash in furrow with pocket application of NPK fertilizers in two equal splits (15 days after ratooning and 135th days after ratooning) in five successive ratoon crops recorded significantly higher cane and CCS yields than conventional practice of trash burning. Further, Kadam et al. (1991) and Nasir Ahmed et al. (1992) observed that the deep placement (10 cm) of nitrogenous fertilizers significantly increased the cane yield over the line method of application of N fertilizers. More and Shinde (1998) also noted the superiority of NPK briquette over non briquette fertilizer in sugarcane crop. Considering quality parameter, results in case of commercial cane sugar per cent were non-significant indicating there is no significant differences in commercial cane sugar per cent due to briquette and straight fertilizer application (Table 1).

Soil studies

The data presented in Table 2 indicated that the soil EC was not significantly influenced under different treatments. However, the soil pH, organic carbon and available N, P and K significantly differed from each other. The higher status of available N, P and K in soil at harvest was recorded only in briquette treated plots which might be due to deep placement and slow release of nutrients from NPK briquette fertilizer. We noted higher status of organic carbon and available N, P and K in soil at harvest by the application of both 100 per cent and 75 per cent NPK RD through briquette along with *in situ* trash management in ratoon crops. This could be attributed to the better availability of nutrients in soil for longer period of time. Jadhav et al. (2000) also reported that keeping trash in furrow with pocket application of chemical fertilizers in two equal splits, first at one side within 15

Table 1. Effect of different treatments on yield parameters of sugarcane ratoon (2009-10, 2010-11 and 2011-12)

Treatments	NMC (“000” ha^{-1})	ACW (Kg)	Cane yield (t ha^{-1})	CCS (%)	CCS (t ha^{-1})
T_1	71.62	0.67	51.55	7.01	13.65
T_2	90.90	1.08	98.62	13.66	13.88
T_3	92.07	1.06	98.00	13.58	13.88
T_4	101.06	1.11	112.41	15.70	13.98
T_5	80.73	1.02	86.73	12.05	13.92
T_6	96.83	1.13	107.02	14.81	13.89
T_7	81.14	0.93	75.05	10.44	13.91
T_8	87.40	0.93	82.88	11.74	14.18
SE(m) ±	1.16	0.03	3.39	0.50	0.16
CD at 5%	3.50	0.08	10.29	1.50	NS
CV %	-	-	6.61	6.95	-

*ACW: Average Cane Weight, NMC: Number of Millable Canes, CCS: Commercial Cane Sugar.

Table 2. Effect of different treatments on soil chemical properties at harvest (2009-10, 2010-11 and 211-12)

Treatments	pH	EC (dS m^{-1})	O.C. (g kg^{-1})	Available nutrients (kg ha^{-1})		
				N	P	K
Initial status	8.04	0.21	6.50	289.00	27.00	310.00
T_1	7.81	0.21	6.00	261.85	21.53	247.20
T_2	7.38	0.23	7.70	305.55	27.54	288.19
T_3	7.58	0.20	7.40	316.65	37.68	302.32
T_4	7.52	0.20	7.80	324.85	37.76	332.72
T_5	7.76	0.20	7.00	313.30	27.46	291.31
T_6	7.57	0.25	7.20	320.49	31.43	318.31
T_7	7.70	0.25	7.40	304.69	20.00	289.80
T_8	7.66	0.22	7.30	307.31	21.19	268.26
SE(m) ±	0.07	0.04	0.30	4.49	3.19	9.11
CD at 5%	0.22	NS	0.80	13.62	9.69	27.63

Table 3. Effect of different treatments on nutrient uptake by sugarcane ratoon (2009-10, 2010-11 and 2011-12)

Treatments	Nutrient uptake (Kg ha^{-1})			Nutrient utilized by sugarcane (Kg tonne^{-1})		
	N	P	K	N	P	K
T_1	121.59	37.07	137.27	2.40	0.58	2.69
T_2	214.95	64.96	225.66	2.19	0.66	2.29
T_3	306.76	60.72	339.99	3.21	0.63	3.54
T_4	330.00	78.88	366.27	2.96	0.72	3.28
T_5	175.62	51.79	207.95	2.03	0.60	2.40
T_6	240.63	61.35	292.08	2.27	0.70	2.77
T_7	170.10	41.74	199.88	2.28	0.60	2.66
T_8	181.24	45.48	237.81	2.20	0.66	2.88
SE (m)$\pm$	6.66	2.32	2.60	-	-	-
CD at 5%	20.20	7.03	7.90	-	-	-

Table 4. Use efficiency of N, P and K by use of briquette and non briquette forms of fertilizers (2009-10,2010-11 and 2011-12)

Treatments	Fertilizer use efficiency (%)				Per cent increase of FUE of briquette over non briquette form of fertilizer		
	NUE	PUE	KUE	Mean			Mean
T_1	-	-	-		-	-	-
T_2	43.43	42.93	39.17	41.84	-		
T_3	60.36	38.95	59.62	52.98	-		
T_4	63.16	53.01	62.52	59.56	4.42	26.53	4.63
T_5	30.77	28.43	33.99	31.06	-	-	-
T_6	49.47	39.58	53	47.35	37.81	28.18	35.87
T_7	28.52	11.19	31.32	23.68	-	-	-
T_8	32.91	18.5	42.28	31.23	13.85	39.51	25.91
Mean	-	-	-	18.53	31.41	22.14	24.02

*FUE: Fertilizer use efficiency, NUE: Nitrogen use efficiency, PUE: Phosphorus use efficiency, KUE: Potassium use efficiency

days after date of ratooning and second on opposite side on 135th day of ratooning in five successive crops maintained the higher level of organic carbon, and available N, P and K in soil at harvest. Talekar and Dongale (1993) and Deshmukh and Tiwari (1996) observed better USG for rice crop in case of available N. More and Shinde (2002) reported higher available N, P and K content in soil at harvest with the use of NPK briquette in sugarcane.

Nutrient uptake

Application of 100 per cent NPK fertilizer dose through briquette recorded significantly higher uptake of NPK (330.00,78.88 and 366.27 kg ha^{-1} respectively) and it was superior over other treatments indicating maximum utilization of N, P and K might be due to better availability of these nutrients in soil for longer period (Table 3). More (1999) and Kadam et al. (1991) obtained higher uptake of NPK and N in sugarcane by the use of NPK briquette and USG, respectively placed at 10 cm depth in soil . In general 2.19 to 3.21 Kg N, 0.58 to 0.72 Kg P and 2.29 to 3.54 Kg K were utilized by sugarcane to produce one tonne of cane yield.

Fertilizer use efficiency

The use efficiencies of nitrogen (NUE), phosphorus (PUE) and potassium (KUE) were maximum with the use of 100 per cent NPK RD through briquettes (63.16, 53.01 & 62.52 per cent respectively). Similar trends were also noticed when 75 per cent and 50 per cent NPK RD was applied through briquette. The results indicated that per cent increase of fertilizer use efficiency (FUE) was also maximum *i.e.* 11.86, 33.95 and 26.26 per cent in all levels of NPK briquette form of fertilizers. From the results, it is evident that the average per cent increase in FUE of briquette over straight fertilizer was 24.02 % (Table 4).

Table 5. Cost of fertilizer and economics of sugarcane under different treatments (2009-10, 2010-11 and 2011-12)

Treatments	Nutrient applied ($kg\ ha^{-1}$)			Yield ($t\ ha^{-1}$)	Mon. Returns ($Rs.ha^{-1}$)	Cultivation cost ($Rs.ha^{-1}$)	Net returns ($Rs.ha^{-1}$)	B:C Ratio
	N	P	K					
T_1	00	00	00	51.55	95367	-	-	-
T_2	300	140	140	98.62	182447	37259	145188	3.90
T_3	300	140	140	96.34	178229	38579	139649	3.62
T_4	300	140	140	112.41	207959	33861	174098	5.14
T_5	225	105	105	86.73	160451	36168	124283	3.44
T_6	225	105	105	107.02	197987	30169	167818	5.56
T_7	150	70	70	75.05	138843	33756	105087	3.11
T_8	150	70	70	82.88	153328	26477	126851	4.79
SE (m)$\pm$	-	-	-	3.39	6275.07	-	6275.07	0.037
CD at 5%	-	-	-	10.29	19033.3	-	19033.3	0.11

1. **Rates of fertilizer**:
   Urea = Rs.5.63 kg^{-1}, SSP = Rs.11.88 kg^{-1}, DAP = Rs. 21.00 kg^{-1} , Decomposting culture = Rs. 40.00 kg^{-1}
2. **Cost of cultivation**: 1.Rs.27011 ha^{-1} (excluding cost of fertilizer and manures & including application cost for conventional method)
   2. Rs. 17174 ha^{-1} (Excluding cost of briquette and including application cost of briquette)
3. **Manuring cost of briquette:** Rs.3.0 Kg^{-1}
4. **Application cost of briquette(16 labour unit per hectare):** Rs. 1920 ha^{-1}
5. **Cane price**: Rs.1850 t^{-1}

Economics

The data presented in Table 5 clearly indicated that application of NPK fertilizer @ 75 per cent NPK RD through briquette gave higher monetary returns (Rs. 197, 987 ha^{-1}), net profit (Rs.167, 818 ha^{-1}) and B: C ratio (5.56) with saving of 25 per cent NPK dose.

Conclusions

The application of fertilizer through briquette by crow bar method (50 per cent at planting and 50 per cent 135 days after start of rationing) was found beneficial for increasing cane and commercial cane sugar yield and for maintaining the soil fertility. Further, in combination with *in situ* trash management it can also save 25 per cent of the recommended dose of NPK for sugarcane ratoon crop.

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Assessment of soil quality degradation due to salinity and sodicity in Mula command area of Ahmednagar district (M.S.)

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ABSTRACT

Detailed soil survey was carried out in distributory No. 2 of Mula command area in Ahmednagar district of Maharashtra. Soil survey interpretations revealed that the soils in Mula command area are mainly developed due to the fluvial action from the basaltic alluvium and the major soils are Inceptisol and Vertisols. Taxonomically, soils were classified as Typic Haplustepts (P_1 and P_3) , Vertic Haplustepts (P_2, P_4 and P_5), Sodic Haplusterts (P_6, P_7, and P_9) and Sodic Calciustert (P_8). The physical and chemical properties of the soils varied greatly and the soils in general were very high in clay (52.0 to 71.0 %), high in bulk density (1.42 to 1.83 Mg m^{-3}) and low in the hydraulic conductivity (0.08 to 1.52 cm hr^{-1}). The soils were moderately to strongly alkaline (pHs 8.10 to 9.16) with electrical conductivity of saturation extract (ECe) varying from 1.41 to 7.40 dS m^{-1}, ESP from 6.58 to 27.23 and highly calcareous in nature. The area affected due to soil salinity and sodicity in the command under study was 22.39 %; out of which 6.11% was saline, 6.18 % saline-sodic and 10.10 % was sodic in nature. Based on the degree of degradation, the wheat yield at different ESP levels increased with the application of gypsum, SWPMC and FYM over RDF. The highest grain yield was recorded under the treatment of ESP level < 5.0 (yield 36.33 q ha^{-1}) whereas highest yield reduction (48.66 %) was recorded in the ESP level of 20 to 25. The soils associated with pedon P_6, P_7, P_8 and P_9 were unsuitable (N_1) for sugarcane and soybean, but marginally suitable (S_3) for wheat and cotton. However, the soils associated with pedon P_1, P_2, P_3, P_4 and P_5 were marginally suitable (S_3) for sugarcane and soybean cultivation but moderately suitable (S_2) for wheat and cotton due to moderate limitations of ESP, drainage, hydraulic conductivity and low fertility status of soil. The soil quality index was high (1.25) for soils of midland region, while it was low (0.79) in the tail region owing to soil degradation due to salinity and sodicity. The Ca:Mg ratio was found to be the most predominant soil quality indicator followed by organic carbon, ESP, CEC/clay and EMP in determination of soil quality. Thus, the soil quality in Mula command area was severely degraded in tail region as compared to head and mid region due to salinity and sodicity.

Key words: command area, land suitability evaluation, salinity, sodicity, soil survey, soil quality, wheat yield

Introduction

The phenomenon of increase in population of both humans and animals in the last century and intensification of agriculture with fast growing industrialization and urbanization in the last few decades have overstrained the natural resource base, which have been getting degraded much faster than ever before. The sign of fatigue in the natural resources is a cause for serious concern to the planners, decision makers and researchers. The database available from soil survey and its interpretation is of great use for optimization of land use on sustainable basis. The soil conditions in the irrigated areas of Maharashtra are fragile and especially the soils of canal command areas are prone to degradation due to salinity and sodicity owing to insufficient management of canal irrigation water, slow permeability due to smectitic predominance, scanty rainfall and high temperature resulting in accumulation of salts. The area affected by salinity and alkalinity in Maharashtra mainly occurs in the canal command areas of Ahmednagar, Solapur, Pune, Dhule, Jalgoan, Nasik, Satara and Sangli districts. Suryawanshi and Deshpande (1998) reported considerable productivity decline in sugarcane due to introduction of irrigation in shrink- swell soils. The severity of salinity and sodicity of these soils is being further aggravated by the semi- arid climate, topography of the land, indiscriminate use of water and restricted drainage. Soil salinity/sodicity is one of the most serious forms of soil quality degradation affecting approximately 10 per cent of the total land surface of the globe. In Maharashtra state about 0.54 million ha of black soils are initially reported to be salt affected which has increased to 1.06 million ha and is about 3.4% of geographical area (Gaikwad and Challa, 1996).

The soils of Mula command area initially were normal under rainfed conditions before introduction of canal irrigation in 1972. The increasing land degradation is causing serious decline in crop productivity and soil sustainability which needs to be arrested by proper management. In this context, the present investigation was therefore, planned for developing the database on soil quality degradation due to salinity and sodicity and its relation with crop productivity in distributory no. 2 (Dy. No.2) of Mula command area of Ahmednagar district, Maharashtra.

Materials and methods

The study area is a part of Mula command area in Rahuri Tahsil of Ahmednagar district of Maharashtra state. The area comprises of Kendal Bk, Kendal Kd and Chandkapur villages in Rahuri Tahsil. The study area is located between 19^{0}51¢ to 19^{0} 54¢ N latitude and 74^{0} 21¢¢ to 74^{0} 25¢ E longitude and covers a total area of 688.53 ha. Its elevation is 502 m above mean sea level and is suited about 15 km east to Rahuri town on both sides of distributory No.2 of Mula right bank canal. The soils of study area are slight to severely salt affected, nearly leveled to very gentle slopping midlands of low lying area of lower and upper pedimont plains (basin shape topography). The slope gradient of study area ranges between 1 to 3 per cent and due to land leveling the natural drains are found to be devastated. The climate of study area is semi-arid tropical and characterized by hot summers (March to May) and general dryness in other months except in rainy season (June to September). The average rainfall of study area is 535.4 mm and the soil moisture regime is ustic and soil temperature is hyperthermic.

The standard methodology of detailed soil survey was followed. The survey of India (SOI) topographical sheets in 1:50,000 scale (47 I/11) were used to collect topographic information. The toposheets were used for location of sample areas, ground truth sites and planning for traverse routes in the field and cultural details. A cadestral map of the area given in the scale of 1:8000 was used as a base map for delineating boundaries and number of soil sample spots of scale 1:250 m was used. In each class, one representative pedon was dug out and examined morphologically (Soil Survey Staff, 2006). Nine representative typifying pedons were selected for this study (Table 1). Horizon wise soil samples were collected, processed and analysed using standard analytical techniques. The soil samples were analysed for physical and chemical properties by using standard procedures (Jackson 1958 ; Page *et al.* 1982; Piper 1966) and the FAO approach of land suitability evaluation (FAO 1976 ; Sys *et al.,*1993) was used for interpretation of soil survey database and land use suggestions. Among the saline and sodic soil units, the degree of degradation was categorized (Richards 1968) based on pHs, ECe and ESP of the saturation extracts of the soils and the extent of the degradation in each class was assessed by making further classes in each category. Based on the degree of degradation, the field experiment on farmers field having variable ESP was conducted during 2007-08. The soil units having ESP in the groups of < 5, 5 to 10, 10-15, 15 to 20 and 20 to 25 were selected. The soil quality index was determined as per the procedure given by Sharma *et al.* (2008). The land suitability evaluation for sugarcane, wheat, cotton and soybean was carried out by using the procedure outlined by Seghal (1996).

Results and discussion

Morphological properties

The structure of soils was moderate to strong sub-angular blocky, but coarse strong angular blocky structure was noticed particularly in slickenside zone. This may be due to swell-shrink phenomenon of smectitic clay dominantly present in these soils resulting in the development of slickensides (Coulombe *et al.* 1996). The soils had high stickiness and plasticity and showed slight to strong effervescence. Vertisols showed well developed intersecting slickensides and developed deep cracks in summer indicating high swell-shrink potential which is due to dominantly smectitic clays. On drying, the soils turned very hard rendering tillage impossible and

Table 1. Details of the pedon, their location, taxanomic classification and tentative soils series

Pedon No.	Location	Taxanomic classification	Identified soil series
P$_1$ -Mid region	Survey No. 17 Village : Chandkapur	Typic Haplustepts	Chandkapur-1
P$_2$- Head region	Survey No. 50Village : Chandkapur	Vertic Haplustepts	Chandkapur-2
P$_3$- Mid region	Survey No. 51Village: Kendal Kd.	Typic Haplustepts	Kendal Kd-1
P$_4$- Head region	Survey No. 255Village: Kendal Kd.	Vertic Haplustepts	Kendal Kd-2
P$_5$- Tail region	Survey No. 167/2Village : Chandkapur	Vertic Haplusterts	Chandkapur-3
P$_6$- Mid region	Survey No. 247/2Village : Kendal Bk.	Sodic Haplusterts	Kendal Bk-1
P$_7$- Tail region	Survey No. 238 Village : Kendal Kd.	Sodic Haplusterts	Kendal Kd-3
P$_8$- Tail region	Survey No. 177Village : Kendal Kd.	Sodic Calciusterts	Kendal Kd-4
P$_9$- Head region	Survey No. 196Village : Kendal Bk.	Sodic Haplusterts	Kendal Bk-2

excessively sticky when wet. The soils in general, dark grayish brown which is due to the basic igneous parent rock rich in ferromagnesian minerals that weather into dark colored soils. The texture of the soils is clayey because of fine grained basaltic parent material.

Physical properties

The particle size distribution showed that majority of the soils had fairly high amount of clay (Table 2). The clay content in different horizons varied from 52.0 to 71.0 per cent. Basalt, being the parent material of these soils is known to produce higher amount of clay. (Murthy *et al.,* 1994). The bulk density of soils ranged from 1.42 to 1.74 Mg m^{-3} which may be due to higher amount of organic carbon and plant root concentration. The Bss horizon of P_9 and P_7 had higher bulk density than the surface and sub-surface horizons which may be due to high clay content resulting in greater compaction of swelling clay soils (Ahuja *et al,* 1988). The hydraulic conductivity was low (0.08 to 1.52 cm hr^{-1}) and it was drastically reduced in the subsoil horizons of the soils of tail region of the command. The lowest values of hydraulic conductivity in sodic soil could be due to increase in sodiumized clay and high dispersion index (Table 2) indicating impairment in physical conditions of the soil. It is generally observed that the soils having high ESP have lower hydraulic conductivity value (Pal *et al.*, 2000) resulting in poor internal drainage conditions. This was also associated with base saturation exceeding 100 per cent. The excess of 100 % base saturation was due to soil modifiers like Zeolites mineral, which decreases the hydraulic conductivity by supplying Mg^{2+} ions to the soil system (Pal *et al.,* 2006).

Chemical properties

The overall pHs values of the studied soils ranged from 8.10 to 9.16, suggesting that soils are moderately to strongly alkaline (Table 2). The increase in pH with depth was observed in the soil profiles. The high pH of more than 9 in some soil horizons is because of calcification during pedogenesis where presence of sodium carbonate and bicarbonate accumulation increases the soil pH. The Electrical conductivity of saturation extract (ECe) varied from 1.41 to 7.40 dSm^{-1} with irregular trend in different horizons. It was more than 4 dS m^{-1} in the soil horizons categorizing them under saline phases which were further categorized into salinity classes in different soil units. The soils under continuous irrigation rises the water table causing secondary salinization or sodiumization. The variability in pH and salinity in different horizons indicates different stages of alkalization and salinization associated with rising water table. The exchange complex of the soils was dominantly saturated with calcium followed by magnesium, sodium and potassium. The concomitant decrease in exchangeable calcium and magnesium with increasing depth due to calification was noticed. The CEC was in general high which ranged from 46.8 to 62.4 cmol (p+) kg^{-1} in different horizons. The higher CEC is attributed to the dominant smectitic mineralogy of these shrink- swell soils (Pal and Deshpande, 1987). The soils had high base status throughout the soil horizons. The ESP of the soils varied from 6.58 to 27.61 in different profiles and showed increasing trend with depth. The soils with high sodium on the exchange complex (ESP >10) in association with high clay content of smectitic nature showed the problems and caused severe restriction in the drainage. The threshold value of 15 ESP for a soil to be termed as sodic is not sacrosanct and physical properties could deteriorate at values lower than this. An ESP limit of 5 has been suggested by Balpande *et al.* (1996) for alkali subgroup of Vertisols in central India that have smectitic content. Sharma *et al.* (1997) reported that an ESP of 5 and 6 in Vertisols could cause considerable deterioration in physical properties.

Most of the soils were calcareous with free $CaCO_3$ content varied from 82.0 to 172.5 g kg^{-1}. The $CaCO_3$ showed increasing trend with depth in the profile. Formation of pedogenic calcium carbonate is the prime chemical reaction responsible for the increase in pH with depth and in the development of sub-soil sodicity (Srivastava *et al.* 2002). Pal *et al*. (2000) advocated that formation of pedogenic $CaCO_3$ has been active in semi-arid climates which is responsible for the development of sodicity. The organic carbon content of soils ranged from 4.50 to 10.9 g kg^{-1} in different pedons and decreased drastically in sodic soils as compared to other soil profiles. The low organic carbon in sodic soils is attributed to the high sodium, high pH and low biological activity in these soils, which is not conducive for both the accumulation of organic matter and its mineralization (Naidu and Ranasamy, 1993).

Kind and degree of land degradation

The soils were categorized into saline, saline-sodic and sodic soils using the criteria of U.S. Soil Salinity Laboratory based on the diagnostic parameters like pHs, ECe and ESP. It revealed that 22.39 per cent soils are found to be degraded out of which 6.11 per cent are saline, 6.18 per cent and saline-sodic and 10.10 per cent are sodic (Fig. 1). These soils are further subdivided as moderately saline soils (92.90 %) and strongly saline soils (7.10 %) based on the degree of degradation. The saline-sodic soils are further divided into moderately saline-sodic (87.22 %) and strongly saline-sodic (12.78 %). The sodic soils are further subdivided as moderately sodic (92.77 %) and strongly sodic soils (7.23 %).

Yield reduction in wheat based on degree of degradation

Based on the degree of degradation, the highest (36.33 q ha^{-1}) grain yield of wheat was recorded under

Table 2. Physical and chemical properties of soil

Horizon	Depth (cm)	pHs	ECe (dSm-1)	O.C. (g kg-1)	$CaCO_3$ (gkg-1)	Exchangeable Cations (cmol(p+)kg-1)					CEC (cmol(P^+) kg-1)	ESP (%)	Clay (%)	B.D. (Mg m-3)	Disp. Intex	H.C. (cm h-1)
						Ca^{2+}	Mg2+	Na+	K+	sum						
Pedon 1 : Chandkapur (Fine, Smectitic hyperthermic Typic Haplustepts)																
Ap	0-22	8.10	5.92	10.9	95.0	32.0	17.2	3.91	1.43	54.6	59.4	6.58	66.0	1.48	15.07	0.58
Bw_1	22-39	8.15	5.08	8.0	110.0	30.0	16.0	4.77	1.48	52.4	58.4	8.17	68.0	1.52	17.10	0.47
Bw_2	39-62	8.12	4.93	7.4	112.5	28.8	16.4	6.07	1.69	53.1	57.0	10.65	68.4	1.56	19.94	0.43
Bw_3	62-88	8.20	5.71	7.0	127.5	26.0	16.6	8.25	1.74	52.6	55.6	14.84	67.5	1.54	17.17	0.46
Bk_1	88-120	8.25	5.29	7.0	155.0	23.2	15.2	6.51	1.64	46.7	54.4	12.76	69.0	1.50	20.10	0.40
Bk_2	120-150	8.30	4.72	6.2	165.0	20.8	14.8	6.94	1.79	44.5	50.4	12.92	67.0	1.46	22.29	0.42
Pedon 2 : Chandkapur (Fine, Smectitic hyperthermic Vertic Haplustepts)																
Ap	0-28	8.10	7.40	10.0	82.5	32.0	20.0	5.21	1.54	58.8	62.4	8.35	61.50	1.42	19.04	0.31
Bw_1	28-62	8.15	6.70	7.0	107.5	32.0	18.0	7.38	1.64	59.1	57.0	12.95	62.00	1.46	22.07	0.18
Bw_2	62-80	8.20	6.34	6.6	127.5	29.2	19.6	6.67	2.00	60.0	55.6	12.10	69.00	1.52	25.82	0.23
Bk_1	80-120	8.15	5.71	5.8	175.0	26.0	18.0	6.70	2.05	53.9	51.6	12.98	58.00	1.47	21.87	0.28
Bk_2	120-150	8.14	5.63	5.7	168.0	25.2	19.2	5.54	1.92	54.9	51.3	10.99	57.00	1.45	20.12	0.22
Pedon 3 : Kendal Kd (Fine, Smectitic hyperthermic Typic Haplustepts)																
Ap	0-18	8.50	4.93	9.6	75.0	33.6	17.6	9.55	1.13	61.88	52.6	15.81	52.00	1.50	33.10	0.78
Bw_1	18-42	8.55	4.72	7.4	95.0	31.2	16.8	9.98	1.23	59.24	58.0	17.21	54.00	1.54	38.08	0.64
Bw_2	42-79	8.60	4.65	6.6	105.0	28.0	15.2	10.4	1.08	54.70	56.8	18.34	58.00	1.58	40.93	0.60
Bw_3	79-115	8.60	4.44	6.4	110.0	25.2	16.8	10.8	1.74	54.64	57.6	18.84	55.00	1.56	43.79	0.62
Bk	115-150	8.65	4.30	5.8	115.0	23.2	16.0	9.98	1.84	51.01	60.4	18.97	56.00	1.58	44.91	0.55
Pedon 4 : Kendal Kd (Fine, Smectitic hyperthermic Vertic Haplustepts)																
Ap	0-21	8.98	4.58	8.0	95.0	30.0	18.00	8.25	1.08	57.31	48.0	17.18	64.00	1.55	36.10	0.28
Bw_1	21-58	8.80	4.44	6.8	105.0	28.4	15.6	9.11	1.18	54.30	51.0	17.86	69.00	1.58	42.00	0.24
Bw_2	58-102	8.90	4.37	6.0	110.0	23.2	16.0	9.88	1.74	50.90	53.8	18.55	67.00	1.56	46.12	0.27
Bw_3	102-125	8.85	4.30	5.5	105.0	19.6	17.2	10.8	1.79	49.41	54.4	19.44	60.00	1.62	37.00	0.35
Bk	125150	8.70	4.25	5.0	102.0	20.2	18.4	11.3	1.80	51.73	55.0	20.6	59.00	1.60	38.00	0.39
Pedon 5 : Chandkapur (Fine, Smectitic hyperthermic Vertic Haplustepts)																
Ap	00-20	8.70	5.78	8.0	85.0	30.0	19.2	9.11	1.18	59.53	49.6	18.37	62.50	1.53	35.94	0.31
Bw_1	20-52	8.75	5.56	6.8	85.0	27.2	17.6	9.55	1.79	52.11	51.0	18.73	68.00	1.58	42.93	0.22
Bw_2	52-79	8.85	5.22	6.0	95.0	23.2	16.0	10.85	2.00	49.38	56.4	19.24	71.00	1.60	47.06	0.30
Bw_3	79-112	8.60	5.15	5.5	105.0	19.6	17.2	10.4	2.15	48.82	51.0	20.43	64.00	1.54	39.00	0.20
Bk	112-150	8.60	5.05	5.4	100.0	18.4	18.0	10.4	2.00	48.60	54.4	19.15	62.00	1.53	38.00	0.20

Pedon 6 : Kendal Bk (Fine, Smectitic (cal.) hyperthermic Sodic Haplusterts)																
Ap	0-19	8.70	2.33	7.40	105.0	26.80	18.00	8.24	0.72	52.1	48.60	16.95	65.00	1.60	24.50	0.12
Bw	19-51	8.65	1.97	6.80	120.0	24.80	17.20	8.68	0.92	51.6	50.40	17.20	67.50	1.64	38.50	0.08
Bss1	51-82	8.52	2.40	6.20	127.5	22.80	16.40	11.28	1.13	51.6	52.80	21.36	69.00	1.65	37.34	0.07
Bss2	82-115	8.65	1.90	5.50	152.5	19.40	16.40	10.42	1.43	47.7	53.60	19.40	64.00	1.68	34.88	0.06
Bssk	115-150	8.65	2.68	4.70	165.0	17.20	16.00	9.98	1.53	44.7	46.80	21.32	60.00	1.58	29.10	0.25
Pedon 7 : Kendal Kd (Fine, Smectitic (cal.) hyperthermic Sodic Haplusterts)																
Ap	0-23	8.60	2.18	7.60	97.50	25.20	18.00	7.81	0.92	51.9	48.00	16.27	59.50	1.64	25.03	0.15
Bw	23-48	8.55	1.97	6.60	127.5	23.20	16.80	9.11	1.02	50.1	54.40	16.75	63.00	1.72	33.00	0.11
Bss1	48-81	8.55	2.89	6.00	130.0	20.40	17.60	12.15	1.23	51.4	55.60	21.85	65.00	1.74	42.25	0.09
Bss2	81-118	8.50	2.75	4.90	155.0	18.80	17.20	13.89	1.49	51.4	52.40	26.51	63.00	1.74	44.00	0.06
Bssk	118-150	8.55	2.60	4.50	165.0	19.20	14.80	13.02	1.69	48.7	48.80	26.68	56.00	1.68	38.00	0.20
Pedon 8 : Kendal Kd (Fine, Smectitic (cal.) hyperthermic Sodic Calciusterts)																
Ap	0-22	8.98	2.25	7.20	105.0	25.2	20.80	8.24	0.92	55.2	48.4	17.02	58.00	1.65	18.03	0.22
Bw	22-51	8.95	1.97	6.40	117.0	25.6	19.20	9.98	0.97	55.7	51.60	19.34	62.00	1.67	23.05	0.19
Bss1	51-84	9.15	2.60	5.80	140.0	24.0	18.40	11.28	1.54	55.2	54.40	20.73	64.00	1.55	25.21	0.15
Bss2	84-110	9.16	2.11	4.70	155.0	19.60	19.60	13.89	2.00	55.1	57.00	27.23	60.00	1.70	26.00	0.19
Bssk	110-150	9.05	2.33	4.50	155.0	17.60	19.20	12.54	1.69	51.0	45.60	27.61	57.00	1.64	21.00	0.35
Pedon 9 : Kendal Bk (Fine, Smectitic (cal.) hyperthermic Sodic Haplusterts)																
Ap	0-17	8.75	1.90	7.20	85.0	28.0	20.0	7.38	0.89	56.2	45.60	16.18	59.00	1.74	25.94	0.15
Bw	17-46	8.70	1.83	6.80	105.0	27.2	18.0	9.55	0.97	55.7	52.40	18.22	56.25	1.80	38.86	0.08
Bss1	46-70	8.71	1.76	6.00	127.5	27.2	16.8	11.28	1.48	56.8	52.00	21.69	55.00	1.81	43.00	0.09
Bss2	70-102	8.70	1.69	5.60	147.5	24.8	16.8	13.89	1.54	57.0	51.00	27.23	57.50	1.81	39.88	0.14
Bss3	102-128	8.75	1.55	5.10	165.0	21.2	18.0	12.59	1.69	53.5	51.60	24.40	56.00	1.82	38.30	0.86
Bssk	128-150	8.75	1.41	4.80	172.5	22.0	20.0	11.28	1.59	54.9	49.60	22.74	58.00	1.83	36.30	1.52

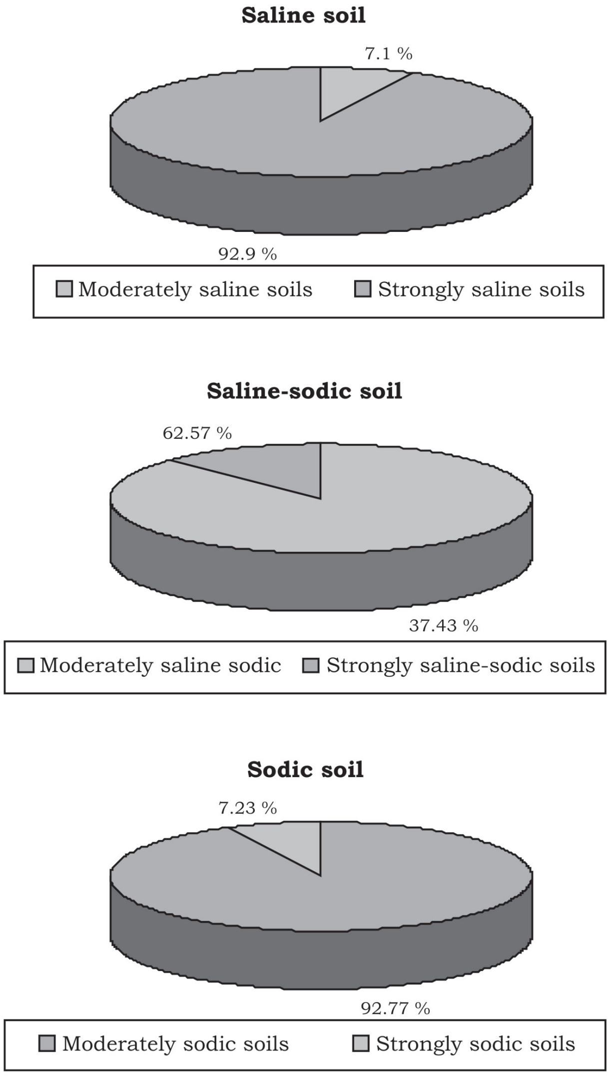

Fig. 1. Extent of severity of salt affected soils of Dy. No. 2 of Mula command area, Ahmednagar district

Table 3. Effect of soil amendments alongwith organics on grain and straw yield of wheat at different levels of ESP on farmers field

ESP levels/ Treatments	T_1	T_2	T_3	Mean
		Grain yield (q ha^{-1})		
< 5-0	34.25	36.33	38.42	36.33
5-10	31.57	33.05	33.95	32.85
	(7.82)	(9.03)	(11.63)	(9.58)
10-15	23.23	25.91	27.10	25.41
	(32.17)	(28.63)	(29.46)	(30.05)
15-20	20.25	22.63	22.93	21.93
	(40.88)	(37.71)	(40.32)	(39.64)
20-25	17.27	18.76	19.93	18.65
	(49.58)	(48.36)	(48.12)	(48.66)
Mean	25.31	27.34	28.47	
	S.E.	CD at 5 %		
L	0.51	1.54		
T	0.56	1.65		
L x T	1.25	NS		
		Straw yield (q ha^{-1})		
< 5-0	60.15	62.86	64.32	62.43
5-10	54.79	57.47	59.86	57.37
	(8.91)	(8.53)	(6.93)	(8.10)
10-15	43.78	46.75	48.24	46.25
	(27.22)	(25.59)	(25.00)	(25.92)
15-20	35.14	37.52	39.90	37.52
	(41.58)	(40.28)	(37.97)	(39.90)
20-25	31.86	33.80	34.84	33.50
	(47.03)	(46.20)	(45.83)	(46.34)
Mean	45.14	47.67	49.43	—
	S.E.	CD at 5 %		
L	1.04	3.40		
T	0.68	2.00		
L x T	1.52	NS		

T1- RDF; T2- 50 % GR +10 ton / ha FYM; T3- 50 % GR +10 ton / ha SWPMC

*figures in the parenthesis indicates per cent decrease in yield over 5.0 ESP level

the treatment of ESP < 5 level (Table 3) and the highest yield reduction (48.66 %) was recorded in the ESP level 20-25. The increase in the yield of wheat was due to response to reclamation process viz., application of gypsum and SWPMC as compared to RDF which could be attributed to the supply of calcium which has helped to replace the sodium on exchange complex of soil and production of organic acids from decomposition of organic matter present in FYM and SWPMC helps in reclamation process thereby improving physical properties like structure, bulk density, hydraulic conductivity and ultimately good drainage system.

Land suitability evaluation

The parametric approach (Seghal, 1996) was considered for evaluating land suitability for sugarcane, cotton, wheat and soybean which includes ten factors like climate, topography, wetness, salinity, sodicity etc. The soil and site characteristics of different soil units are compared with the crop requirements and the overall suitability was determined. The land associated with pedons P_6, P_7, P_9 (Sodic Haplusterts) and P_8 (Sodic Calciusterts) was not suitable (N_1) for sugarcane and cotton but marginally suitable (S_3) for wheat and soybean. These soils have the main constraints of high ESP with imperfect to poor drainage, very low hydraulic conductivity, high $CaCO_3$ and low fertility status. The soils of pedons P_1, P_2, P_3, P_4 and P_5 were marginally suitable (S_3) for sugarcane and cotton, due to severe limitations of ESP, poor drainage, fine texture with high swell-shrink potential, low hydraulic conductivity and low fertility status of these soils.

Soil quality evaluation

Soil quality index was calculated for different 40 soil units using the approach given by Sharma et al. (2008).

Table 4. Per cent contribution of soil quality indicators in assessing soil quality

Sr. No.	Soil quality indicators	Per cent contribution
1.	Ca/Mg ratio	19
2.	Organic carbon	17
3.	ESP	15
4.	CEC/clay	12
5.	EMP	10
6.	Bulk density	8
7.	Available phosphorus (kg/ha)	7
8.	HCO_3/Ca	5
9.	Available potassium (kg/ha)	3
10.	% $CaCO_3$	3
11.	% Base saturation	1

Among the 40 soil units in the command area, soil quality index ranged from 0.77 to 1.31. The highest soil quality index was obtained for Kendal Kd -2-3 (1.31) soil unit on the midland in the command area. The lowest soil quality index value (0.79) was obtained for the soils under well water irrigation (Kendal Kd-4-2). The soils in the tail region also recorded lowest value of soil quality index (Kendal Bk-1-4, 0.81). The soil quality index was low for the soils of Chandkapur -3-1 (0.83) and Chandkapur -3-5 (0.80) soil units in the lowland (Tail region) due to more degradation.

The contribution of each indicator in governing soil quality was given in Table 4. The Ca/Mg ratio was found to be most predominant soil quality indicator having highest contribution (19 %) in determining the soil quality. This was reflected earlier in the correlation of Ca/Mg with soil properties. The organic carbon in soil was found to be the next important soil quality indicator in deciding the soil quality having contribution of (17 %) which was closely followed by the contribution of Ca/Mg. It was also revealed that the ESP, the third most important soil quality indicator in governing the soil quality in command area. The soil quality index was correlated with pH, ECe, ESP and yield of major crops. It was observed that the soil quality index was negatively correlated with pH ($r = -0.45^{**}$), ECe ($r = -0.51^{**}$) and ESP ($r = -0.64^{**}$) indicating that the soil quality is affected with the increase in pH, ECe and ESP in the command area and the SQI was positively correlated with the yield of sugarcane ($r = 0.79^{**}$), cotton ($r = 0.83^{**}$) , wheat ($r = 0.75^{**}$) and soybean ($r = 0.78^{**}$) indicating that the soil quality index causes significant variation in the yield of different crops grown in the command area.

Conclusions

The soil quality index (determined by principle component analysis) was high (1.25) for soils of midland region, while it was low in the tail region (0.79) owing to soil degradation due to salinity and sodicity in tail region of the command. The Ca : Mg ratio was found to be the most predominant soil quality indicator followed by organic carbon, ESP, CEC/clay and EMP in determination of soil quality. Thus, these results indicated that the soil quality in Mula command area was severely degraded in tail region as compared to head and mid region due to salinity and sodicity

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