ISSN 0976-0806

Journal of Soil Salinity and Water Quality

Volume 7 2015 Number 1

CONTENTS

Journal of Soil Salinity and Water Quality 7(1), 1-11, 2015

Assessing the Hazards of High SAR and Alkali Water: A Critical Review

SK Gupta

ICAR-Central Soil Salinity Research Institute, Karnal -132001, Haryana

Abstract

Based on the chemical composition, waters have been classified as saline, high SAR saline, alkali and toxic. While diagnosis and assessment of hazards of saline water are quite well understood, high sodium adsorption ratio (SAR), alkali and toxic water pose several problems either in diagnostics or in assessing the hazards of such waters on soils and crops. This paper deals with the assessment of the hazards of high SAR and alkali waters on physico-chemical properties of soils. A critical review of various parameters such as SAR, adjusted SAR (Adj. SAR) and adjusted sodium hazard (adj. R_{Na}) has been made as these are commonly used to assess the soil ESP irrigated with high SAR or alkali waters. It emerged that there is need to modify the SAR equation to take care of role of magnesium alone or high Mg/Ca ratios commonly encountered in water from arid and semiarid zones. Modifications proposed in the paper needs to be tested and evaluated under varying agro-climatic conditions. While use of adj. SAR may be dispensed with, adj. R_{Na} seems to be the most promising parameter. This parameter may even make the use of RSC as redundant, which itself requires modification because soil conditions usually encountered in agriculture may not cause Mg to precipitate. Two parameters namely permeability index (PI) and soil structure stability have been considered in assessing the adverse impact on infiltration rate and soil structure. It has emerged that these parameters may prove superior over the qualitative data from FAO and Rhodes diagram commonly used for assessment purposes. It has been shown that even a good quality water having low EC and medium carbonate (CO_3 + HCO_3) content can reduce the permeability by about 25% and impact the soil structure. Finally, a stepwise procedure to assess the hazards and role of management options in getting the targeted yields is described. As we make advancements in diagnostics and assessment procedures, such management tools can be used to assess the potential of poor quality waters in agriculture.

***Key words**:* Adj. SAR, Adj. R_{Na}, Alkali water, Permeability index, Saline water, Structural stability

Introduction

The aims underlying the application of poor quality water for irrigation are to maximize the use of the water resource, to maximise production, to minimize on-site and off-site adverse impacts especially on receiving soil and vegetation and to return the nutrients to the soil vegetation system. The use of poor quality waters may prove to be counter-productive if adverse impacts/hazards eventually result in land degradation and/or loss of productivity. The key issues concerning irrigation water quality effects on soil, plants and water; and relevant parameters/indices for various hazards are as follows:

- Salinity hazard- total dissolved salts (TDS), total soluble salt content (Electrical Conductivity, EC)
- pH
- Sodium hazard- soluble sodium percent, SSP, SSP (possible), relative proportion of sodium (Na^+) to calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions (Sodium Adsorption Ratio, SAR)
- Alkalinity hazard- carbonate and bicarbonate (Residual Sodium Carbonate, RSC; Adjusted Sodium Adsorption ratio, Adj. SAR and Adjusted R_{Na} and others)
- Permeability hazard- permeability index
- Specific ions- chloride (Cl), sulphate (SO_4^{2-}), boron (B), and nitrate-nitrogen (NO_3-N) and heavy metals; their build-up in soils and crops
- Other potential contaminants- BOD, COD, and pathogenic contaminants.

Although assessment of each kind of hazard has its own procedural problems, assessment of sodium and alkali hazards has been the most misunderstood and has remained quite controversial. Therefore, it is proposed to critically look at various indices related to this hazard to understand their effect on diagnostic capability and soil infiltration rate in order to assemble reasonable guidelines. It is not claimed that this paper provides the solutions to this problem, yet an earnest attempt is made to address various issues that should enable the users to arrive at knowledgeable decisions based on the sodium and alkali hazards of irrigation water.

Materials and Methods

A critical review of commonly used indices/ parameters to assess sodium and associated permeability hazard has been made for their relative application potential. The indices/parameters included are: SSP, SSP (possible), Mg/Ca ratio, SAR, Adj. SAR with or without Mg, Adj. R_{Na}, RSC with or without Mg together with few combinations of these parameters. For permeability hazard, Rhoades diagram, FAO table, soil structure stability diagram and permeability index have been used. Based on the critical analysis, some modifications in several indices/parameters are suggested.

Seven samples of water were selected from the vast data available for the state of Haryana. These water samples belonged to seven categories of water identified as per classification of AICRP/CSSRI (Good, Marginally saline, saline, high SAR saline, marginally alkali, alkali and high SAR alkali; Table 1). All the indices/parameters discussed in this paper were assessed for all the seven samples and compared with the results anticipated from the critical analysis. Based on the critical analysis and the results obtained, recommendations have been framed to assess the sodium and permeability hazard of water. Comments in the guidelines have been added on the basis of Indian experiences. A flow chart is developed to know the potential of assessed water for its use in irrigation so as to manage targeted yields.

Critical Analysis

Sodium hazard

Eaton (1950) used soluble sodium percentage (SSP) to describe the hazard of water that contained high concentration of sodium as follows:

$$SSP = [(Na+K) * 100] / (Ca + Mg + Na+K) \quad \ldots(1)$$

Considering that anionic composition of the water is not included in the SSP, a term SSP (possible) has been proposed. It included bicarbonate ions and is calculated as follows:

$$SSP\ (possible) = [(Na+K) * 100] / [(Ca + Mg + Na+K) - (CO_3 + HCO_3)] \quad \ldots(2)$$

Such that deduction part in eq. (2) does not exceed (Ca + Mg) in the water. In essence it combines the SSP and residual sodium carbonate (RSC) as follows:

$$SSP\ (possible) = [(Na+K) * 100] / [(Na+K) - RSC] \quad RSC < 0.0 \quad \ldots(3)$$

For RSC > 0.0, SSP (Possible) =100%

Apparently SSP (possible) is higher than SSP. It is however, interesting to note that while RSC < 0.0 are of little concern, yet even the negative values of RSC are used in eq. (3). The guidelines to

Table 1. Chemical constituents of various kinds of water

Parameter	Good	Marginally saline	Saline	High SAR saline	Marginally alkali	Alkali	High SAR alkali
EC (dS/m)	0.61	2.56	6.52	14.04	1.04	1.83	2.53
pH	8.60	8.30	8.3	8.55	8.05	8.20	8.50
Na (meq/l)	2.20	7.00	30.8	103.60	6.10	12.20	21.70
Ca (meq/l)	2.10	3.00	8.3	22.64	1.50	2.70	2.10
Mg (meq/l)	1.70	9.70	19.7	12.60	3.30	3.10	1.70
Cl (meq/l)	2.20	6.00	33.00	102.00	3.60	3.80	6.80
SO_4 (meq/l)	0.90	3.10	25.40	36.75	0.50	1.70	9.80
CO_3+HCO_3 (meq/l)	4.20	13.20	6.00	2.40	7.60	13.00	10.60
Village	Allipur	Barota	Bindrala	Durjanpur	Alipur	Amunpur	Kabulpur
Block	Nissing	Nissing	Assandh	B. Khera	Nissing	Nissing	Assandh
District	Karnal	Karnal	Karnal	Bhiwani	Karnal	Karnal	Karnal

Data source: AICRP, Use of Saline Water Scheme, CCS HAU, Hisar

Table 2. Some parameter/indices for rating ground water quality for irrigation (Ayers and Westcot, 1985, Eaton, 1950 and Wilcox, 1948)

Class	SSP (%)		SAR $(meq/L)^{1/2}$ Values	Sustainability for irrigation Comment
I	<20	Excellent	< 10	Use on sodium sensitive crops such as avocados and on heavy textured soils* needs caution
II	20-40	Good	10-18	Amendments (such as gypsum, sulphitation press mud*, distillery spent wash*) and leaching needed
III	40-80 (40-60)*	Fair (Permissible)	18-26	Generally unsuitable for continuous use
IV	>80 (60-80)	Poor (Doubtful)	> 26	Generally unsuitable for use
V	(>80)	Unsuitable		

*Classification in Parenthesis by Wilcox (1955); *added by the author based on Indian experience

characterize the water on the basis of SSP are given in Table 2. Wilcox (1955) proposed a diagram relating SSP and EC and rated the water quality as excellent to good, permissible to doubtful, doubtful to unsuitable and unsuitable (Table 2). Since there are no guidelines on SSP (possible), the guidelines for SSP can be used for SSP (possible) as well. The values of SSP or SSP (possible) are rarely used in India to assess the water quality although it may provide valuable information on the water quality.

Sodium Adsorption Ratio

Most widely used parameter to assess the sodium hazard of water is sodium adsorption ratio (SAR) expressed as:

$$SAR = \frac{Na}{[(Ca + Mg)/2]^{½}} (meq/L)^{1/2} \qquad \ldots(4)$$

Here concentration of the ions is expressed in meq/L.

An unusual aspect of the SAR is that Ca and Mg have been lumped together making it controversial. Considering various opposing arguments, scientists are veering around the view that Mg does not affect the soil as adversely as Na but is not as beneficial as Ca. Being intermediate of Na and Ca, its clubbing with Ca is questionable especially for Indian conditions where Mg/Ca ratios of 2-4 are commonly encountered and even can go as high as 16 (Gupta and Gupta, 1987). AICRP guidelines stipulate that if Mg/Ca ratio is more than 3, some chemical amendments are needed to manage such kind of water (Minhas and Gupta, 1992). Thus, under Indian conditions where Mg/Ca ratios tend to increase with salinity of water, SAR may underestimate the sodium hazard of irrigation water. The only justification to club calcium with magnesium appears to be that in the past Ca and Mg were reported together and since the calcium plus magnesium is divided by 2, one need not worry much about the Mg until the Mg/Ca ratio remains around 1.0. With slight manipulation, eq. (4) can be written as:

$$SAR = \frac{Na}{\sqrt{Ca}\,[(1 + Mg/Ca)/2]^{½}} (meq/L)^{1/2} \qquad \ldots(5)$$

Apparently, SAR is underestimated with increasing Mg/Ca ratios, even though high Mg/Ca ratios are known to cause dispersion and build-up of higher ESP in soils than waters with low Mg/Ca ratios (Yadav and Girdhar, 1981). For the same amount of Na and Ca in waters, SAR will be 0.63 times the SAR of the water for Mg/Ca ratio of 4 compared to Mg/Ca ratio of 1.0. Therefore, to avoid such underestimation, eq. (4) should be used with the following stipulations:

For non-calcareous soils, actual value of Mg/Ca may be taken in eq. (5) if it is less than 1. If it is more than 1, Mg/Ca in the water may be taken as 1.0 irrespective of its value such that:

$$SAR = \frac{Na}{\sqrt{Ca}} (meq/L)^{1/2} \qquad \ldots(6)$$

For calcareous soils, limit of Mg/Ca ratio may be increased to 2.0 such that actual values below 2 are used in eq. (5). For Mg/Ca greater than 2.0, eq. (5) is given as:

$$SAR = \frac{0.82\ Na}{\sqrt{Ca}} (meq/L)^{1/2} \qquad \ldots(7)$$

It may be noted that contrary to their appearances, eq. (6) or eq. (7) do not neglect Mg but takes it equal to Ca or twice the Ca respectively. Eq. (6) has earlier been proposed by Gupta and Gupta (2002) albeit without this justification. Data in Table 3 reveal that SAR calculated with eq. (6) is more closely related to ESP of the soil than conventional SAR.

General guidelines on the use of SAR to characterize irrigation waters are given in Table 2 along with some comments on the management options. Several other Tables have also appeared in the literature making the issue quite complex because of wide differences in the guidelines. For example; tolerance of crops to SAR of the irrigation water for non-saline conditions given in Table 4 are quite high especially for moderately tolerant and tolerant crops. Since SAR in general is high in high EC waters, to have a non-saline environment with such high SAR values may not be possible. Clearly, such Tables may have limited applications under Indian conditions. Until guidelines conforming to Indian conditions are available, guidelines given in Table 2 can be safely used.

USSL Diagram for Water Quality Characterization

High SAR adversely affects the crop yield but not in isolation from EC of water. Thus, Richards (1954) combined the effect of EC and SAR in a USSL diagram which is frequently used and quoted to categorize irrigation waters. Some confusion has emerged on the use of this diagram. In this diagram, for a better quality rating of the water, water having high EC needs to have low SAR. Some users compare it with Rhoades diagram or FAO data set wherein high SAR water should have high EC to maintain the infiltration rate. These opposing contentions cause confusion. It should be noted that both these classifications are complementary and not contrary to each other. While the former is related to crop performance, later is to maintain the soil's infiltration rate. Studies have proved that for the same EC of water, high SAR water will produce lesser yields than a low SAR water (Table 5). Similar results have also been reported by Minhas and Gupta (1992). Notwithstanding other limitations, if any, USSL diagram can be safely used to have a first guess of EC and SAR hazard of poor quality irrigation waters.

Adj. SAR and Adj. R_{Na}

To overcome the limitations of SAR and considering that anions especially carbonates and bicarbonates affect the quality of irrigation water, attempts have been made to include the relevant anions and cations

Table 3. Comparison of SAR (Eq. 4) and SAR (Eq. 6) values of irrigation waters in relation to observed ESP of soils

Location	Irrigation water				Irrigated soils	
	EC (dS/m)	Mg/Ca ratio	SAR (eq. 4) $(meq/l)^{1/2}$	SAR (eq. 6) $(meq/l)^{1/2}$	SAR_e $(meq/l)^{1/2}$	ESP
Kaparda	10.8	4.4	28	59	31	60
Jelwa	5.9	8.1	23	36	28	38
Shikarpura	4.5	16.0	8	26	32	35

Table 4. Tolerance of crops to SAR under non-saline environment

Tolerance	SAR of irrigation water	Crop	Condition
Very sensitive	2-8	Deciduous fruits, nuts, citrus, avocado	Leaf tip burn, leaf scorch
Sensitive	8-18	Beans	Stunted, soil structure favourable
Moderately tolerant	18-46	Clover, oats, rice, tall fescue	Stunted due to nutrition and soil structure
Tolerant	46-102	Wheat, barley, tomatoes, beets, tall wheat grass, crested grass, lucerne	Stunted due to poor soil structure

Source: Extracted from the Australian Water Quality Guidelines for Fresh & Marine Waters (ANZECC) http://www.mfe.govt.nz/publications/water/anzecc-water-quality-guide-02/revision-water-quality.html. Adopted from Pearson (1960)

Table 5. Effect of saline water (EC 8 dS/m) with varying SAR on yields of two cropping sequences (2003-07)

SAR	Sequence 1		Sequence 2	
	Pearl millet	Wheat	Dhaincha	Wheat
control	3.03	4.14	2.09	3.69
10	1.94	3.78	1.79	3.36
20	1.53	3.52	1.67	3.12
30	1.06	2.92	1.58	2.43
40	0.56	2.58	1.44	2.10

Source: Anonymous, 2009

in evaluating the water quality. The most appealing index has been the adj. SAR, which is calculated by the following relation (Ayers and Westcot, 1976):

$$\text{Adj. SAR} = \text{SAR}\,(1 + 8.4 - pH_c) \qquad \ldots(8)$$

Such that pH_c is given as:

$$pH_c = (pk_2 - pk_c) + p(Ca+Mg) + p(Alk) \qquad \ldots(9)$$

The pHc in eq. (9) is calculated considering sum of Ca, Mg and Na for $(pk_2 - pk_c)$, sum of Ca and Mg for {p(Ca+Mg)} and sum of CO_3 and HCO_3 for {p(Alk)} using Tabulated values. The tests proved that eq. (8) over predict the sodium hazard and should be multiplied by a factor of 0.5 to evaluate more correctly the effect of HCO_3 on calcium precipitation. For several waters, values of Adj. SAR are nearly double the values of SAR (Table 6, Minhas and Gupta, 1992) but can be up to 3 times the SAR values. Some workers attempted to use eq. (9) taking Ca ignoring Mg to calculate p(Ca) instead of p(Ca +Mg). Although it resulted in lower values of adj. SAR, but that didn't resolve the overestimation problem. The overestimation has also been recognized while developing guidelines for SAR and Adj. SAR in some countries, being 2-3 times higher for Adj. SAR than SAR (Table 7). Besides, SAR values are quite low for various anticipated problems as compared to the guidelines reported in Table 2. Therefore, it is recommended that use of adj. SAR may be dispensed with except for studies related to its improvement.

For bicarbonate rich waters, where calcium precipitation is expected, Suarez (1981) proposed another equation which was reported by Ayers and Westcot (1985) in the form of Adj. R_{Na} as follows:

$$\text{Adj. } R_{Na} = \frac{Na}{[(Ca_x + Mg)/2]^{1/2}} \qquad (10)$$

Here Ca_x is the value of Ca in the water that takes care of EC_{iw} and HCO_3/Ca ratio of the water and the estimated partial pressure of CO_2 in the surface few mm of the soil. The Ca_x values represents Ca (meq/l) expected to remain in the soil solution at equilibrium. Interestingly, development of the index states that there is no precipitation of Mg. It only utilizes Ca, HCO_3 and EC of the water to calculate Ca_x. Minhas and Sharma (2006) stated that as on today, this index is most appropriate to calculate ESP development in soils. If it is so, then the role of Mg in various equations especially in RSC needs to be reassessed. Minhas and Gupta (1992) also mentioned that Adj. R_{Na} equation does not account for CO_3 in water although it is known that carbonates are more hazardous to soils than HCO_3. Currently, this issue can be resolved by taking CO_3 + HCO_3 together especially because CO_3 + HCO_3 are reported together in many cases. Yet the inclusion of Mg still remains an issue. Should the correction proposed in the SAR equation (Eq. 6 and eq. 7) be applied here as well? If yes, how? Probably more research efforts are needed in this regard.

Table 6. SAR, Adj. SAR with and without modification

EC	SAR	Adj. SAR, p(Ca+Mg)	Adj. SAR, with p(Ca)
3.2	21.4	38.2 (1.8)*	ND
1.5	19.5	41.0 (2.1)	33.1
1.4	15.8	31.6 (2.0)	25.3
1.4	13.5	26.7 (2.0)	19.6
1.4	15.8	31.6 (2.0)	25.3
1.5	11.6	25.6 (2.2)	17.4
3.0	25.0	52.6 (2.1)	35.0
1.1	4.9	10.4 (2.1)	ND
1.4	15.8	33.0 (2.1)	27.2

ND not determined because Ca+ Mg were reported together for this sample; Values in Parenthesis are ratios of Adj. SAR/SAR

Table 7. Guidelines for use of SAR and Adj. SAR of waters

Application	Anticipated problems				
	None	Increasing	Significant	High	Severe
		SAR			
Most production systems	<1	1-2	2-4	4-5	>5
		Adj. SAR			
Direct plant impact	<3	3-6	6-8	8-9	>9
Permeability of natural soil	<6	6-7	7-8	8-9	>9

Anonymous. Guide to Interpreting Irrigation Water Analysis. Spectrum Analytic Inc. Washington C.H. Ohio USA. 20 p. Comment: Values seems quite low and higher limits are used in India.

Minhas and Sharma (2006) on the other hand proposed that Adj. R_{Na} concept should be used to predict the alkali hazard of waters taking into account the dilution and dissolution processes commonly occurring under field conditions. They modified eq. (10) by considering a concentration factor, CF and a simple dissolution factor, DF and arrived at the following equation:

$$\text{Adj. } R_{Na}\text{(mod.)} = [1/(Drw/Diw)\{ET/(Drw+ET)\}^{1/2}] * \text{Adj. } R_{Na} \quad \ldots(11)$$

$$= A * \text{Adj. } R_{Na} \quad \ldots(12)$$

Values of A for the data reported by Minhas and Sharma (2006) are given in Table 9 for various cropping systems and climatic conditions. The values vary with rainfall, irrigation and ET depending upon the crop rotation. It may be noted that when the rainfall is in 60-70 cm range, factor A follows the order Rice-wheat> Maize/millet-wheat > cotton-wheat >fallow-wheat. But if rainfall is less as in two cases of fallow-wheat (30-40 cm), the factor in fallow -wheat is even higher than Maize/millet-wheat. All the data sets given in Table 8 are for the alluvial soils of Punjab and Haryana. Factors for other soils and climatic conditions need to be worked out.

Absolute Concentrations of Carbonate/Bicarbonate and Residual Sodium Carbonate

When water containing carbonates is applied, calcite is formed and Ca concentration in the soil solution goes a sea change. As such Ca does not counteract the negative effects of Na, and problems related to high Na are exuberated. Such waters may cause severe problems if used for irrigation through overhead sprinklers resulting in precipitation of calcium carbonate forming a white scale on leaves and fruits and possibilities of clogging of the irrigation equipment. Absolute concentration of bicarbonate ions in amounts greater than 10.0 meq/L also affects plant growth in other ways such as: by affecting the soil structure and mineral nutrition and by reducing the availability of iron in many plants thereby causing iron chlorosis.

Two indices are mainly used to assess the carbonates hazard of irrigation water namely direct

Table 8. Values of A of eq. (12) for various agro-climatic and cropping conditions

Rainfall (D_{rw}) (cm)	Irrigation water (D_{iw}) (cm)	ET (cm)	Modification factor, A = $[1/(D_{rw}/D_{iw})\ \{ET/(D_{rw}+ET)\}^{1/2}]$
71	38	40	0.89 (Fallow-wheat)
70	38	40	0.90 (Fallow-wheat)
35	40	42	1.55 (Fallow-wheat)
30	40	42	1.75 (Fallow-wheat)
72	53	105	0.96 (Cotton-wheat)
60	130	105	2.72 (Rice-wheat)
72	137	100	2.50 (Rice-wheat)
77	142	100	2.45 (Rice-wheat)
70	56	80	1.10 (Maize/millet-wheat)
72	62	80	1.19 (Maize/millet-wheat)

Table 9. Potential limitation of irrigation water due to carbonate level

Carbonates (meq/L)	Potential limitation
<1.5	Generally safe for irrigation
1.5 - 8.5	Increasing problem
>8.5*	Severe problem

In literature a value of 7.5 meq/l is also given; Camberato (2001). http://www.scnla.com/ Irrigation_Water_Quality.pdf

Table 10. Bicarbonate (HCO_3) hazard of irrigation water (meq/l)

RSC	None	Slight to moderate	Severe
International	1.25	1.25-2.5	> 2.5
India	<2.5	2.5-4.0	>4.0

measurement of carbonate and bicarbonate (Table 9) and the residual sodium carbonate (RSC). Often the negative impact of absolute concentrations is ignored if RSC values are within the desired range, which may not always be true as is shown later in this section.

In order to have an idea of the sodicity hazard, concept of residual sodium carbonate (RSC) has been propounded, which is given as:

$$RSC = (CO_3 + HCO_3) - (Ca + Mg) \quad \ldots(13)$$

The basic premise is that it is not the absolute bicarbonate and carbonate concentrations that are important, but instead, the relative concentrations of bicarbonate and carbonate compared to concentrations of calcium and magnesium.

This index is also controversial. While it appears in few reports, in others it is not even mentioned. In some reports it has been included in initial versions but does not find mention in the revised editions. Arguments is also made that this parameter only indicates whether the calcite is likely to be formed or not and has no diagnostic value. It is the ultimate SAR or Adj. R_{Na} likely to remain in the soil solution that will govern the quality of irrigation water. In fact, Adj. R_{Na} does not consider RSC but the absolute values of HCO_3 and Ca present in the water without making any distinction for waters having RSC or no RSC. If RSC guidelines are any indications, very low values of RSC have been recommended for no or even for severe hazard. Most reports propose severe damage at RSC (meq/l) of 2.5 (Table 10). Under the Indian condition, this value is considered safe.

Irrespective of what is stated, the parameter is widely used in India. Nonetheless, it needs a fresh look especially the way RSC is calculated. Since the conditions required to precipitate Mg do not prevail in agricultural lands, it is suggested that Mg may be taken out from the RSC equation while calculating RSC. Thus, RSC equation can be written as:

$$RSC = CO_3 + HCO_3 - Ca \quad \ldots(14)$$

Infiltration/Soil Structure Problems

High sodium concentration besides affecting crop yield adversely impact the infiltration rate, hydraulic conductivity and structural stability of the soils. In some cases, rate may be reduced to such an extent that the crop may not be able to draw enough water. The hydraulic conductivity of the soil profile might become too low to ensure adequate transport of soil moisture and even result in impeded drainage. Other problems that may be encountered are crust formation, temporary saturation of the surface soil, high pH and increased potential for diseases, weeds, soil erosion, lack of oxygen and inadequate nutrient availability. To assess irrigation water response to likely changes in infiltration and or on soil structure, several Tables and diagrams have been proposed. In some only EC and SAR are considered. Since SAR does not account for precipitation of Ca in the soil solution, the second set also takes into account the anionic composition of water. It may be mentioned that irrigation waters in India are rarely examined for this hazard although it may be important consideration to decide about the application of an amendment.

SAR and soil salinity

Values of EC that must be used with a given SAR to avoid adverse impact on infiltration rate and soil structure are given in Table 11. It may be noted that for extremely low salinity water, even low SAR may result in problems. Since it is difficult to specify universally applicable critical values of SAR and EC of irrigation water, a diagram has been devised by which the permeability hazard is assessed by ascertaining whether the SAR-EC combination lies to the left (problem likely) or to the right (no problem likely) of the threshold line (Fig. 1). Since SAR of the top soil is in near equilibrium with SAR of irrigation water when EC_e is equal to EC_{iw}, it can be

Table 11. Irrigation water quality criteria (EC, dS/m) for various SAR values of water

SAR	EC for various degrees of restriction on use		
	No	Slight to moderate	Severe
< 3	<0.7	0.7—0.2	>3
3-6	>1.2	1.2-0.2	<0.2
6-12	>1.9	1.9-0.5	<0.5
12-20	>2.9	2.9- 0.5	<0.5
20-40	>5	5 - 2.9	<2.9

Source: Ayers and Westcot (1985)

concluded that the irrigation waters having SAR, 10, 20 and 30 should not have EC of water less than 1, 2 and 3 dS/m, respectively. The tabulated values reported by Ayers and Westcot (1985) are generally higher than these values (Table 11).

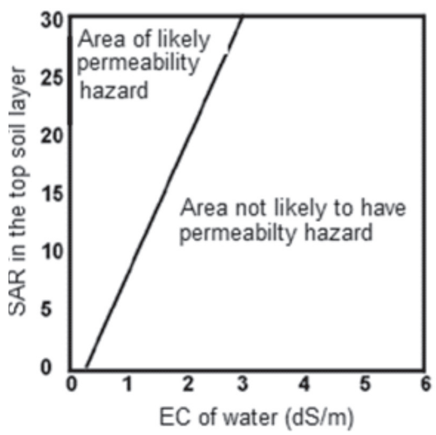


Fig. 1. Relative rate of water infiltration as affected by salinity and SAR (Rhoades, 1977)

To predict soil structural stability, a diagram showing relationship between SAR and EC has been proposed (Fig. 2). Water quality that falls to the right of the dashed line is unlikely to cause soil structural problems. Water quality that falls to the left of the solid line is likely to induce degradation of soil structure calling for corrective management (e.g. application of gypsum or some suitable amendment). Water that falls between the lines is of marginal quality and should be treated with caution depending upon the soil properties and rainfall.

Permeability Index

According to Doneen (1964), the permeability Index (PI) is calculated by using the following equation:

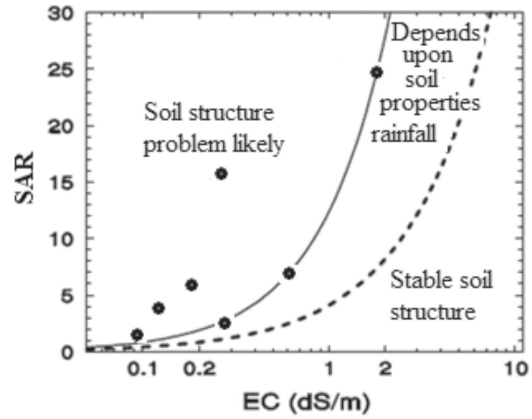


Fig. 2. Relationship between SAR and EC of irrigation water for predicting soil structural stability (Source: ANZECC, 2000)

$$PI = 100 *(Na + “HCO_3)/ (Na + Ca + Mg + K) \quad ...(15)$$

It may be noted that unlike other equation/ diagrams, it takes into account bicarbonate content of the water, although does not account for carbonates. Nonetheless, it may be possible to modify the equation by adding K and CO_3 in the numerator. The classification of the water is then made in the three groups shown in Fig. 3. Class 1 shows no problem while class II and Class III mean 25 and 75% reduction in permeability.

Applications and Discussions

Calculated water quality parameters for the seven samples reported in Table 1 are given in Table 12. SSP varies from a low value of 35.5 for the marginally saline water to 85.1 for high SAR saline

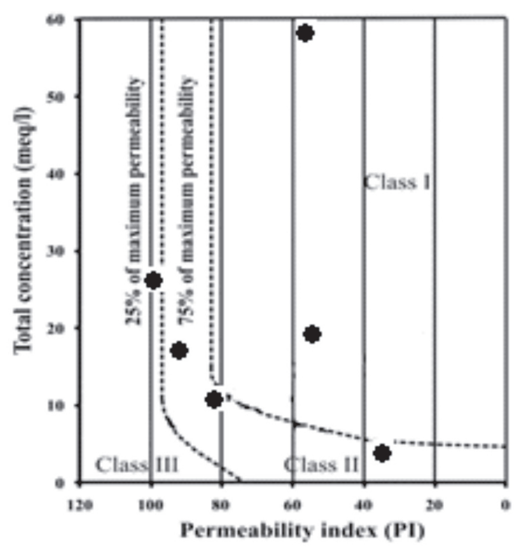


Fig. 3. Classification of irrigation water on the basis of permeability index

Table 12. Chemical constituents of various kinds on water

Parameter	Good	Marginally saline	Saline	High SAR saline	Marginally alkali	Alkali	High SAR alkali
SAR (Eq. 4) $(meq/L)^{1/2}$	1.6	2.9	8.2	24.8	3.9	7.2	15.7
SAR (Eq. 6) $(meq/L)^{1/2}$	1.6	4.0	10.7	24.8	5.0	7.4	15.7
% change in SAR	-	39.8	29.7	-	27.6	3.1	-
Adj. SAR $(meq/L)^{1/2}$	3.2	8.1	19.0	62.7	7.2	18.2	33.5
Adj. R_{Na} $(meq/L)^{1/2}$	1.8	3.1	9.1	29.4	4.3	8.8	19.5
RSC (meq/L)	0.4	1.5	Nil	Nil	2.8	7.2	6.8
RSC (meq/L)	2.1	10.2	Nil	Nil	6.1	10.3	8.5
Mg/Ca ratio	0.8	3.2	2.4	0.6	2.2	1.15	0.8
Cl/SO_4 ratio	2.4	1.9	1.3	2.8	7.2	2.2	0.7
SSP	36.6	35.5	52.3	74.6	56.0	67.8	85.1
SSP possible	100	100	58.3	75.9	100	100	100
PI (%)	33 (II)	54 (I)	57 (I)	76 (I)	81 (II)	88 (II)	98 (III)

water. SSP (Possible) varied from 58.3% for saline water to 100% for all waters having positive RSC irrespective of the RSC values. Even the water categorized as good had SSP (possible) as 100%. Although it may appear contrary to expectation, it is shown that because of low salinity and medium CO_3+HCO_3, this water may cause permeability problems. The values of Adj. SAR are the highest for all the waters and lowest with SAR equation given as eq. (4). The SAR values with modified equations suggested are equal to or higher than the values of SAR calculated with the help of eq. (4). The difference varied from as low as 3% to as high as 40% for water having Mg/Ca ratio of 3.23. For a very high Mg/Ca ratio of 16, SAR (eq. 6) was 3.25 times the SAR given by eq. (4) (Table 3). The values of Adj. R_{Na} are in between the values of SAR and Adj. SAR (Table 12). Irrespective of the RSC, precipitation of Ca resulted in higher values of Adj. R_{Na} than SAR (Eq. 4). Based on the critical review along with the analysis of permeability hazard and results presented in Table 12, it emerges that a single parameter Adj. R_{Na} may be sufficient to assess the Na hazard of irrigation water. Adj. R_{Na} of the top 30 cm of the soil can be calculated by the procedure outlined by Minhas and Sharma (2006) and shown through eq. 12 and Table 8. It has been proved that Adj. R_{Na} (modified) has one to one relationship with ESP of the 30 cm profile (Minhas and Sharma, 2006).

Based on PI, out of seven samples, 3 falls in class I (one sample plot not shown because it was out of scale of the Figure), 3 in class II and 1 in class III. While alkali waters falling in class II and III is understandable, good quality water falling in class II was critically examined and seems to be in line with the current assessment procedures often ignored by the researchers and planners. The water in question has low EC and medium carbonates content (Table 9). Thus, the water quality of this nature calls for precautions as permeability loss may be around 25%. It seems that all waters assessed for Adj. R_{Na} may also be examined for its impact on infiltration/ permeability using the PI index and Fig. 3. This analysis in association with Adj. R_{Na} would reveal whether carbonates in water irrespective of RSC will or will not be hazardous to soil permeability. To understand the adverse effect on soil structure, all water samples from Table 12 are plotted on Fig. 2. While all alkali water may cause soil structural problem, even the good quality water may result in soil structure problems as emerged from PI analysis as well. High SAR saline and other waters fall on the boundary. Clearly caution is needed even in the use of these waters. The tabulated data of Table 11 however reveal slight to moderate problems for high SAR alkali water and no problem with high SAR saline water calling for the use of Fig. 2 and Fig. 3 in the hazard analysis of waters.

From the critical analysis and assessment of water quality of selected samples, it emerges that:

- The sodium hazard can be best estimated by Adj. R_{Na} making use of SAR/RSC redundant. The next best option is to use a combination of eqs. (5) and (6) for non-calcareous and eqs. (5) and (7) for calcareous soils. In any case, use of Adj. SAR should be avoided as it may cause unnecessary confusion.

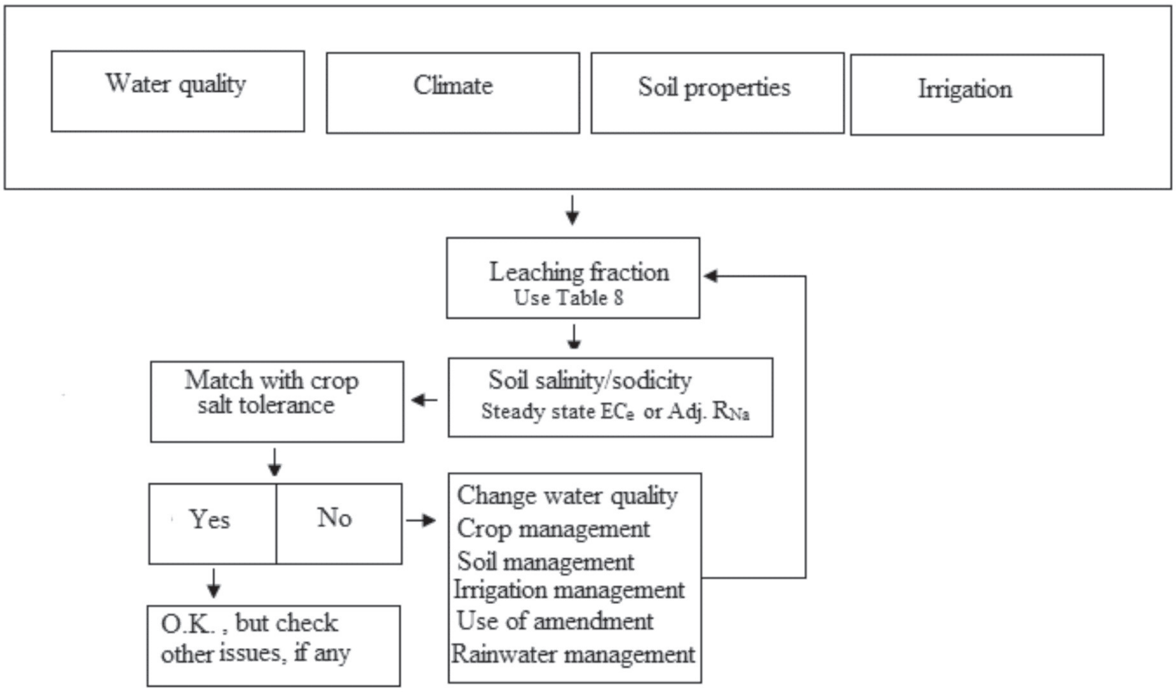


Fig. 4. Flow diagram for evaluating salinity and sodicity impacts of irrigation water

- Existing equations developed using Adj. SAR can be used by replacing Adj. SAR with Adj. R_{Na}.
- In all equations, HCO_3 alone should be replaced with $CO_3 + HCO_3$.
- Permeability index appears to be the best way to assess permeability hazard of waters.

Water quality and management options for use

In spite of our expanded knowledge on soil water chemistry, use of poor quality irrigation water has remained an art rather than a science. A major area of concern is that while art is developing, science behind the use has taken a back seat causing hardships in generalizations and upscaling of field results. The adverse impacts of the water depend upon the type of crop and its salt tolerance, the characteristics of the soil, soil and water management practices being adopted and climate especially the rainfall and its management (Fig. 4). Besides, the effect of salinity and sodicity of irrigation waters are very site specific, making it difficult to set some rigid numbers for irrigation or some other use. Therefore, a stepwise procedure to determine the suitability of poor quality water for crop production is proposed in Fig. 4. The steps include collection of data on water quality, climate (rainfall), identification of soil properties and irrigation application rates/methods. The information on these parameters is used to estimate the leaching fraction and the average root zone salinity and sodicity (Adj. R_{Na}). In the next step, the information is used to estimate relative crop yield and compared with the target yield. If inappropriate, one or a combination of the management options are identified that may help change the salt and water balance in the root zone. The process of assessment continues until target yield is achieved. If adverse impacts are expected on broader catchment issues such as regional water table, ground water pollution and surface water quality etc., these can also be included in the assessment.

References

Anonymous. *Guide to Interpreting Irrigation Water Analysis*. Spectrum Analytic Inc. Washington C.H. Ohio USA. 20 p (Year not available).

Anonymous (2009). Biennial Report (2007-08). AICRP on Management of Salt Affected Soils and Use of Saline Water in Agriculture. CSSRI, Karnal. 212p.

ANZECC (Australian and New Zealand Environment and Conservation Council) (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality: The Guidelines. Paper No. 4. Agriculture and Resource Management Council of Australia and New Zealand, Canberra. 314 p.

Ayers RS and Westcot DW (1976). *Water Quality for Agriculture*. Irrigation and Drainage Paper, 29. FAO, Rome.

Ayers RS and Westcot DW (1985).Water quality for agriculture FAO irrigation and drain. Paper No 29(1): 1-109.

Camberato (2001). http://www.scnla.com/Irrigation_Water_ Quality.pdf

Doneen LD (1964). Notes on water quality in agriculture. Published as a water science and engineering paper 4001, Department of Water Science and Engineering, University of California.

Eaton FM (1950). Significance of carbonate in Irrigation waters. *Soil Sci.,* **67**: 128-133.

Gupta IC and Gupta SK (2003). *Use of Saline Water in Agriculture: A Study of Arid and Semi-arid Zones of India*. Scientific Publishers (India), Jodhpur. 302p.

Gupta SK and Gupta IC (1987). *Management of Saline Soils and Water*. Oxford and IBH Publication Co., New Delhi, India. 399 p.

Minhas PS and Gupta RK (1992). *Quality of Irrigation Water – Assessment and Management*. Indian Council of Agricultural Research, New Delhi, 123p.

Minhas PS and Sharma DR (2006). Predicability of existing indices and an alternative coefficient for estimating sodicity build-up using adj R_{Na} and permissible limits for crops grown on soils irrigated with waters having residual alkalinity. *J. Ind. Soc. Soil Sci.* **54** : 331-338.

Pearson GA (1960). Tolerance of Crops to Exchangeable Sodium. Agricultural Information Bulletin 206, Agricultural Research Service, US Department of Agriculture, Washington DC.

Rhoades JD (1977). Potential for using saline drainage waters for irrigation. Proc. Water Management for Irrigation and Drainage. ASCE, Reno, Nevada. 85-116.

Richards LA (Ed.) (1954). *Diagnosis and Improvement of Saline and Alkali Soils*. USDA Handbook No. 60. U.S. Salinity Laboratory, Riverside, California. 160p.

Suarez DL (1981). Relationship between pH_c and SAR and an alternate method for estimating SAR of soil or drainage water. *Soil Sci. Soc. Am. J.* **45**: 469-475.

Wilcox LV (1955). *Classification and Use of Irrigation Waters*, USDA, circular 969, Washington DC, USA.

Wilcox LV (1948). *The Quality of Water for Irrigation Use*. Vol 40. US Department of Agriculture Technology Bulletin 962, Washington DC.

Yadav JSP and Girdhar IK (1981). Effect of different magnesium: calcium ratios and sodium adsorption ratio values of leaching water and properties of calcareous versus non-calcareous soil. *Soil Science* **131**: 194-198.

Received: December, 2014; Accepted January, 2015

Journal of Soil Salinity and Water Quality 7(1), 12-18, 2015

Unlocking Production Potential of Degraded Coastal Land through Innovative Land Management Practices: A Synthesis*

D Burman*, Subhasis Mandal, BK Bandopadhyay, B Maji, DK Sharma[1], KK Mahanta, SK Sarangi, UK Mandal, S Patra, S De, S Patra, B Mandal[2], NJ Maitra[3], TK Ghoshal[4] and A Velmurugan[5]

ICAR-Central Central Soil Salinity Research Institute, Regional Research Station, Canning Town – 743329, West Bengal

[1]ICAR-Central Central Soil Salinity Research Institute, Karnal- 132 001, Haryanal

[2]Bidhan Chandra Krishi Viswavidyalaya, Mohanpur- 741 252, West Bengall

[3]Ramkrishna Ashram Krishi Vigyan Kendra, Nimpith- 743 338, West Bengall

[4]ICAR-Central Institute of Brackishwater Aquaculture, Kakdwip Research Centre, Kakdwip- 743 347, West Bengal

[5]ICAR-Central Island Agricultural Research Institute, Port Blair, Andaman & Nicobar Islands-744101

[*]Corresponding author: burman.d@gmail.com

Abstract

Coastal land resources are vulnerable to various processes of land degradation like salinization, waterlogging, drainage congestion, etc. Unlocking the production potential of degraded land in coastal region is the biggest challenge towards achieving regional food security as well as contributing to national food basket. Implementing innovative land management practices like land shaping technique (LST) in combination with productive utilization opportunities of the coastal areas are major concerns. Different land shaping techniques like farm pond; deep furrow and high ridge; shallow furrow and medium ridge; paddy-cum-fish cultivation; broad bed and furrow; three tier-pair beds and brackish water aquaculture pond techniques for improving drainage facility; rain water harvesting; salinity reduction; and cultivation of crops and fish (freshwater and brackish water fish) for livelihood and environmental security were tested on about 400 ha salt-affected land in Sundarbans region of Ganges delta (West Bengal) and *Tsunami* affected areas in Andaman & Nicobar Islands. The results have been summarized. Raising of land and creating water harvesting structures reduced the problem of drainage congestion during *kharif* season and this provided the scope for growing high value crops like vegetables during this season and it also facilitated early sowing of *rabi* crops. Salinity building up in the soil of different land situations especially medium land and highland/ridges/ dikes in land shaped area was reduced and, fertility status and biological activities in soil were increased under land shaping techniques. The cropping intensity increased up to 240 % from a base level value of 100%. Land shaping techniques have increased the employment and income of the households by many times. Net income per ha of farm land increased from Rs 22000 to Rs 1,23,000 in Sundarbans and Rs 22400 to Rs 1,90,000 in Andaman & Nicobar Islands. Brackishwater aquaculture was demonstrated through shaping of land into more than 110 shallow depth ponds in Sundarbans particularly near the brackish water rivers. Farmers were benefitted from this technique with a net income of about Rs 1,43,000 ha^{-1} of pond area. Land shaping techniques were financially viable and attractive proposition for the coastal region. However, major constraints for adoption of land-shaping techniques were marginal land holdings that too divided into several parcels, high initial investment, presence of acid sulphate soils near surface or at shallow depth at places, and distance from residential village.

Key words: Land degradation, Coastal salinity, Land management, Land- shaping, Water harvesting structures

Introduction

Land resource has become scarce and is under threat of degradation. Land degradation is a major global issue because of its adverse impact on food security, livelihood and environment. It refers to a temporary or permanent decline in the productive capacity of

*The paper was presented in The National Seminar "Innovative Saline Agriculture in Changing Environment" held by Indian Society of Soil Salinity & Water Quality at Rajmata Vijayaraje Scindia Krishi Vishwa Vidayalaya, Gwalior (12-14 December, 2014).

the land or its potential for environmental management (Scherr and Yadav, 1996). Land degradation is intrinsically linked with the degradation of other natural resources like, soil, water, forests and biodiversity. Land degradation is increasing in severity and extent in many parts of the world. About 24% of land in the world has been affected by various forms of land degradation (Nkonya *et al.*, 2011). This degraded area is equivalent to the annual loss of about 1 % of global land area, which could produce 20 million Mg of grain each year, or 1 % of global annual grain production. About 1.5 billion people and 42 % of the very poor people live on the degraded land. In India about 114.01 m ha out of total geographical area of 328.84 m ha is under degraded and wastelands (Maji *et al.*, 2010).

The coastal region plays a vital role in the global economy due to its rich natural resources, productive habitats and biodiversity. Total coastline of the world is 3,56,000 km and the coastal area covers more than 10% of the earth surface (SAC, 2012). India has a coastline of 7517 km (SAC, 2012), its peninsular region bounded by the Arabian Sea on the west, the Bay of Bengal on the east and the Indian Ocean to its south. According to Velayutham *et al.* (1999) Indian coastal agro-eco system occupies 10.78 m ha and extends over the states/ union territories of West Bengal, Odisha, Andhra Pradesh and Pondicherry on the Bay of Bengal in the East, and Tamilnadu, Kerala, Karnataka, Goa, Maharashtra and Gujarat on the Arabian sea in the West besides, the two island groups viz. the Andaman & Nicobar and Lakshadwip. Land resource in the coastal region is vulnerable to degradation due to combinations of natural, hydrological and anthropogenic factors. In India, the major features for the degradation of land in the coastal region are salinization/ sodification due to the presence of brackish groundwater table near the soil surface or sea water intrusion, acidification, reduced organic matter content and microbial activities, poor vegetation/ forest cover, waterlogging with fresh/ brackish water, drainage congestion, desertification/ lack of fresh water, erosion, etc. Out of these, salinization, waterlogging and drainage congestion besides the climatic constraints are the major processes of land degradation in the coastal region. Salinity build-up in coastal land takes place mainly due to salinity ingress of ground water aquifers, for which the main factors responsible are presence of saline ground water near land surface, excessive and heavy withdrawals of ground water from coastal plain aquifers, seawater ingress, tidal water ingress, relatively less recharge, and poor land and water management (Bandyapadhyay *et al.,* 1987; Yadav *et al.*, 2009). Most of the lands in the coastal area are low-lying and flat in topography resulted in deep waterlogging and drainage congestion especially during *kharif* season following heavy monsoon shower.

Yet, agriculture, which is one of major occupations of the rural people in the coastal regions of India, is less productive and productivity in this ecosystem is generally lower than the country's average. Enhancing agricultural productivity of degraded coastal land for improving food security and livelihood of poverty stricken rural men and women in the face of the increasing demand for food for country's burgeoning population, changing climatic scenario and degradation of the finite land and water resources is the biggest challenge. In spite of several constraints, there are tremendous opportunities to attain the production potential of the degraded land and water in the coastal region. The land management practices which address key challenges like land and water degradation (salinity), drainage congestion and scarcity of fresh water for irrigation could enhance agriculture production and livelihood security of people in coastal region. This paper deals with innovative land management practices, termed as land shaping techniques which provide the scope for enhancing the productivity of degraded land and water and livelihood security of the farming communities, experiences learned from on-farm implementation and limitation in adoption.

Innovative Degraded Land Management Practices

Land shaping techniques

Unlocking the production potential of degraded land in coastal region is the biggest challenge towards achieving food security of the country. Implementing innovative land management practices in combination with productive utilization of opportunities of the coastal areas like excess rainwater and vast brackish water resources could be a best approach to meet the challenge. Land shaping is the innovative land management practice in which the surface of the land has been altered to meet the requirements of the users. In land shaping, the surface of the land is modified primarily for creating source for irrigation especially for dry season by harvesting excess rain water which is otherwise goes waste as run-off water, lowering degrading of land by reducing salinity build up primarily from sub-surface saline groundwater, reducing drainage congestion by creating raised land and harvesting excess rain water, growing multiple and diversified crops, integrated cultivation of crop and freshwater fish and also cultivation of fish with brackish water resources which is available in plenty in the coastal region. Different innovative land shaping techniques that suit to different land situations, farm size and farmers' requirements under coastal agro-ecosystem are described below (CSSRI-NAIP, 2014, Burman *et al.*, 2013):-

(i) *Farm pond:* About 20% of the farm area is converted into on-farm pond of about 3m depth to harvest excess rainwater. The dug-out soil is used to raise the land to form high land/dike and medium land. Raised land and original low land are used for growing multiple and diversified crops throughout the year. High land/dike is used for growing high value vegetables and fruit crops round the year. During *kharif* season high yielding variety of rice are grown in medium land and low land is used for paddy + fish cultivation. The low water requiring crops like sunflower, groundnut, and cotton are grown on the medium land and rice is grown on lowland during *rabi*/summer season. The pond is used for harvesting of about 5000 m^3ha^{-1} rainwater for irrigation and poly-culture of fish.

(ii) *Deep furrow and high ridge:* About 50 % of the farm land is shaped into alternate ridges (1.5 m top width and1.0 m height) and furrows (3m top width and 1.0 m depth). Dug out soil from furrows is used for making ridges. About 1875 m^3ha^{-1} of rainwater is harvested of in the deep furrows and is used for fish cultivation and irrigation during *rabi*. The ridges are used for cultivation of vegetables and other horticultural crops/ multi-purpose tree species (MPTs) round the year. Remaining portion of the farmland including the furrows is used for growing more profitable paddy + fish cultivation in *kharif*. During *rabi*/ summer season farm land (non-furrow and non-ridge area) is used for low water requiring crops.

(iii) *Shallow furrow and medium ridge:* About 40 % of the farm land is shaped into shallow furrow of 0.50-0.75m deep at a distance of about 4-5m and medium ridges of 0.80- 1.00m high along the furrows. The furrows are used for rainwater harvesting of about 1200 m^3ha^{-1} and paddy + fish cultivation during *kharif*. The cropping schedule is similar to that followed in deep furrow & high ridge except rice can be grown in furrows in *rabi*/summer with lesser supplementary irrigation.

(iv) *Paddy-cum-fish cultivation:* Deep trenches (3-5m width and 1.5 m depth) are dug around the periphery of the farm land and the dugout soil is used for making dikes (1.5 - 4 m width and 1.5 m height) to protect free flow of water from the field and harvesting more rain water in the field and trench. A small ditch is dug out at one corner of the field as shelter for fishes when water will dry out in trenches. The dikes are used for growing vegetables and/or green manuring crops/fruit crops/multi-purpose tree species (MPTs) round the year. Remaining portion of the farm land including the trenches is used for more profitable paddy + fish cultivation in *kharif*. The farm land (non-trench and non-dike area) is used for growing low water requiring crops during dry (*rabi*/summer) season with the harvested rainwater of about 1400 - 3500 m^3ha^{-1} in the trenches.

(v) *Broad bed & furrow:* This involves shaping of land for broad beds (4-5 m width and 1 m height) and furrows (5-6 m width and 1m deep) with a provision of (2 m x 4 m x 1 m) fish shelter at the end of the furrow alternatively in low-lying lands. Raised beds are used for cultivation of vegetables round the year and fish is cultivated in the furrows. This system provided the scope for *in-situ* rainwater harvesting of about 3800 m^3ha^{-1} and which is used to cultivate second crop during dry seasons.

(vi) *Three tier land configuration:* In this technique of land shaping degraded low-lying land is shaped into three equal portions as raised land, medium or original land and pond with a depth of 2.5-3 m and dikes of 5 m wide and 1.5 m height. Pond at the lower part of the land is used for harvesting of rain water of about 4500 $m^3\ ha^{-1}$ and poly-culture of fish. Paddy in medium (original) land along with vegetables on raised land and dikes are cultivated.

(vii) *Paired bed technique:* In paired bed technique degraded low lying land is shaped into broad furrow of 9 m width x 2 m depth and two beds of 6 m width. In this technique a nursery pond of 5 m x 9 m size is also created at one end of the furrow for raising finger lings while broad furrow is used for brooders. Two dikes are created of 2-3 m width at both ends. Broad furrow is used for harvesting of rain water of about

3750 m^3ha^{-1}. Vegetables are grown round the year in the raised beds and dikes.

(viii) *Brackish water aquaculture pond:* There are many areas in the coastal areas particularly near the brackish water river or sea coast remain highly saline throughout the year and not suitable for crop cultivation. These lands are shaped into shallow depth brackish water pond. The pond size varies from 0.13 - 0.4 ha with a depth of 1.0 -1.5 m. The height of the embankment of the pond is determined by the tidal height occurring in the area, generally about 30 cm above the maximum flood level. In general about 1.2 m hight and 1.6 m wide embankment is made on the periphery of the pond. Polyculture system of brackishwater fish farming with tiger shrimp (*Penaeus monodon*) along with brackishwater fish like golbhangon/bhangon (*Liza tade*) and aansbhangon (*Mugil cephalus*) is practiced in the pond with brackishwater from the nearest river.

Lessen Learned from Implementation of Land-shaping Techniques

Different land-shaping techniques for improving drainage facility, rain water harvesting, salinity reduction and cultivation of crops and fish (fresh water and brackish water fish) for livelihood and environmental security were tested on about 400 ha degraded and low-productive land in disadvantaged areas in Sundarbans region of Ganges delta (West Bengal) and *Tsunami* affected areas in Andaman and Nicobar Islands covering 32 villages in 4 districts (South 24 Parganas and North 24 Parganas districts in West Bengal and South Andaman and North and Middle Andaman districts in Andaman and Nicobar Islands) during 2010-2014. In the pilot area it was observed from base line survey that the land holding was very low and fragmented in Sundarbans region with dominance of marginal farmers (about 90%) with average land holding ranged between 0.19-0.56 ha (Mandal *et al.*, 2011). The land holding size was higher in the study area in Andaman and Nicobar Islands and the average holding size was 1.80 - 2.80 ha. The land topography was dominated by low land (80%) in Sundarban region and the same was 10-23% in case of villages in Andaman and Nicobar Islands. In Andaman and Nicobar Islands substantial area was under hilly and undulated topography and not suitable for agricultural crop cultivation. Due to low-lying nature of the land, waterloging coupled with severe drainage congestion was prevalent in the study area during monsoon months. In contrast during non-monsoon months due to non-availability of good quality water, salinity builds up gradually and make the crop cultivation challenging. In Sundarbans, agriculture was the primary occupation of the majority of the households (39-56%) followed by daily labourers, migration to distance places for alternative livelihoods, fisheries and others. Average family income in Sundarbans was calculated to be Rs 22000-25000 per family per year during 2011-12. In Andaman and Nicobar Islands, services were the major occupation and agriculture as primary occupation was practiced by very few households (< 5 %). Overall the cropping intensity in the study region was low (114-127%) in the Sundarbans region with low level of crop diversification. The cropping intensities in Andaman and Nicobar Islands were relatively higher (137-188%) primarily due to presence of perennial crops. The soil in the study area was affected by high level of soil salinity (ECe upto 18 dS m^{-1}) and water salinity (EC upto 22 dS m^{-1}) that limits the choice and options of growing crops in the area.

With land-shaping techniques, different land situations like, high land, medium land and low land (original) apart from rainwater harvesting structures like farm pond/furrows/trenches were created in low-lying and degraded farmers' fields. Raising of land and creating water harvesting structures reduced the problem of drainage congestion during *kharif* season (Table 1) and this provided the scope for growing high value crops like vegetables during this season. It also facilitated early sowing of *rabi* crops so that the farmers could get better return. It was observed that the salinity build up in the soil of different land situations especially medium land and highland/ridges/ dikes in land shaped area was relatively less compared to original salt-affected coastal low land (without land shaping) (Table 1). Lower soil salinity build up in the raised soil might be due to : i) increased distance between the saline groundwater table and the surface soil resulting in decreased accumulation of salt through upward capillary flow and/or ii) due to the presence of fresh water (harvested rain water) in the furrows/trenches, the soil at the bottom region of ridges/dikes/raised bed, remains almost saturated with fresh water in the initial months after the *kharif* season (or as long as there was fresh water available in the furrows) thereby, decreasing the soil water potential at the bottom region of ridges, which resulted in less

Table 1. Average depth of standing water and soil properties under different land situations created through land shaping techniques

Land situations	Depth of standing water (cm) in *kharif*	ECe (dSm^{-1})	pH	Organic C (%)	MBC ($\mu g\ g^{-1}$ dry soil)	Available N ($kg\ ha^{-1}$)	Available P ($kg\ ha^{-1}$)	Available K ($kg\ ha^{-1}$)
Low land (without LS)	40-50	15.5	7.2	0.61	187.7	195.8	15.4	673.8
Low land (LS)	30-40	13.2	7.5	0.80	244.0	234.0	17.1	628.4
Medium land (LS)	15-20	7.3	7.4	1.10	279.0	238.1	18.9	480.3
High land (LS)	0	6.6	7.3	1.20	280.5	251.7	22.4	430.5

LS= land shaping technique

Table 2. Enhancement in cropping intensity, employment generation and net income under different land shaping techniques in Sundarbans and Andaman and Nicobar Islands

Land shaping	Cropping intensity (%)		Employment generation (man-days $hh^{-1*}\ yr^{-1}$)		Net return ($Rs\ ha^{-1}\ yr^{-1}$)	
technologies	Before land shaping	After land shaping	Before land shaping	After land shaping	Before land shaping	After land shaping
Farm pond	114[a], 100[b]	193[a], 200[b]	87[a], 8[b]	227[a], 22[b]	22000[a], 10000[b]	140000[a], 148000[b]
Deep furrow & high ridge	114[a]	186	87	218	22000[a]	102000[a]
Paddy-cum-fish	114[a], 100[b]	166[a], 200[b]	87[a], 8[b]	223[a], 35[b]	22000[a], 24000[b]	127000[a], 148000[b]
Broad bed & furrow	100[b]	240[b]	9[b]	48[b]	24000[b]	212000[b]
Three tier	100[b]	220[b]	10[b]	42[b]	30000[b]	221000[b]
Paired bed	100[b]	240[b]	9[b]	54[b]	24000[b]	216000[b]
Brackishwater aquaculture pond	0/100	-	25[a]	100[a]	-	146000[a]

Note: Costs and returns at current price of 2012-13 $*hh^{-1}$: per household (av. holding was 0.35 ha in Sundarbans [a], av. holding of implementation was 0.20 ha in Andaman & Nicobar Islands [b])

upward capillary movement of saline groundwater. Due to creation of different land situations and following cultivation of crops round the year organic C, available N, P and K and biological activities (microbial biomass C) in surface soil have been increased under land shaping techniques compared to land without land shaping (Table 1).

About 1950 water storage structures were created under different land-shaping techniques and 13,05,000 m^3 rainwater has been harvested annually in these structures in the study area and with this harvested rain water, about 260 ha areas which were earlier under mono-cropping with rice due to shortage of irrigation water have been brought under irrigation for growing multiple crops round the year. The cropping intensity has been increased up to 240 % from a base level value of 100% due to implementing the land-shaping techniques (Table 2). These land shaping techniques are very popular among the farmers of both Sundarbans and Andaman & Nicobar Islands as these technologies have increased the employment and income of the farm family by manifolds compared to base line value (Table 2). Average net income per ha of farm land has been increased from Rs 22000 to Rs 1,23,000 in Sundarbans and Rs 22400 to Rs 1,90,000 in Andaman and Nicobar Islands.

Brackishwater aquaculture was demonstrated through shaping of land into more than 110 shallow depth ponds in the coastal areas of Sundarbans particularly near the brackishwater rivers which was remain almost fallow and not being utilized for any agricultural activity on account of high soil salinity. Farmers were benefitted from this brackishwater aquaculture with a net income of about Rs1,46,000 ha^{-1} of pond area. Farming activities under land shaping techniques have enhanced the employment opportunities for the farm families in the study areas.

Table 3. Factors affecting adoption of land shaping techniques

Factors	Name	Co-efficient	SE
Constant		1.3471***	0.0214
X1	Farm size (in ha)	0.435***	0.0473
X2	No of parcels in farm holdings (no)	-0.0187***	0.0045
X3	% of lowland area	0.0952***	0.0388
X4	Distance of land from residential area (binary var, 1=within 1km, 0 otherwise)	-0.2110*	0.012
X5	Aggregate family income (Rs/year)	0.0871***	0.0126
X6	% of off-farm income (Rs/year)	-1.1543***	0.0.4422
X7	Family size (no)	0.0675***	0.0548
X8	Availability of irrigation water (binary var. 1= available for at least 4 months, 0 otherwise)	-0.4871***	0.1789
X9	Education level (no of years of education of key respondents)	0.1510***	0.0984
X10	Rental value of land (Rs/year/ha)	0.0511^{NS}	0.0432
	-2 Log Likelihood	149.52	
	Correct Prediction (%)	68.93	
	No of observation	180	

***$p \leq 0.01$, * $p \leq 0.05$, NS - not significant

As the farmers could get employment in their own farm land throughout the year, this has also checked the seasonal migration rate of the farm family in search of their livelihood. Social security is also established through this technology by ensuring income security. Consumption of vegetables and fish from won farm land has improved their nutritional security.

Financial analysis of land shaping techniques indicated, these were financially viable and attractive proposition for the coastal region (Mandal *et al.,* 2013). Different factors that influence the farmers' behaviour towards adoption of land shaping techniques and also probability of adoption were analyzed in the study areas. It was noticed that as the farm size, % of lowland area, aggregate family income, family size and educational level increased, the probability of adoption of these techniques also increased (Table 3). Whereas as the no. of parcels in farm holdings, distance of farm land from residential area, % of off-farm income and availability of irrigation water from sources (e.g. canals, creeks, reserviours, etc.) decreased the probability of adoption of these techniques. The rental value of land was not a significant factor to influence adoption behaviour of these techniques.

Conclusions and Recommendations

In coastal area the land shaping is an innovative technology for addressing the key challenges like land degradation (salinity), drainage congestion and scarcity of fresh water for irrigation and in turn have the potential to enhancing production, productivity, income and employment. This is one of the most important strategies not only to control run-off in the region and soil loss but also contribute to climate change mitigation as well as increased ecological resilience due to improvement of degraded land and water quality and more carbon sequestration due to more plant cover. These techniques are financially viable and attractive proposition for the coastal region. However, major constraints for adoption of land-shaping techniques are marginal land holdings that too divided into several parcels, high initial investment, presence of acid sulphate soils near surface or at shallow depth at places, distance from residential village etc. Though the technology have been well adopted at farm level, there is lack of information on larger watershed or basin level hydrological impacts such as availability of rainwater for downstream flow and groundwater recharge. There is a need to understand and resolve issues on large scale dissemination of land-shaping technology covering the areas of input-supplies and management, market and marketing environment – the driver of change in cropping pattern and production, credit needs and absorption of the farmers, and the role financial institutions therein. More intensive study, particularly the long term implications of these techniques should be undertaken to address those issues so that the land-shaping will be adopted in a large scale for the sustainable agricultural development in the salt-affected coastal region.

References

Bandyopadhyay BK, Bandyopadhyay AK and Sen HS (1987). Physico-chemical characteristics of coastal saline soils of India. *Journal of Indian Society of Coastal Agricultural Research* **5:** 1-14.

Burman D, Bandyopadhyay BK, Mandal, Subhasis, Mandal UK, Mahanta KK, Sarangi SK, Maji B, Rout S, Bal AR, Gupta SK and Sharma DK (2013). Land shaping – A unique technology for improving productivity of coastal land, Bulletin No. CSSRI/Canning Town/Bulletin/2013/02. Central Soil Salinity Research Institute, Regional Research Station, Canning Town, West Bengal, India. p. 38.

CSSRI-NAIP (2014). Final Report of NAIP sub-project on: Strategies for Sustainable Management of Degraded Coastal Land and Water for Enhancing Livelihood Security of Farming Communities (Component 3, GEF funded) (eds. D. Burman, S. Mandal & K. K. Mahanta). Central Soil Salinity Research Institute, Regional Research Station, (CSSRI, RRS), Canning Town - 743 329, South 24 Parganas, West Bengal. p. 104

Maji AK, Reddy GP, Obi and Sarkar D (2010). Degraded and Wastelands of India: Status and Spatial Distribution. Indian Council of Agricultural Research, New Delhi, India. p. 159.

Mandal S, Bandyapadhyay BK, Burman D, Sarangi SK, Mahanta KK, De S, Patra P (2011). Baseline Report. Central Soil Salinity Research Institute, Regional Research Station, Canning Town, West Bengal. p. 47.

Mandal Subhasis, Sarangi SK, Burman D, and Bandyopadhyay BK, Maji B, Mandal UK and Sharma DK (2013). Land shaping models for enhancing agricultural productivity in salt affected coastal areas of West Bengal – An economic analysis. *Indian Journal of Agricultural Economics* **3:** 389-401.

Nkonya E, Koo J, Marenya P and Licker R (2011). Land Degradation: Land under Pressure. In Global food policy report. International Food Policy Research Institute, Washington, DC , USA. pp. 63-67.

SAC (2012). Coastal Zones of India. Space Applications Centre, ISRO, Ahmedabad, Gujarat. p. 597.

Scherr, S.J. and Yadav, Satya (1996). Land degradation in the developing world: Implications for food, agriculture and the environement to 2020. Food, Agricultutre and the Environment Discusssin Papers 14, Internation Food Policy Research Instittue, Washington, DC, USA. p. 36.

Velayutham M, Sarkar D, Reddy R S, Natarajan A, Krishan P, Shiva Prasad CR, Challa O, Harindranath CS, Shyampura RL, Sharma JP and Bhattacharyya T (1999). Soil resosurce and their potentialities in coastal areas of India. *J. Indian Society of Coastal Agricultural Research* **17**: 29-47.

Yadav JSP, Sen HS and Bandyopadhyay BK (2009). Coastal Soils —Management for higher agricultural productivity and livelihood security with special reference to India. *Journal of Soil Salinity & Water Quality* **1(1-2)**: 1-13.

Received: December, 2014; Accepted: December, 2014

Journal of Soil Salinity and Water Quality 7(1), 19-28, 2015

Geo-electrical Investigations to Characterize Subsurface Lithology and Groundwater Quality in Assandh Block of Karnal District, Haryana

S K Lunkad[1], Vikas Tomar[2]* and S K Kamra[2]

[1]Department of Geology, Kurukshetra University, Kurukshetra, Haryana
[2]ICAR-Central Soil Salinity Research Institute, Karnal-132001, Haryana
*Corresponding Author: vikasgeologist@gmail.com

Abstract

Direct current resistivity surveys were conducted to characterize the subsurface lithology and groundwater conditions upto 50 m depth at 4 locations in Assandh block of Karnal district in Haryana (India). The groundwater level in the study sites ranged from 4- 12 m and its TDS varied between 371 to 2080 ppm (0.6 to 3.3 dS/m). Vertical Electrical Soundings (VES) based on Schlumberger configuration were carried out at these locations using Aquameter CRM-AT resistivity meter. The curve matching and computer software approaches were employed to estimate the thickness and resistivity of subsurface horizons with support of field observations on subsurface lithology and groundwater salinity. The 3 layer curve matching approach indicated a combination of A and K type curves suggestive of either fresh to marginal groundwater salinity or dominance of finer material layers in a thick alluvial zone in the study area. Computer software based inversion methodology highlighted the presence of fine to medium sand of 10 to 27 ohm m resistivity in 10- 35 m depth aquifer zone. At 3 sites (Yatriwala, Bindrala and Kala Singh), low resistivity values of 8- 17 ohm m in saturated layers below watertable represent fine to medium sand of marginally saline groundwater. At fourth site, Balpabana, higher resistivity of 57- 69 ohm m in 10 to 20 m layers represents a mixture of loam and fine sand of relatively good quality water while a lower resistivity of 27 ohm m beyond 35 m represents coarser sand though of marginally higher water salinity. Based on analysis of Dar Zarrouk parameters of Longitudinal Unit Conductance (S) and Transverse Unit Resistance (T), and supporting field evidence, it can be concluded that Balpabana and Kala Singh, amongst 4 study sites, have respectively the best and the worst quantitative and qualitative aquifer potential upto 50 m depth; the remaining 2 sites of Bindrala and Yatriwala falling in between. For long term protection, the farmers in the area may be advised to explore better aquifer below 50 m depth with the help of VES surveys and competent professional interpretation.

Key words: Resistivity; VES; Lithology; Groundwater quality; Type curves

Introduction

The monitoring of the groundwater levels over past 3 to 4 decades exhibits a declining trend of water level in 12 districts of Haryana (Malik *et al.*, 2013). The main reason for this decline is that pumping of groundwater has exceeded its natural recharge (Lunkad, 2006). It is important to make an assessment of the hydro-geological conditions in different regions for optimal planning, development and management of groundwater resources. Often such investigations are carried out using conventional and costly geotechnical methods which provide information at discrete selected points only. Surface geophysical surveys, a veritable tool in groundwater exploration, have the basic advantage of saving cost of borehole construction by locating target aquifer before drilling is embarked upon (Obiora and Ownuka, 2005).

Vertical electrical sounding (VES) is a common and useful method employed for measuring vertical distribution of electrical resistivity (Heilan, 1940), more successfully when a good resistivity contrast exists between the water bearing aquifer formations and the underlying rocky zone (Zohdy *et al*., 1974). Of different electrode configurations, Schlumberger array has been reported to be more suitable and common in both alluvial and weathered hard rock terrains (Vivekanath *et al.,* 2014). A large number of resistivity surveys have been undertaken in India with the basic aim to provide information on sub-surface lithology. Singh and Yadav (1984) and Yadav and Singh (1987) conducted these for delineation of fresh and saline water zones in the alluvial Ganga plains in eastern Uttar Pradesh. In the same region, Bajpai and Kumar (1988) and Bajpai (1989) used resistivity data to characterize the lateral and longitudinal extent of deeper aquifers based on the stratigraphic interpretation. In India, there are limited applications of VES surveys for alluvial regions despite its huge scope to map the extensive plains without the need to drill bores.

This paper aims to provide a practical methodology on the application of resistivity surveys to characterize sub-surface lithology and the extent and quality of groundwater

Material and Methods

Study area

Karnal district (Fig. 1) is located in the northeastern part of Haryana state covering an area of 2520 sq.km between latitude 29⁰25'05"- 29⁰59'20" N and longitude 76⁰27'40" - 77⁰13'08" E. Irrigation to crops in the district is provided by both canal and groundwater supplies, the latter covering nearly 70% of the net irrigated area. Rain fall, irrigation losses and seepage from the river Yamuna and canal networks are the principal sources of ground water recharge in the area. Groundwater occurs under water table conditions at shallow depths and under semi confined to confined conditions in the deeper aquifers. Assandh is one of the six blocks located in south-western part of Karnal district under Upper Yamuna command of vast Indo-Gangetic plains in which groundwater is contained essentially in the unconsolidated alluvial deposits of Quaternary age.

Fig. 1. Selected sites in Karnal District of Haryana state

Resistivity survey methodology

The electrical resistivity method involves the detection of effects of electric current flow at the land surface and consequent determination of resistivity distribution in the subsurface layers. The basic principle is passing of controlled current between two electrodes placed at defined distance apart and the measurement of potential difference between two additional electrodes placed in line with or between the first two electrodes. For each series of measurements, the distance between the first two electrodes is increased in a certain proportion depending upon the actual electrode configuration used. By multiplying the resistance obtained in each measurement by a geometric factor appropriate for the chosen electrode configuration, a series of apparent resistivity (ρ_a) values are obtained. These are normalized to relate these with the geo- electrical properties of a uniform subsurface zone and the geometric configuration of the electrodes (Ramachandra Rao, 1975).

Electrode configurations

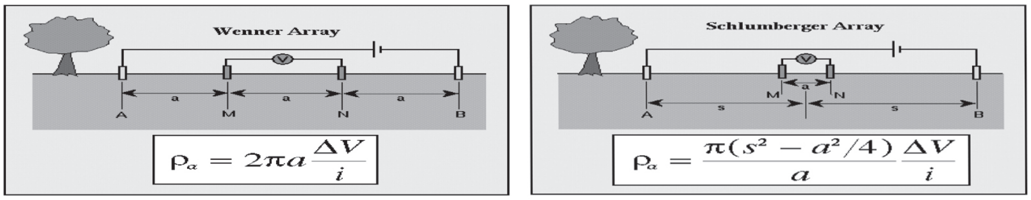
A number of electrode configurations have been applied in the resistivity surveys; the most common being the Wenner and Schlumberger arrays (Fig.2 a and b). In Wenner configuration, the four electrodes (A, B: current electrodes; M, N: voltage electrodes) are spaced at equal interval (a) along a line on a flat ground surface. In Schlumberger array, the potential electrodes are placed at a closer distance (a) than distance (s) between the current electrodes. The distance in meters measured from the centre of the current electrodes A and B and potential electrodes M and N are also represented as AB/2 and MN/2 respectively in literature.

In this study we conducted VES under Schlumberger configuration (Fig 2b), for which ρ_a (ohm m) for each set of electrode placements was computed as:

$$\rho_a = k\,(\Delta V/i) \qquad \ldots(1)$$

where ΔV is the potential difference (volts), i the current (amperes) and K is the geometric factor given by

$$K = [\pi\,(s^2 - a^2)\,/4a)] \qquad \ldots(2)$$



(a) (b)

Fig. 2. (a) Wenner configuration and (b) Schlumberger electrode configuration used in resistivity surveys

To increase the depth of exploration, s is gradually increased symmetrically about the centre of the spread while the potential electrode spacing (a) remains fixed. For large 's', 'a' is also increased to allow a measurable potential. A guiding principle in Schlumberger surveys is that potential electrode spacing (a) must be less than 40% of the current electrodes spacing (s).

Resistivity surveys in Assandh block

VES under Schlumberger configuration were carried out at different times during 2009-10 at 4 sites (Fig.1) in Assandh block of Karnal district in Haryana using "Aquameter CRM-AT" resistivity meter. In selection of sites for VES, it was ensured that there were no outcrops or electric cable near the fields. Resistivity corresponding to increasing values of 'a' and 's' were measured along with a specified orientation as per guidelines of Kunetz (1966). The following spacing of current and potential electrodes (Table 1) were adopted at each VES location.

Interpretation of VES data

The primary aim of geophysical interpretation of resistivity data is to determine the thickness and resistivity of different subsurface horizons. The observations of resistance at different 'a' and 's' values on the land surface give rise to an unique pattern of 'type curves' of apparent resistivity at any site. From the shape of these type curves, the resistivity of different layers is derived by standard curve matching technique using available master curves or by indirect inversion methods by related software. In the master curve technique, the subsurface zone is divided into 2, 3 or 4 horizontal layers based on the shape of the type curves (Yadav, 2004). In two layer approach, the curves are designated as Ascending ($\rho_2 > \rho_1$) or Descending ($\rho_2 < \rho_1$) depending upon the resistivity contrast between 2 layers. Similarly the entire set of 3 layer sounding curves is divided into 4 groups, depending upon resistivity contrast between layers. These are called as

H (minimum: $\rho_1 > \rho_2 < \rho_3$) type

A (double ascending: $\rho_1 < \rho_2 < \rho_3$) type

K (maximum : $\rho_1 < \rho_2 > \rho_3$) type and

Q (double descending : $\rho_1 > \rho_2 > \rho_3$) type.

The representative shapes of 3 layer curves (A, K, H and Q) are presented in Fig. 3. In 4-layer curve matching approach, curves are characterized by 8 subgroups: HA ($\rho_1 > \rho_2 < \rho_3 < \rho_4$), HK ($\rho_1 > \rho_2 < \rho_3 > \rho_4$), QH ($\rho_1 > \rho_2 > \rho_3 < \rho_4$), QQ ($\rho_1 > \rho_2 > \rho_3 > \rho_4$), KH ($\rho_1 < \rho_2 > \rho_3 < \rho_4$), KQ ($\rho_1 < \rho_2 > \rho_3 > \rho_4$), AA ($\rho_1 < \rho_2 < \rho_3 < \rho_4$), AK ($\rho_1 < \rho_2 < \rho_3 > \rho_4$). In interpretation through computer software, more than 4 layers area can also be characterized. It may be pointed out that in both curve matching or inversion software approaches, available information on aquifer lithology and groundwater salinity are always helpful.

In addition to interpretation based on apparent resistivity and thickness of layers, Dar Zarrouk parameters of Longitudinal Unit Conductance (S)

Table 1. VES current and potential electrode spacing adopted in Assandh block

Configuration No.	1	2	3	4	5	6	7	8	9	10	11
Half Current electrode spacing (s/2), meter	1	2	3	4	5	6	7	8	10	10	12
Half Potential electrode spacing (a/2), meter	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	2.0	2.0
Configuration No.	12	13	14	15	16	17	18	19	20	21	22
Half Current electrode spacing (s/2), meter	15	20	25	25	30	40	50	60	80	90	100
Half Potential electrode spacing (a/2), meter	2.0	2.0	2.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0

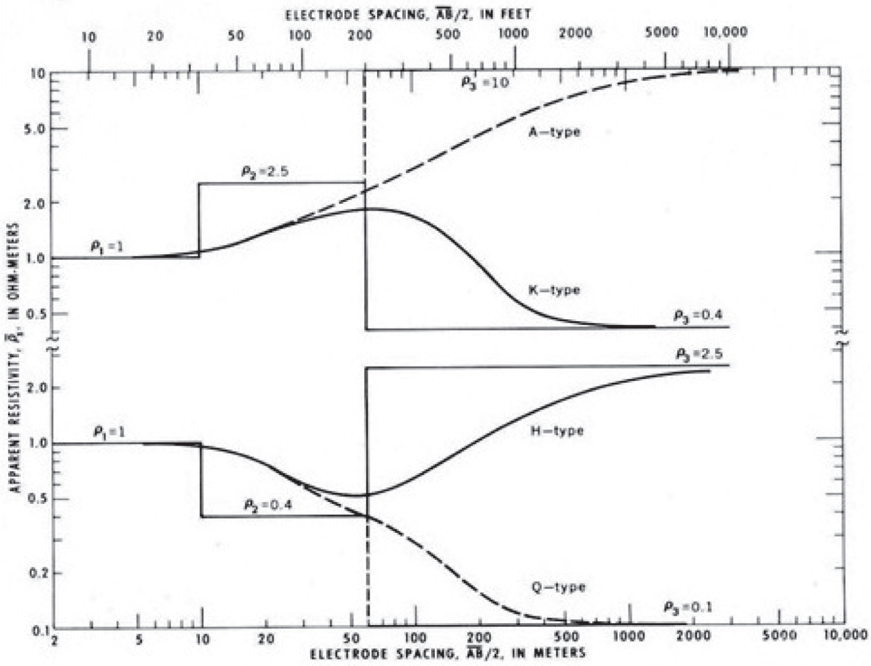


Fig. 3. Examples of the four types of 3 layer schlumberger sounding curves for three layer Earth models

and Transverse Unit Resistance (T), introduced by Maillet (1947) are also helpful in characterizing the potential of different aquifer layers in terms of quantity as well as quality of water. For a sequence of n horizontal, homogeneous and isotropic layers of resistivity, these parameters are defined as

$$S = \sum_{i=1}^{n} \left(\frac{h_i}{\rho_i} \right) \quad \ldots(3.a)$$

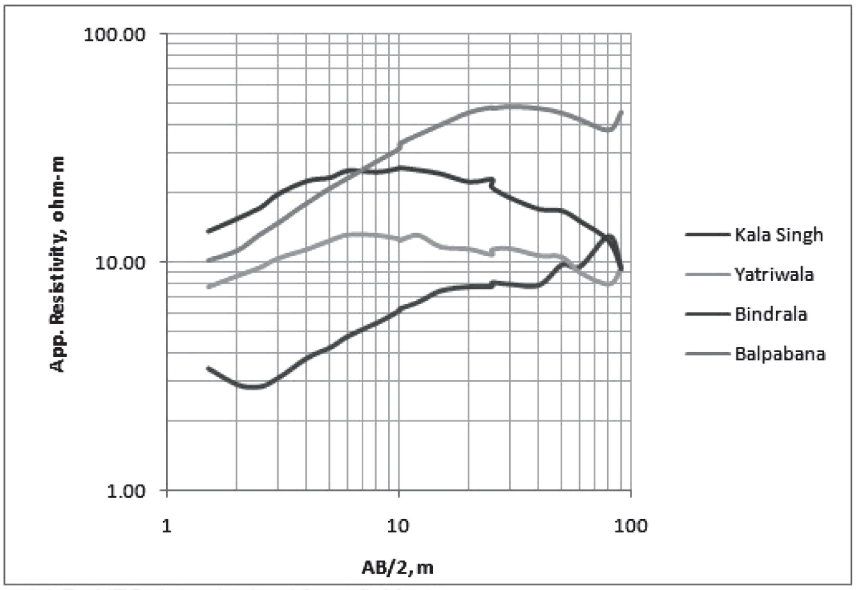
$$T = \sum_{i=1}^{n} \left(h_i \rho_i \right) \quad \ldots(3.b)$$

where n is the number of layers, h_i is the thickness and ρ_i is the resistivity of the i^{th} layer respectively. Both S (in ohm^{-1}) and T (ohm m^2) are of primary significance in the development of interpretation theory of VES (e.g Orellana, 1963; Zohdy, 1965,1975; Kunetz and Rocori, 1970; Jha et al., 2008). If the thickness of the aquifer column is fixed, then the variations in S and T reflect the conductivities or resistivities of the column. Also if the quality of groundwater is more or less uniform in particular area, a combination of low S and high T values can be considered as representing a potential aquifer (Chandra and Athavale, 1979).

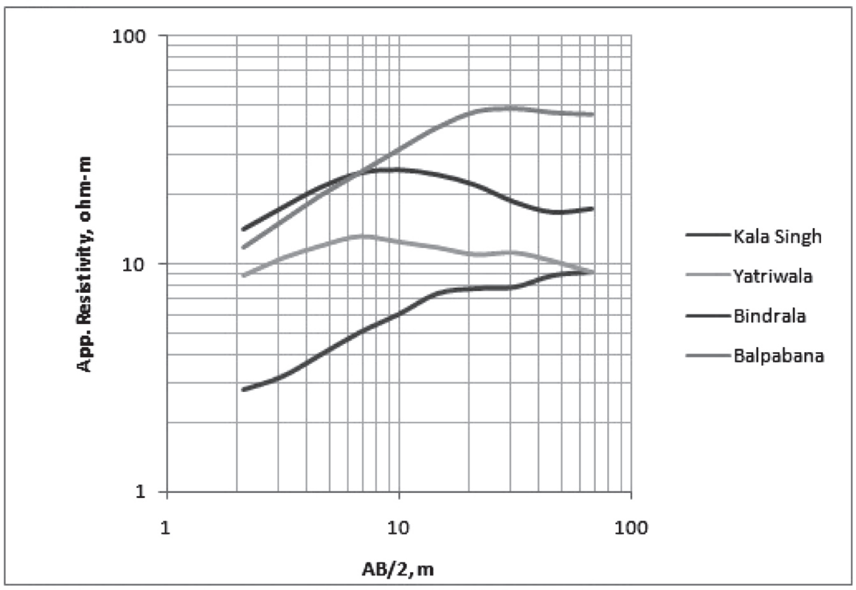
Results and Discussion

A resistivity field curve provides a general qualitative picture of the vertical resistivity distribution over the area around the sounding point. At four locations (Yatriwala, Balpabana, Kala Singh and Bindrala) in Assandh block of Karnal District, the shape of the VES curves, obtained by plotting apparent resistivity (r_a) against AB/2 on a log- log scale, by 3 layer curve matching and computer software program, (InterpretVES version 1.0 by Jerry F.Ayers) approaches are presented in Fig. 4a and 4b respectively. Both approaches provide quantitative interpretations of these curves to estimate the resistivity and thickness of different horizon layers to different levels of certainty and accuracy. It can be seen that the shapes of all four curves derived by curve matching and computer software approaches are quite similar. However, computer software is able to delineate a larger number of layers as compared to 3 layers derived by curve matching approach as will be discussed further in next section. With the advent of computer software, interpretation has become easier through mechanical while curve matching approach depended largely on the human expertise of the interpreter.

The qualitative interpretation of results (Fig. 4a) suggests a HA-H type of sounding curve at Kala Singh site and AK-K type curve at other three sites. In general A and K type curves or combination of these curves are obtained over most of the region having either marginal groundwater salinity or finer alluvial material in layers of high thickness.



(a) By VES data obtained from field



(b) By Inversion program using InterpretVES software

Fig. 4. Types of sounding curves at different sites

Subsurface geo-electric layers

From quantitative point of view, the interpretation of VES data suggests that there were 5 to 6 geo-electric layers (Table 2) in this region. The outputs of the software include the depth, resistivity and expected lithology classification of geo- electrical layers in the study area. This information along with estimated Dar Zarrouk parameters, S and T, provide good diagnostic guidelines on the groundwater potential of different horizons in terms of quantity and quality. However, for further strengthening of interpretation, the VES survey results were supplemented with actual texture of different layers and groundwater quality (total dissolved solids, ppm) determined from bore hole sampling near to the VES locations.

The combined results of estimated thickness and resistivity of different layers and observed texture for 4 sites are presented in Figure 5. These, along with expected lithology classification provided by computer software and observed groundwater quality, are summarized for individual study sites in Table 3-6. The combined results presented in Table 2 and 6 have been utilized for interpreting the aquifer potential of individual sites in the subsequent sections.

Table 2: Geoelectrical parameters* of different site

VES Points		Layers I	II	III	IV	V	VI	Entire Aquifer Column
Balpabana	ρ/h	9/2	36/1	69/12	57/10	27/∞		
	S	0.22	0.03	0.17	0.18			0.60
	T	18	36	828	570			1452
Yatriwala	ρ/h	8/2	18/4	8/6	10/13	14/25	3/∞	
	S	0.25	0.22	0.33	1.30	1.78		3.88
	T	16	72	48	130	350		616
Kala singh	ρ/h	2/2	8/11	9/15	7/20	55/”		
	S	1.00	1.38	1.60	2.86			6.84
	T	4	88	135	140			367
Bindrala	ρ/h	13/2	71/2	17/5	20/15	14/16	7/∞	
	S	0.15	0.03	0.29	0.75	1.14		2.36
	T	26	142	85	300	224		777

*Horizon thickness (h) in m, apparent resistivity (ρ) in ohm-m, longitudinal unit conductance (S) in ohm^{-1} and transverse unit resistance (T) in ohm m^2

Balpabana

The water level in Balpabana was 12 m below ground surface at the time of investigation. The interpretation of VES data suggests that there were five geo-electric subsurface layers in the study area. These consisted of surface layer (top soil), clay mix with loam, fine sand with loam and successive saturated mixture of fine and medium sand layers (Fig 5; Table 3). The topmost layer of 9.1 ohm-m resistivity and 1.5 m thickness represents dry top soil with appreciable clay content. The second layer with higher resistivity of 36.3 ohm-m and 1 m thickness indicates the unsaturated mixture of clay and loam. The third layer of 68.5 ohm-m resistivity and 12 m thickness represents finer material, i.e loam with very fine sand.

The fourth layer having resistivity of 57 ohm-m and 10 m thickness indicates coarser material than above layer i.e. fine to medium sand. The resistivity in the fifth layer extending to a good undefined depth decreases from 57ohm m in upper layer to 26.5 ohm-m representing fine sand conditions.

The horizon resistivity values represent the integrated effect of texture and groundwater quality and it requires good professional expertise and prior knowledge about the hydro geological conditions to separate out these effects. It can be seen that groundwater quality in terms of TDS, though not acceptable from drinking water criteria, is still suitable for irrigation till 24 m depth of the 4th layer and to some additional depth below in 5th layer considering the permissible threshold level being 1300 ppm. The fourth layer of about 10 m thickness of medium to fine sand and 800- 900 ppm quality offers the best possibilities of groundwater within the investigated depth in Balpabana. Relatively deeper water level (12 m) at this site vis-a – vis at other sites is also indicative to reflect such possibilities.

The integrated effect of whole aquifer column, represented through Dar Zarrouk parameters, indicates that relatively low (0.6 ohm^{-1}) value of S and high value (1452 ohm m^2) of T point to potential existence of a good aquifer in the 4th layer. Based only on the comparative values of S and T, it can be stated with certainty that Balpabana has the best quantitative and qualitative aquifer potential amongst 4 sites reported in this paper. The increasing trend of TDS of groundwater with depth beyond 24 m recommends either restriction of aquifer to within 4th and part of 5th layer or explore for still better strata in deeper layers.

Yatriwala

The water level in Yatriwala was very shallow at 4 m below ground surface at the time of investigation. The interpretation of VES data suggests existence of 5-6 geo- electric sub-surface layers in the study area. These consisted of surface layer (top soil), fine sand with marginally saline groundwater at shallow depth and successive saturated mixture of fine and medium sand layers (Fig 5; Table 4).

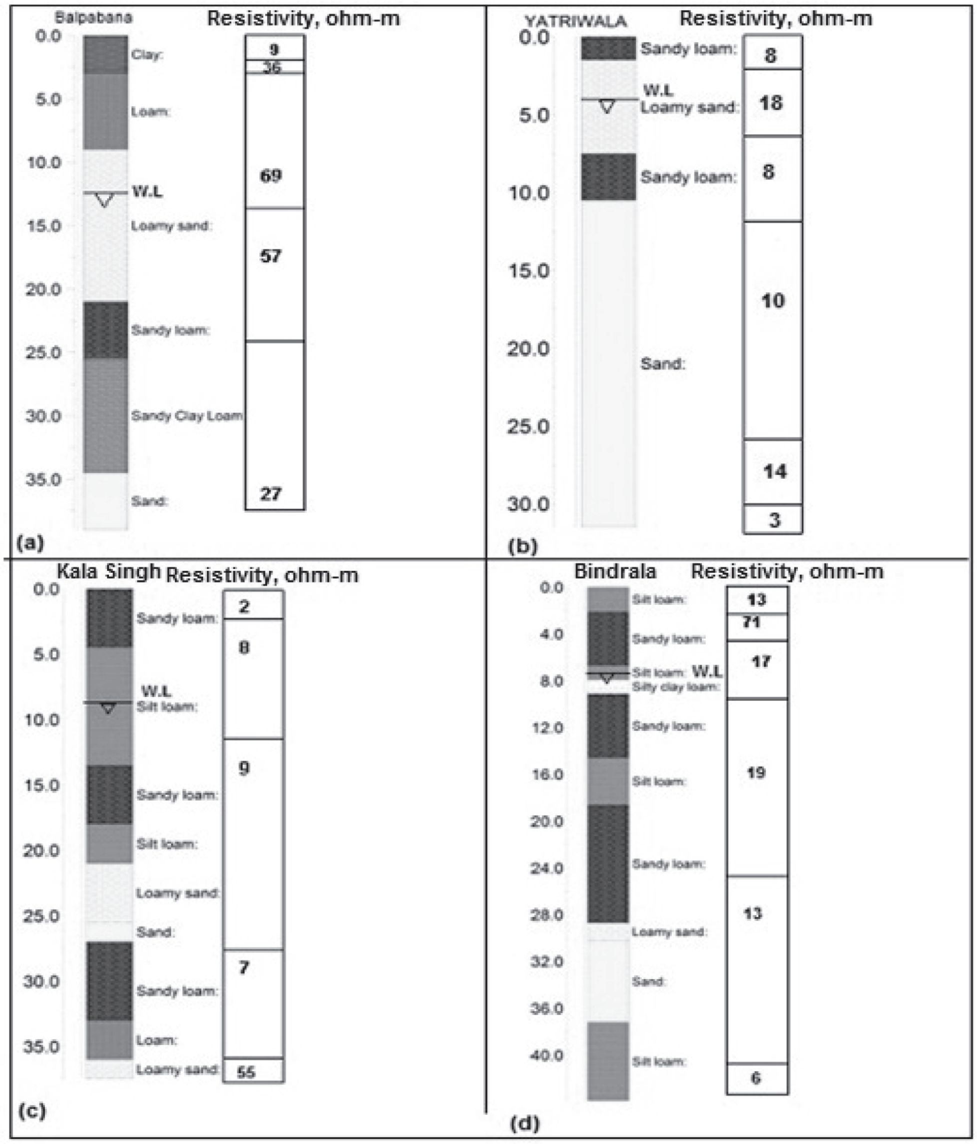


Fig. 5. Observed lithology and resistivity of the corresponding layers at different sites

Table 3. Resistivity survey and field observation results at Balpabana

Computer software output			Bore hole observations	
Depth (m)	Resistivity (ohm-m)	Lithology classification	Texture	Groundwater quality (TDS in ppm)
0-1.5	9.1	Top dry soil	Clay	
1.5-2.5	36.3	A mixture of clay and loam	Clay	
2.5-15	68.5	A mixture of loam and fine sand	Loam/Loamy sand	845
15-24	57	A mixture of fine to Medium sand	Loamy sand/sandy loam	915
24-∞	26.5	Mixture of very fine to fine sand	Sandy loam /sand	1375

The topmost layer of 7.7 ohm-m resistivity and 1.5 m thickness represents loamy saline soil while the second 4 m thick layer of 18.3 ohm m resistivity indicates the saturated fine sand zone resulting from shallow groundwater of 1152 ppm salinity. The third layer of 8.1 ohm-m resistivity and 6 m thickness depicts finer aquifer material like a mixture of loam and fine sand. Low resistivity of this layer can be due to combined effect of fine aquifer material and marginally higher (1408 ppm) salinity of

Table 4. Resistivity survey and field observation results at Yatriwala

Computer software output			Bore hole observations	
Depth (m)	Resistivity (ohm-m)	Lithology Classification	Texture	Groundwater Quality (TDS in ppm)
0-1.5	7.7	Top Soil	Sandy Loam	
1.5-5	18.3	A mixture of sand and loam	Loamy Sand	1152
5-11	8.1	A mixture of loam and fine sand	Sandy Loam/Loamy Sand	1408
11-25	10.2	A mixture of fine to Medium sand	Sand	966
25-49	14.4	A mixture of medium to Coarse sand	Sand	582
49-∞	3.3		Sand	

Table 5. Resistivity survey and field observation results at Kala Singh

Computer software output			Bore hole observations	
Depth (m)	Resistivity (ohm-m)	Lithology classification	Texture	Groundwater quality (TDS in ppm)
0-1.5	2.2	Top Soil	Clay Loam	
1.5-12	8.2	Mixture of Silty clay and fine sand	Silt clay-Sandy Loam	1856
12-27	9.4	Saturated Mixture of Fine to medium Sand	Loamy sand/Sandy Loam/ Silt Loam	582
27-47	6.5	Saturated Mixture of very fine to fine sand with Silty clay	Sand/Sandy Loam	371
47-∞	54.5	Fine Silty clay	Silty Clay Loam	

groundwater. About 40 m thickness of the fourth and fifth layers spanning from 11- 49 m or still below have resistivity values of 10 to 14 ohm-m indicative of medium to coarse sand and lesser groundwater salinity of 582- 966 ppm. Relatively higher values of S (3.88 ohm^{-1}) and lower values of T (616 ohm m^2), however, are indicative of restricted scope despite fresh to marginal nature of saline water and medium to coarse sandy aquifer material. The deceasing trend of TDS of groundwater with depth beyond these layers, however, point to possibilities of better aquifer material layers deeper than those investigated in this study.

Kala Singh

The water level in Kala Singh was 8 m below ground surface at the time of investigation. The interpretation of VES data suggests presence of 5 geo-electric sub-surface layers in the study area. These consisted of surface layer (top soil), mixture of silty clay and fine sand with moisture content, saturated fine to medium sand with saline groundwater at shallow depth and successive saturated mixture of very fine sand and silty clay layers (Fig 5; Table 5). The surface layer of 2.2 ohm-m resistivity and 1.5 m thickness represents clay loam saline soil, while the second layer 8.2 ohm-m resistivity and 10.5 m thickness indicates the moisture laden mixture of fine sand and silty clay in the region of saline groundwater having TDS of 1856 ppm.

The third layer having resistivity of 9.4 ohm-m and thickness of about 15 m depicts saturated mixture of fine to medium sand material in the aquifer, while the fourth layer of 20 m thickness has still lower salinity of 6.5 ohm-m. The laboratory determined texture of bore hole samples, however, indicate finer material like loam than fine to medium sand interpreted by software approach. Despite good quality of groundwater of 371- 582 ppm in third and fourth layers, very low resistivity values and finer texture of aquifer material indicate no potential of groundwater in depth upto 47 m at Kala Singh. This is further corroborated by estimated high (6.84 ohm^{-1}) value of S and lower values of T (367 ohm m^2) at this site. Out of four locations, Kala Singh site seems to have minimum groundwater potential upto 50 m depth.

Bindrala

The water level at Bindrala was at 7.5 m below ground surface at the time of investigations. The

Table 6. Resistivity survey and field observation results at Bindrala

Computer software output			Bore hole observations	
Depth (m)	Resistivity (ohm-m)	Lithology classification	Texture	Groundwater quality (TDS in ppm)
0-2	12.9	Top Soil	Silt Loam	
2-4	71.1	Mixture of Silty clay and fine sand	Sandy Loam	
4-9	17.2	Saturated sand with fine mixture of silt and clay	Silty clay-Sandy Loam	2067
9-24	19.3	Saturated Medium sand mix with clay	Sandy-Silt-Sandy Loam	1400
24-40	13.2	Medium to coarse saturated sand	Loamy Sand-Sand	2080
40-∞	6.4	Fine Silty material	Silty Loam	

interpretation of VES data suggests presence of six geo- electric sub-surface layers in the study area. These consisted of surface layer (top soil), mixture of silty clay and fine sand, saturated sand with silt and clay mixture, medium to coarse saturated sand and fine silty material at bottom layers (Fig 5; Table 6).

The topmost layer of 12.9 ohm-m resistivity and 2 m thickness represents dry top soil which may be silt loam. The second layer with higher resistivity of 71.1 ohm-m and about 2 m thickness indicates a mixture of silty clay and fine sand .In the third layer of about 5 m thickness resistivity drops to 17.2 ohm-m having thickness of about 5 m depicts the saturated condition of the aquifer having fine mixture of silty clay and fine sand with TDS content of 2067 ppm. The fourth layer having resistivity value of 19.3 ohm-m and thickness of about 15 m indicated the medium sand with few lenses of clay in the aquifer with decrease in TDS to 1400 ppm ,the fifth layer having resistivity value of 13.2 ohm-m and thickness of about 16 m consist of coarser aquifer material i.e. medium to coarse sand and increase in TDS of aquifer to 2080.

From Geophysical resistivity surveys employing Schlumberger (Sounding) method, it is concluded that the specific conductance of groundwater is limited to 1400 to 2080 ppm making groundwater moderately saline while the aquifer material varies from silty clay, fine sand to medium sand.

Summary and Conclusions

Four alluvial aquifer sites in Assandh block of Karnal district in Haryana were investigated using Schlumberger VES surveys to characterize sub-surface hydro-geological conditions up to 50 m depth. The groundwater level in the study sites ranged from 4- 12 m and its salinity (TDS) varied between 371 to 2080 ppm (0.6 to 3.3 dS/m). The conventional 3 layer curve matching and computer software approaches were employed to estimate the thickness and resistivity of different subsurface horizons and related Dar Zarrouk parameters of Longitudinal Unit Conductance (S) and Transverse Unit Resistance (T). These were further supplemented with bore- hole field data on subsurface lithology and groundwater salinity for making reliable interpretation of VES surveys results. Following salient observations and conclusions can be made based on results of this study:

1. Vertical electrical sounding (VES) is a cost-effective approach to characterize subsurface lithology and groundwater salinity in an area, but need good expertise on proper interpretation of results.
2. Qualitative interpretation of the data through curve matching approach indicated a combination of A and K type curves for the study area suggesting either fresh to marginal groundwater salinity or dominance of layers of finer material in thick alluvial zone.
3. Computer software approach to delineate the thickness and provide resistivity estimates of different geo- electric layers has distinct advantages over conventional curve matching approaches. Interpretation of the VES results through this approach highlighted the presence of fine to medium sand aquifers, characterized by resistivity values of 10 to 27 ohm m in varying thick layers at 10- 35 m below ground level.
4. At 3 sites (Yatriwala, Bindrala and Kala Singh), low resistivity values of 8- 17 ohm m in saturated layers below water level represent fine to medium sand of marginally saline groundwater.

At Balpabana, the fourth site, higher resistivity values of 57- 69 ohm m in 10 to 20m layers represent a mixture of loam and fine sand of relatively good quality groundwater. The lower resistivity of 27 ohm m beyond 35 m at this site represents better aquifer lithology though of marginally higher groundwater salinity.

5. Based on analysis of S and T values and supporting evidence, it can be safely stated that Balpabana, amongst 4 study sites, has the best quantitative and qualitative aquifer potential. Kala Singh site has the most unfavorable hydro-geological conditions upto 50 m depth while remaining 2 sites of Bindrala and Yatriwala fall in between these extremes.

6. Though the expected TDS of groundwater in the study site area upto 50 m depth is likely to be within 500-2000 mg/l (fresh to marginally saline) range, quite suitable for irrigation, excessive withdrawal of groundwater in these areas may lead to deterioration in pumped water quality. For long term protection, the farmers may be advised to explore better aquifer below 50 m depth with the help of VES surveys.

References

Bajpai VN (1989). Surface and subsurface evidence of neotectonics and the aquifer disposition in Central Gangetic Alluvial terrain of Kanpur-Unnao region in Uttar Pradesh, India. Photonirvachak. *Journal of the Indian Society of Remote Sensing* **17 (2):** 47-53.

Bajpai VN and Kumar H (1988). Aquifer disposition and palaeochannel morphology in Kanpur-Unnao region of Central Ganga Plain, India. In: Singh S, Tiwari RC(eds.), *Geomorphology and Environment*. Allahabad Geographical Society,Allahabad, pp. 142-152.

Chandra PC and Athavale RN (1979). Close grid resistivity survey for demarcating the aquifer encountered in bore well at Koyyur in lower Maner basin. *Technical Report No. GH-11-GP-7,Hyderabad.*

Heilan C A (1940). *Geophysical Exploration*. Prentice Hall, NewYork, N.Y., 240 pp.

Jha MK, Kumar S and Chowdhury A (2008). Vertical electrical sounding survey and resistivity inversion using Genetic Algorithm optimization technique. *J. Hydrology* **359(1-2):** 71-87.

Kunetz G (1966). *Principles of Direct Current Resistivity Surveying*. Gebrüder Borntraeger, Berlin pp103.

Kunetz G and Rocori JP (1970). Traitment automatique des sondages electriques. *Geophysical prospecting* 18, 157-198pp.

Lunkad SK (2006). The present and the future of groundwater resources of Haryana, India, In: Venketaswara Rao B. et al. (eds) Proceedings of International Conference on Hydrology and Watershed Management (ICHWAM-2006), Dec. 5-8, Jawahar Lal Nehru Technical University, Hyderabad, India, 1, pp165-181.

Maillet R (1947). The fundamental equations of electrical prospecting: *Geophysics* 12, 529- 556 pp.

Malik A, Setia B and Kamra SK (2013). A GIS based quantity and quality analysis of groundwater in alluvial regions of Haryana. In: Sundar V, Srinivasan K and Murali, K (eds) Proceedings of the Hydro 2013 International XVIII Conference on Hydraulics, Water Resources, Coastal and Environmental Engineering, Chennai (India), December 4- 6, 2013, pp 1019- 1028.

Obiora DN and Onwuka OS (2005). Groundwater exploration in Ikorodu, Lagos-Nigeria: a surface geophysical survey contribution. *The Pacific Journal of Science and Technology* **6(1):** 86-93.

Orellana E (1963). Properties and drawing of the so-called Dar Zarrouk curves. *Geophysics* **28:** 99-110

Ramachandra Rao MB (1975). *Outlines of Geophysical Prospecting: A Manual for Geologists*. 38pp.

Singh CL and Yadav GS (1984). Geoelectrical soundings for ground water investigations of Kushmi area of Ghazipur district, U.P. *The Journal of Scientific Research* **34 (I):** 197- 205.

Vivekananth A, Gowtham B and Hussain SM (2014). Identification of groundwater potential zones in Kadayanallur watershed,Tirunelveli district, Tamil Nadu, using remote sensing and geophysical data. *Gondwana Geological Magazine.* Special Vol. No. **14**, pp. 41-48.

Yadav GS and Singh CL (1987). Groundwater investigations using Schlumberger sounding in the Vindhyan Fringe belt of Ahraura region, Mirzapur, U.P. *Journal of Geophysics* **8:** 237-245.

Yadav GS (2004). Parameter identification- Electrical methods. In: Rai, SN (ed) *Role of Mathematical Modeling in Groundwater Resource Management,* National Geophysical Research Institute, Hyderabad- 500007, India, pp 177- 216

Zohdy AAR (1965). Geoelctrical and Seismic refraction investigations near San jose, California. *Groundwater,* **3**(3): 41-48.

Zohdy AAR (1974). *Use of Dar Zarrouk Curves in the Interpretation of Vertical ElectricalSounding Data.* United States Geological Survey Bulletin, **1313-D**: 41 p.

Zohdy AAR (1975). Automatic interpretation of Schlumberger sounding curves using modified Dar-Zarrouk functions. *United States Geological Survey Bulletin*, **1313-E**: 39 p.

Received: January, 2015; Accepted March, 2015

Journal of Soil Salinity and Water Quality 7(1), 29-34, 2015

Impact of *Eucalyptus* Plantations on Soil Aggregates and Organic Carbon in Sodic-Saline Waterlogged Soils

Sharif Ahamad and JC Dagar

ICAR-Central Soil Salinity Research Institute, Karnal-132001, Haryana

Abstract

The total water stable aggregates were compared in sodic-saline waterlogged soil under cloned *Eucalyptus tereticornis* plantations with non-planted conditions. These were influenced due to variation in pH of soil and waterlogging. Average total water stable aggregates and their indices were significantly ($p \leq 0.05$) higher (38.24 %) in 0-30 cm soil layer and decreased with increase in soil depth. Average macro-aggregates were also decreased with increase in soil depth. The average soil organic carbon (SOC) after seven years of plantation was recorded to be 0.35 % in soil profile (0-120 cm) compared to unplanted area (0.11 %). The SOC was higher (0.83 %) in upper (0-15 cm) soil layer followed by 0.41 % in 15-30 cm soil depth under plantations. The higher SOC in the surface layer was due to the fact that the litter fall and its decomposition mainly took place on surface and influenced mainly upper soil layers. There was significant ($p \leq 0.05$) correlation between macro-aggregates and soil organic carbon, which were maximum in upper soil layers under cloned *Eucalyptus tereticornis* (C-7) plantations.

Key words: Aggregates, Sodic-saline soils, *Eucalyptus tereticornis* plantations, Soil organic carbon, Canal command area, Waterlogging, Soil physical properties, Water stable aggregates (WSA)

Introduction

Canal command areas are facing a major challenge due to rise in groundwater table followed by waterlogging and secondary soil salinization in arid and semi-arid regions. It is estimated that in India, about 6.41 m ha land in considered waterlogged, out of which 4.75 m ha is due to sub-surface waterlogging and 1.66 mha due to surface ponding (Maji *et al.*, 2010). For rehabilitation and reclamation of such soils the plantation of *Eucalyptus* has been promoted and successfully grown as ridge plantation (Jeet-Ram *et al.*, 2011). Trees plantation has a great potential in carbon sequestering in above-ground and below-ground soil and helps in mitigating the greenhouse effect by reducing carbon emissions (Albrecht and Kandji, 2003). Tree plantation is thus the most viable option to tackle land degradation and to bring about eco-restoration and sustenance of soil resources (Dhyani and Chauhan, 1995). Soils have the capacity to store carbon, accounting for more carbon than is found in the atmosphere and living plant biomass combined (Jobbagy and Jackson, 2000). Soil aggregates, a group of primary soil particles,which by soil physical, chemical and biological influences, helps in sequestering carbon and protecting against microbial decomposition (Six *et al.*, 2000). Some of the most important factors influencing the aggregation include surface tension, intermolecular attractive forces between water and solids, precipitated solutes, roots and fungal hyphae and various chemical phenomena.The complex dynamics of aggregation are the results of the interaction of many factors, including the environment, soil management factors, plant influences and soil properties such as mineral composition, texture, soil organic carbon (SOC) concentration, pedogenic processes, microbial activities, exchangeable ions, nutrient reserves, and moisture availability (Kay, 1990). These soil aggregations are the basic index for appraisal of soil physical properties, especially structure, and that is important to sustain soil fertility by reducing soil erosion and mediates air permeability, water infiltration and nutrient cycling (Spohn and Giani, 2011; Zhang *et al.*, 2012). Soil aggregate stability has also been shown to provide a good index of soil erodibility (Kay, 2000; Diaz-Zorita *et al.*, 2002). The soil aggregate stability may be affected by soil texture, organic matter, soil and moisture content (Mostaghimi *et al.*, 1988; Oztas and Fayetorbay, 2003). The abundant water stable aggregates (WSA) in size 0.25-0.1 mm at the upper soil surface layer (0-15 cm) determine the potential for sheet erosion and crust formation (Shouse *et al.*, 1990). For the assessment of physical properties of such soil; and for sustainable crop production and soil health, it is important to examine water stable aggregate (WSA) distribution across the soil profile (Ahamad *et al.*, 2012). Aggregates occur in a variety of manner and size. These are often grouped by size: macro-aggregates (>0.25 mm) and micro-aggregates (<0.25 mm). These groups are further divided by size depending upon soil properties such as binding agents and carbon and nitrogen (N) distribution (Tisdall and Oades, 1982). In the present study an attempt was made to investigate aggregate pattern and carbon contents under *Eucalyptus* plantations of waterlogged sodic soil.

Material and Methods

Study area

The study was carried out in cloned *Eucalyptus tereticornis* (C-7) block plantation waterlogged field at village Puthi, Hisar District, Haryana, northwest India. The study site is situated between 76°142 E longitude and 29°042 N latitude along canal Mitathal in Hisar district. The climate of the area is semi-arid and receives an annual rainfall of 235 mm, of which more than 80% is received during the three monsoon months (July-September). The mean maximum and mean minimum temperature in the region is 32.7 and 17.5 ^{0}C, respectively, which exceeds 41 ^{0}C in May-June and drips about 6 ^{0}C during December-January. At times the maximum temperature exceeds 45 ^{0}C in summer and drops below 0 ^{0}C in winter.

Soil sampling and analysis

Soil samples were collected from pre-planted *Eucalyptus* (seven years old) block plantation under subsurface waterlogging following standard procedure at the soil depths of 0-15, 15-30, 30-60, 60-90 and 90-120 cm. Soil samples were divided in two parts. First part was used for chemical analysis. After grinding, the air-dried soil samples were passed through a 2 mm sieve and analyzed for different soil parameters. The mechanical analysis was done by the Pipette method (Piper, 1967). Another part air dried and grounded samples were passed through 5 mm sieve and were used for estimating aggregate size distribution by wet sieving method (Yoder, 1936) by using a set of sieves having pore diameter 2.0, 1.0, 0.5, 0.25, 0.10 and 0.05 mm for the measurement of total water stable aggregate percentage, macro-aggregate percentage, aggregate stability, mean weight diameter and geometry mean diameter. Samples were used for estimating such indices without dispersion and after dispersion with 5 % (w/v) sodium hexametaphosphate in 1:3 (soil: solution) ratio by mechanically stirring the suspension for five minutes before the vertical oscillation of the apparatus for 30 minutes at the frequency of 50 cycles per minute with taking care that the samples on the top sieve remain immersed throughout the stroke. Before starting the oscillation, soil was left for shaking in water for two minutes. Sieves were then taken out and kept until water was drained out. The water stable aggregates (without dispersion) of different sizes were collected from the respective sieves separately and weighted after oven drying at 50 ^{0}C for 24 h. Water stable macro-aggregate and total water stable aggregates. The macro-aggregates were determined by adding the aggregates retained over 0.25 – 2.0 mm sieves while the total water stable aggregates referred to adding retained on 0.05 – 2.0 mm sieves using the formula:

WSA (%) = [(weight of soil + sand)i – (weight of sand)]/ weight of soil sample

where 'i' denotes the size of the sieve. The percentage of water stable macro-aggregates and water stable micro-aggregates is the summation of soil aggregates size fractions of >0.25 mm and <0.25 mm, respectively. These two summed up to estimate the total water stable aggregates.

Mean weight diameter (MWD) and geometry mean diameter (GMD) of aggregates were calculated as:

$$MWD\ (mm) = \Sigma^{n}_{i=1} XiWi / \Sigma^{n}_{i=1} Wi$$

$$GMD\ (mm) = \exp\ [\Sigma^{n}_{i=1} Wi \log Xi / \Sigma^{n}_{i=1} Wi]$$

where n is the number of fractions (0.1-0.25, 0.25-0.50, 0.50-1.0, 1.0-2.0 and >2.0 mm), Xi is the mean weight diameter (mm) of the sieve size class (0.175, 0.375, 0.75, 1.5 and 2.0 mm) and Wi is the weight of soil (g) retained in each sieve.

The aggregate stability (AS) of soils was computed as:

AS = (Percent soil particles > 0.25 mm – Percent primary particle >0.25 mm)/ (Percent primary particle <0.25 mm)

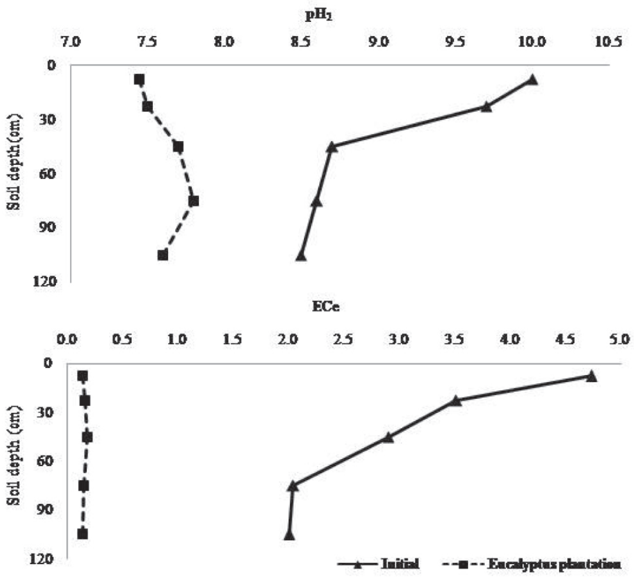


Fig. 1. Soil pH and electrical conductivity (ECe) before and after Eucalyptus plantation

The aggregate ratio (AR) of soils was computed as:

AR=[Percent of water stable macro-aggregates]/[Percent of water stable micro-aggregates]

Statistical analysis

Statistical analysis was performed using SPSS programme to determine the statistical significance of soil condition effect. Duncan's Multiple Range Test (DMRT) was used to compare mean through least significant difference. The 5 % probability level is regarded as statistically significant.

Results and Discussion

Results showed that the pH_2 and ECe were significantly ($p\leq0.05$) lower under the planation in 0-15 cm soil depth than unplanted land left nearby plantations (Fig.1 and Table 1). Kumar *et al*. (2014) also observed the pH, EC and physical properties of sodic soil improved under the *Eucalyptus* plantation. The litter fall of trees release acidity during their decomposition (Noureen *et al*., 2008), cause reduce pH, EC and improved soil physical properties.

Soil organic carbon (SOC)

In present study the distribution of soil organic carbon (SOC) among the soil profile are strongly influenced ($p\leq0.05$) by the plantation of *Eucalyptus* under waterlogging (Fig. 2). The average SOC after seven years of plantation was recorded to be 0.35 % in soil profile (0-120 cm) compared (0.11 %) to unplanted area. The SOC was higher (0.83 %)in upper (0-15 cm) soil layer followed by 0.41 % in 15-30 cm soil depth. The higher SOC in the surface layer is due to fact that the litter fall takes place mainly on the surface layers (Kumar *et al*., 2014; Mongia *et al*., 1998).

Soil aggregation

The results from the wet sieving method for water stable aggregates and its indices of *Eucalyptus* plantation area are shown for soil depths (Table 2). The results showed that average total water stable aggregates were found highest (33 %) in 15-30 cm layer followed by 30 % and 28 % in lower 0-15 and 30-60 cm depth, respectively. Das *et al*. (2014) also reported that the soil aggregates decreased with increasing the soil depth. Chaudhury *et al*. (2014) expressed in a study that soil aggregation increased by improving of organic matter in soil, which can manage through conservational tillage and residue management, in tropical soils. However, in present study the maximum (38.24 %) total water stable aggregates were found in waterlogged soil condition in 0-35 cm soil depth followed by 33.81 % in 15-30

Table 1. Soil condition under *Eucalyptus* plantated on sodic-saline waterlogged condition

Soil Depth	Na (me/l)		Na (me/l)		Ca (me/l)		Mg (me/l)	
	Initial	*Ecalyptus* plantation	Initia	*Ecalyptus* plantation	Initial	*Ecalyptus* plantation	Initial	*Ecalyptus* plantation
0-15	6.17	1.51	0.01	0.02	5.00	9.25	2.50	5.3
15-30	1.81	0.96	0.04	0.04	0.50	6.25	1.00	3.5
30-60	0.85	1.13	0.04	0.04	0.50	7.85	0.50	4.9
60-90	0.80	0.56	0.04	0.03	0.40	7.85	0.40	4.9
90-120	0.73	0.47	0.03	0.04	0.30	7.50	0.40	5.0
Mean	2.07	0.93	0.03	0.04	1.34	7.74	0.96	3.92
SD	2.34	0.45	0.01	0.01	2.05	1.12	0.90	1.29

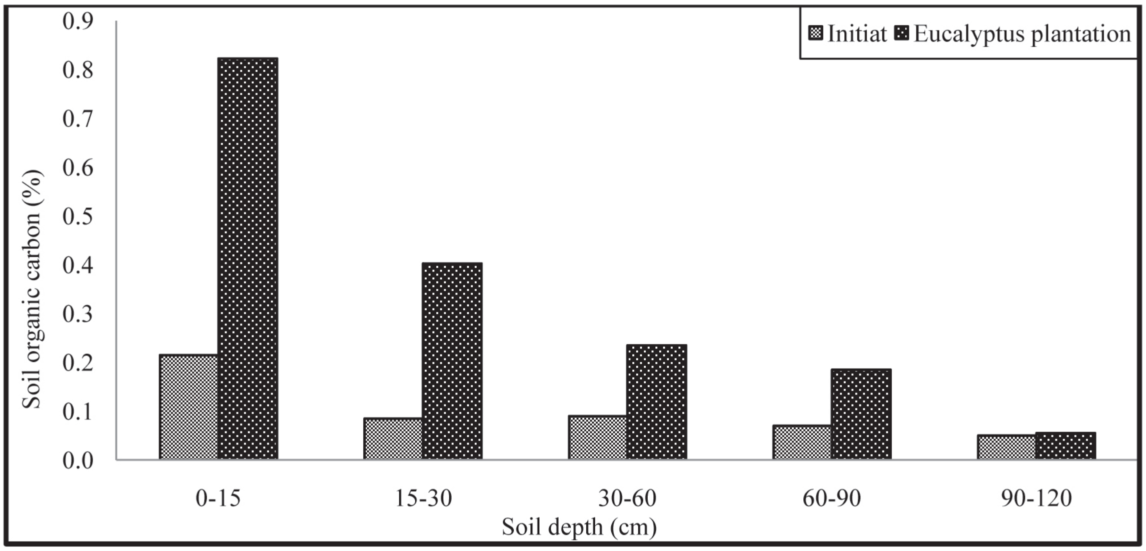


Fig. 2. Soil organic carbon contents in different soil depths under *Eucalyptus* plantations and left over unplanted soil

Table 2. Soil aggregates and its indices under *Eucalyptus* plantation in sodic-saline waterlogged condition

Treatments	TWSA (%)	TWSMaA (%)	TWSMiA (%)	MWD	GMD	AR	AS
0-15 cm depth							
Initial	22.59^{b} ± 1.20	9.09^{b} ± 0.58	13.51^{a} ± 1.64	0.63^{a} ± 0.02	0.59^{a} ± 0.05	0.70^{b} ± 0.11	0.09^{b} ± 0.01
Ecalyptus plantation	37.65^{a} ± 0.53	24.87^{a} ± 0.60	12.78^{a} ± 1.10	0.61^{a} ± 0.01	0.63^{a} ± 0.02	1.98^{a} ± 0.20	0.26^{a} ± 0.01
Mean	30.12	16.98	13.15	0.62	0.61	1.34	0.16
15-30 cm depth							
Initial	27.40^{b} ± 0.19	18.57^{b} ± 1.13	8.83^{b} ± 1.09	0.57^{a} ± 0.04	0.64^{a} ± 0.04	2.20^{a} ± 0.41	0.19^{b} ± 0.01
Ecalyptus plantation	38.82^{a} ± 1.53	28.33^{a} ± 0.30	10.49^{a} ± 1.75	0.60^{a} ± 0.03	0.68^{a} ± 0.00	2.85^{a} ± 0.43	0.30^{a} ± 0.00
Mean	33.11	23.45	9.66	0.59	0.66	2.53	0.25
30-60 cm depth							
Initial	28.18^{a} ± 3.09	8.07^{a} ± 5.71	20.11^{a} ± 2.66	1.44^{a} ± 0.23	0.14^{a} ± 0.14	0.51^{a} ± 0.40	0.10^{a} ± 0.07
Ecalyptus plantation	27.89^{a} ± 1.28	8.29^{a} ± 1.04	19.61^{a} ± 0.50	1.37^{a} ± 0.02	0.11^{a} ± 0.02	0.42^{a} ± 0.05	0.10^{a} ± 0.01
Mean	28.04	8.18	19.86	1.41	0.13	0.47	0.1

Within column with a common letter are not statistically different at $p \leq 0.05$

cm soil depth. The contained of water stable aggregates in soil improved the nutrient status especially nitrogen and carbon (Qiang *et al.*, 2007).

The results showed that the upper layer contained more macro-aggregates which decreased with increased soil depth in the soil profile. Chaudhury *et al.* (2014) also reported that the macro aggregates decreased with increasing soil depth. The macro-aggregates increased from 9.9% at pH 8.5 to 20.3% at pH 9.5 at soil depth 0-15 cm in waterlogged condition. In contrast, in non-waterlogged soil conditions the macro-aggregates decreased from 8.7 at pH 8.5 to 2.8% at pH 9.5 at the same soil depth (Ahamad *et al.*, 2012). Under the waterlogged conditions, organic matter decomposition rate was very slow as compared to soil of lower pH, that might had prevented the decomposition of organic residues, hence hindering in formation of soil aggregation. However, in the waterlogged condition under low pH it helps in improving the soil aggregation. The result showed that the trend of micro-aggregates increased with increasing with soil depth and the same trend was also reported by Chaudhury *et al.* (2014) and Ahamad et al. (2012). Moreover, macro-aggregate contents were found directly correlated (($p \leq 0.05$)) with soil organic carbon (Fig. 3) showing that increase in organic carbon in soil due to plantation improves soil aggregates, which are indicators of soil health.

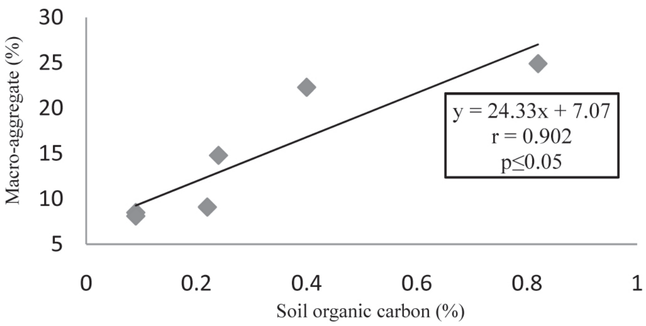


Fig. 3. Correlation between soil organic carbon and macro-aggregates

Conclusion

The total water stable aggregates and soil organic carbon under seven years old *Eucalyptus* plantation increases through adding of litter and its decomposition. Improvement in soil aggregation is the indicator of improving soil health and sequestering carbon in sodic-saline waterlogged soil in terms of reducing soil pH and electrical conductivity and increase in organic carbon more so in upper 30 cm layer. *Eucalyptus* plantation can successfully be grown as ridge as well as block plantation on waterlogged soil. Tree plantation is thus the most viable option to tackle land degradation and to bring the eco-restoration and sustenance of soil resources.

Acknowledgements

The authors are thankful to Director ICAR-Central Soil Salinity Research Institute, Karnal for facilities and encouragement. Authors acknowledge the grant from ICAR in the form of Emeritus Scientist Scheme.

References

Ahamad S, Chaudhari SK, Dagar JC and Basak N (2012) Soil aggregates as indicator of soil health in watergged sodic soil. *J Soil Salinity and Water Quality* **4(2)**: 92-96.

Albrecht A and Kandji ST (2003) Carbon sequestration in tropical agroforestry systems. *Agric Ecosyst Environ* **99**: 15-27.

Choudhury SG, Srivastava S, Singh R, Chaudhari SK, Sharma DK, Singh SK and Sarkar D (2014) Tillage and residue management effect on soil aggregation, organic carbon dynamics and yield attribute in rice-wheat cropping system under reclaimed sodic soil. *Soil Tillage Res* **136**: 76-83.

Das B, Chakraborty D, Singh VK, Aggarwal P, Singh R, Dwivedi BS and Mishra RP (2014) Effect of integrated nutrient management practice on soil aggregate properties, its stability and aggregate-associated carbon content in an intensive rice-wheat system. *Soil Tillage Res* **136**: 9-18.

Dhyani SK and Chauhan DS (1995) Agroforestry interventions for sustained productivity in north-eastern region of India. *J Range Manage Agroforestry* **16**: 79-85.

Diaz-Zorita M, Perfect E and Grove JH (2002) Disruptive methods for assessing soil structure.*Soil Till Res* **64**: 3-22.

Jobbagy EG and Jackson RB (2000) The vertical distribution of organic carbon and its relation to climate and vegetation. *Ecol Appl* **10**: 423-436.

Kay BD (2000) Soil structure. In: Summer EM (ed) *Handbook of Soil Science*. Boca Raton, London, New York, pp 229- 264.

Kay BD (1990) Rates of change of soil structure under different cropping system. *Advances in Soil Science* **12**: 1-52.

Kumar P, Chaudhari SK, Mishra AK, Singh K, Rai P, Singh R and Sharma DK (2014) Labile carbon dynamics and soil amelioration in six-year old *Eucalyptus tereticornis* plantation in sodic soils. *J Soil Salinity and Water Quality* **6(2)**: 91-95.

Maji AK, Obi Reddy GP and Sarkar D (2010) Degraded and Wastelands of India: Status and Special Distribution. ICAR, New Delhi.

Mostaghimi S, Young RA, Wiltts AR and Kenime AL (1988)Effect of frost action on soil aggregate stability. *T ASAE* **31**: 435-439.

Noureen S, Arshad M,Mahmood K and Ashraf MY (2008) Improvement in fertility of nutritionally poor sandy soil of Cholistan Desert, Pakistan *Calligonum polygonoides*. *Pak J Bot* **40(1)**: 265-274.

Oztas T and Fayetorbay F (2003) Effect of freezing and thawing processes on soil aggregate stability. *Catena* **52**: 1-8.

Piper CS (1967) *Soil and Plant Analysis*. Asia Publishing House, New Delhi, India.

Qiang MA, Wan-Tai YU, Shao-Hua Z and Lu Z (2007) Relationship between water-stable aggregates and nutrients in black soil after reclamation. *Pedosphere* **17 (4)**: 538-544.

Jeet-Ram, Dagar JC, Lal K, Singh G, Toky OP, Tanwar VS, Dar SR and Chauhan MK (2011) Biodrainage to combat waterlogging, increase from productivity and sequester carbon in canal command areas of northwest India. *Curr Sci* **100 (11)**: 1673-1680.

Shouse PJ, Gerik TJ,Russel WB and Cassel DK (1990) Spatial distribution of soil particle size and aggregate stability index in a clay soil. *Soil Sci* **149**: 351-360.

Six J, Elliott ET and Paustian K (2000) Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. *Soil Biol Biochem* **32**: 2099-2103

Spohn M and Giani L (2011)Impact of land use change on soil aggregation and aggregate stabilizing compound as dependent on time. *Soil Biol Biochem* **43**: 1081-1088.

Tisdall JM and OadesJM (1982) Organic matter and water-stable aggregates in soils. *J Soil Sci* **62**: 141-163.

Yoder RE (1936) A direct method of aggregate analysis of soil and the study of the physical nature of erosion losses. *J Am Soc Agron* **28**: 337-351

Young A (1989) *Agroforestry for Soil Conservation*. CAB International ICRAF, pp 276

Zhang S, Li Q, Zhang X, Wei K, Chen L and Liang W(2012) Effect of conservation tillage on soil aggregation and aggregate binding agents in black soil of Northeast China. *Soil Tillage Res* **124**: 196-202.

Received: January, 2015; Accepted March, 2015

Journal of Soil Salinity and Water Quality 7(1), 35-39, 2015

Effect of Sodic Water Irrigation with Application of Sulphur as Single Super Phosphate on Yield, Mineral Composition and Soil Properties in Rice-Wheat System

NPS Yaduvanshi*, K Lal* and A Swarup*

Division of Soil and Crop Management, ICAR-Central Soil Salinity Research Institute, Karnal-132001, Haryana

Abstract

The effects of sulphur as single super phosphate with different levels of sulphur (0, 30 and 45 kg ha^{-1}) were studied in rice- wheat crops on clay loam soil at Farmers' field, Dera Bhaini Majra, Kaithal. The grain yield of wheat increased significantly with the application of 45 kg S ha^{-1} through single super phosphate with recommended doses of NPK fertilizer over control. The N-S composition of plant and their uptake were considerably higher with 45 kg S ha^{-1} with recommended doses of NPK fertilizer at all growth stages. The N and S composition of plant and their uptake were considerably higher with 45 kg S ha^{-1} at all growth stages. Use of sodic water with 100% NP during two years slightly decreased the soil pH and SAR from the initial value of 8.6 and 16.2, respectively. However, treatments involving the use of 45 kg S ha^{-1} significantly decreased the soil pH and SAR over 100% NP treatments. The results suggest that 45 kg S ha^{-1} through single super phosphate with recommended doses of NP fertilizer must be used to sustain the productivity of rice – wheat system in areas having sodic ground water for irrigation.

Key words: Sodic water, single superphosphate, rice –wheat sequence, Sulphur content

Introduction

In many arid and semiarid regions of the world, sodic groundwater is the main source of irrigation and its use poses a threat to improved rice and wheat production. Moreover, a large number of farmers have discontinued their source of underground water for irrigation on account of soil deterioration leading to drastic reduction in the yield of crops. In spite of poor quality, the water is being used for irrigation as there are no alternatives. Application of gypsum as a soil or water amendment is commonly recommended to offset the deteriorating effects of these types of water (Yaduvanshi and Swarup, 2005). In view of non-availability of gypsum, there is strong need to alternative sources of gypsum, especially S content fertilizer, in order to supplement the S supply through chemical fertilizers as single super phosphate are multi-nutrients compound. Thus, there is an urgent need to work out sulphur fertilizer use strategies to enhance and sustain higher level of crop and soil productivity of rice - wheat system in reclaimed alkali soils under sodic water irrigation conditions. These poor quality waters constitute about 47% in Punjab (Bajwa *et al.,* 1974; Sehgal *et al.*, 1985), 62% in Haryana 84% in Rajasthan, 38% in Karnataka, 32% in Andhra Pradesh, 30% in Gujarat and 50% in Agra, Aligarh, Etah, Mainpuri and Mathura districts of UP (Dixit, 1974). Since rice-wheat is the most commonly practiced crop rotation system in the Indo-Genetic plains, improving its productivity, particularly in areas with poor-quality groundwater, is a major challenge. Keeping in the view the above problems, the work was undertaken to find out the ways for managing such hazardous waters by sulphur application through single super phosphate for sustainable crop production in the area.

Material and Methods

A field experiment was conducted during 2004-05 and 2005-06 on a gypsum amended sodic soil to evaluate the use of sulphur fertilizer (single super phosphate) in rice-wheat cropping system under high RSC irrigation water at Farmers' field Dera, Bhaini Majra, Kaithal. The experimental soil (0-15cm) had pH 9.0, EC_2 0.79 dS m^{-1}, SAR 16.2 (m mol l^{-1})$^{1/2}$; organic carbon 0.44%, available P 14.8 kg ha^{-1}, available and K 275 kg ha^{-1}. The treatment consisted

Correspondence e-mail: npsyaduvanshi@gmail.com

*Present addressed. Indian Agricultural Research institute, New Delhi.

of: T_1, 0 kg S ha^{-1}; T_2, 15 kg S ha^{-1}; T_3, 30 kg S ha^{-1}; T_4, 45 kg S ha^{-1}. The experiment was laid out in randomized block design with four replications. The recommended dose of 120 kg N and 26 kg P ha^{-1} were applied to whole treatment. One third of N and full dose of S and P were added at the time of transplanting of rice as per treatments. The remaining dose of nitrogen was top dressed in two equal splits at 21 and 40 days after rice transplanting. The sources of S, N and P were single super phosphate, urea/di-ammonium phosphate (DAP), respectively. Rice cv Jaya (30-day-old seedling) was transplanted in standing water during *kharif* season. Grain yield of rice was computed on 14 per cent moisture content and straw yield on oven dry basis.

Wheat cv HD 2329 was sown during the second week of November at a row spacing of 20 cm in every years. Wheat was sown at a rate of 100 kg ha^{-1} or 10 g m^{-2}. The inorganic fertilizer treatments as given to rice were also applied to wheat. One third dose of N and the full amount of S and P were added at the time of sowing. The remaining dose of nitrogen was top dressed in two equal splits at 21 and 40 days after sowing. Wheat crop was harvested during second week of April every year. Yields of both grain and straw were recorded on air-dry basis (air temperature up to 40^0 C). Soil samples (0 - 15 cm) were taken before starting the experiment in 2004 and after the harvest of wheat. The soil samples were air-dried and ground to pass through a 2 mm sieve and were analyzed for pH, organic carbon and available N, P, K and S by standard methods. The plant samples collected at different growth stages were washed thoroughly with tap water, 0.05 N HCl and deionised water in succession and dried at 70 ^{0}C in a hot-air oven. The dried samples were ground in a stainless steel Willey mill and digested in di-acid mixture ($HClO_4$ and HNO_3 in 1:3 ratio). These were analyzed for total S in plant samples (Jackson, 1967). Three hundred surface soil samples (0-15 cm) were collected from rice-wheat growing belt of Karnal and Kaithal district of Haryana. The soil samples were air dried and milled to pass through a 2 mm sieve for analysis. Available SO_4 – S in the extract was determined turbidimetrically (Chesnin and Yien, 1950).

Results and Discussion

Yield

The grain yield of rice and wheat increased significantly (from 3.33 t ha^{-1} to 4.40 t ha^{-1}) with the application of 45 kg S ha^{-1} with recommended doses of NP fertilizer over that of control. But the same was not affected in rice yield during the first year. The mean response of rice and wheat yield varied from 6.6 to 19.0 and 15.0 to 40.7 per cent, respectively over 100% NP fertilizer. In the absence of S application, considerable reduction of yield of rice and wheat was noticed due to the advanced of sodic water to soil and led to increased sodium concentrations. This might be caused by better vegetative growth of plant at higher rates of sulphur due to minimizing the adverse affect of sodic water. The addition of single super phosphate as S sources to soils irrigated with sodic water increased yield of wheat significantly (Table 1).

Content and uptake of sulphur

The data showed at all growth stage, S and N content in rice and wheat was higher at higher rate of sulphur application. The different growth stage ranged from 0.09 to 0.15, 0.05 to 0.12, 0.06 to 0.12 and 0.08 to 0.18% in rice and 0.10 to 0.21, 0.08 to 0.14, 0.09 to 0.21 and 0.05 to 0.12% at 30 DAT, 60 DAT, grain and straw, respectively. Application of sulphur combined with 100% NP fertilizer significantly increased the concentration of sulphur and nitrogen as compared to 100% NP fertilizer (Fig. 1 and 2). The concentration of sulphur and nitrogen increased with the increase in sulphur rates but there were no significant differences were obtained with application of 30 and 45 kg S ha^{-1}. In the absence of S application, considerable reduction in S content was noticed due to the reduced availability of soil S and led to imbalanced nutrient concentrations (Table 1). The S and N concentration in plant was highest at 30 DAT stage and decreased with advancement in the age of the crop due to increased biomass and dilution effect. Similar trend was also reported by others (Yoshida and Chaudhury, 1979). Yaduvanshi (1998) also found that the total S concentration in sugarcane plant was higher at maximum tillering stage and decreased with increase in the age of the crop on sandy loam soil. The uptake of S also increased with increasing rate of S rate with 100% NP fertilizer in both crops (Table 2). Total mean uptake of N and S in two crop cycles varied between 124.3 kg ha^{-1} at the lowest yield levels in plots receiving 100% NP treatment to 203.3 kg ha^{-1} under highest yields obtained in the plots of 100% NP + 45 kg S ha^{-1} treatment. This might be caused by better vegetative growth of plant at higher rate of S with recommended doses of NP fertilizer.

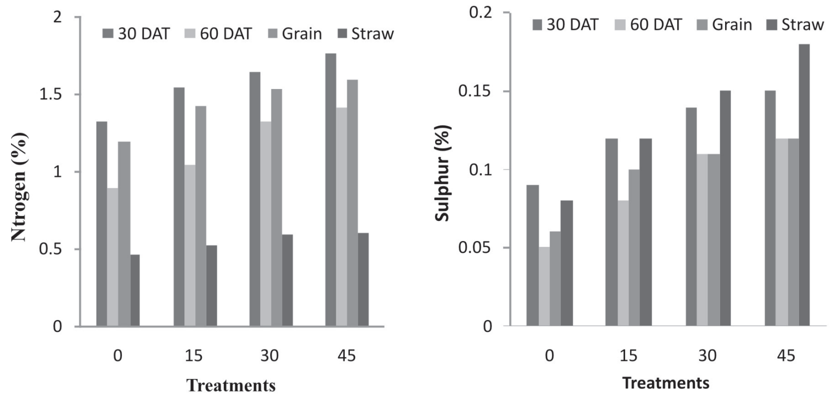


Fig. 1. Nitrogen and sulphur contents of rice under different treatments

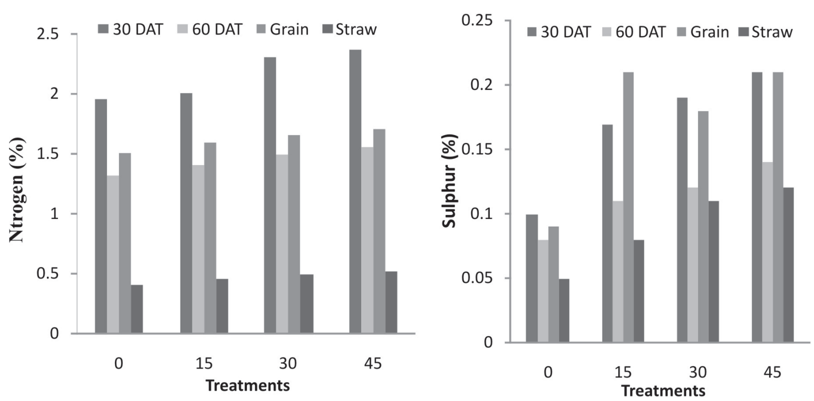


Fig. 2. Nitrogen and sulphur contents of wheat under different treatments

Table 1. Effect of sulphur fertilizer on yield of rice and wheat

Sulphur (kg ha^{-1})	Rice yield (t ha^{-1})				Wheat yield (t ha^{-1})			
	Grain		Straw		Grain		Straw	
	2004	2005	2004	2005	2004-05	2005-06	2004-05	2005-06
0	3.30	3.33	5.17	5.03	2.61	2.30	3.10	3.25
15	3.43	3.65	5.36	5.46	2.73	2.92	3.32	3.41
30	3.45	3.97	5.40	5.66	2.87	3.14	3.84	3.72
45	3.49	4.40	5.54	5.84	3.25	3.66	3.98	4.05
LSD(p=0.05)	NS	0.78	NS	0.81	0.54	0.27	0.24	0.21

Soil properties

The soil pH, after two cycles of rice-wheat rotation, slightly declined over initial status in all the treatments (Table 3). The magnitude of decreased, however was greater in plots receiving sulphur with 100% NP fertilizer compared to 100% NP fertilizer. Application of sulphur with 100% NP fertilizer significantly decreased the sodium absorption ratio (SAR) of surface soil (0-15cm) in two year of rice and wheat crop harvest over that of 100% NP fertilizer under use of sodic water irrigation (Table 3). The beneficial effect of gypsum (20% S) towards reducing SAR or ESP of sodic water irrigated soil has also been reported earlier by Sharma *et al.* (2001) and Sharma and Minhas (2004). The buildup of low SAR in the surface 15 cm soil layer despite its receiving large number of irrigations with sodic water during growth of rice – wheat crops has been attributed to the greater dissolution of calcium from $CaCO_3$ owing to high leaching fraction and high pCO_2 attained during rice growth under submerged conditions (Sharma *et al.,* 2001).

Table 2. Effect of sulphur on uptake (kg ha^{-1}) of N and S in rice and wheat crop

Sulphur (kg ha^{-1})	Rice				Wheat			
	N		S		N		S	
	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain
0	23.5	39.5	3.18	2.56	13.0	38.7	1.59	2.30
15	28.2	50.3	3.47	2.73	16.9	43.4	2.78	4.44
30	32.6	56.8	3.78	3.01	18.5	49.7	4.16	5.42
45	34.1	69.5	4.02	3.46	20.9	59.2	4.82	7.27
LSD (p=0.0 5)	1.68	3.00	0.21	0.18	0.96	2.73	0.18	0.27

Table 3. Effect of sulphur on soil properties

Sulphur (kg ha^{-1})	pH	S (mg kg^{-1})	Available nutrient (kg ha^{-1})		SAR (m mol/l)$^{1/2}$
			N	P	
0	9.03	49.5	84	46	16.2
15	8.95	52.2	96	45	12.8
30	8.92	53.1	96	45	11.6
45	8.89	57.1	98	44	11.1
LSD (p=0.05)	NS	4.45	NS	NS	0.72

Table 4. Status of sulphur in reclaimed sodic soils of Karnal and Kaithal district of Haryana

Location	No. of samples	% of samples		
		Deficient (<10 mg S kg^{-1})	Medium (10-20 mg S kg^{-1})	Sufficient (>20 mg S kg^{-1})
Karnal	150	Nil	16	84
Kaithal	150	Nil	2	98

Addition of 45 kg S ha^{-1} increased significantly in available SO_4 – S content of the soil over 100% NP fertilizers. The highest available SO_4 – S was obtained with the addition of 45 kg S ha-^{1}. There is no buildup of available soil N and P during two years experiment.

Available S status of farmers' fields

The available Sulphur content in soils collected from different farmers'fields of rice –wheat growing areas in Karnal and Kaithal ranged from 12 to 216 mg kg^{-1}. About 17 and 2% of soil samples were below upto 20 mg S kg-1 in Karnal and Kaithal districts of Haryana, respectively (Table 4).

The higher content of available SO_4 – S was obtained in Kaithal district in comparison to Karnal district. The sufficient amount of available SO_4 – S were 83 and 98% of soils above 20 mg S kg-1 in Karnal and Kaithal districts of Haryana, respectively. The reason for buildup of available SO_4 –S in salt affected soils may be due to continuous use of gypsum application for reduced the adverse effects of sodicity under rice-wheat system.

References

Bajwa MS, Singh NT and Randhawa NS (1974). Chemical composition of underground waters Punjab. *J. Res. PAU , Ludhiana* **12:** 117-122.

Chesnin L and Yien CH (1950). Turbidimetric determination of available sulphate. *Soil Science Society America Proceeding* **15**: 149-151.

Dixit SP (1974). Quality of irrigation water from different sources in western Uttar Pradesh. Proceedings of All India Symposium on Soil Salinity, pp.107-11, UP Institute of Agriculture Science, Kanpur.

Jackson M L (1967). *Soil Chemical Analysis.* Prentice Hall of India Pvt. Ltd., New Delhi.

Sehgal JL, Bajwa MS and Khurana PK (1985). Soils of Punjab and their management. In *Soils of India*. FAI, New Delhi. pp. 316-42.

Sharma D R and Minhas PS (2004). Soil properties and yields of upland crops as influenced by long-term use of water having variable residual alkalinity, salinity and sodicity. *Journal of the Indian Society of Soil Science* **1**: 100-104.

Sharma DR, Minhas PS and Sharma D K (2001). Response of wheat to sodic water irrigation and gypsum application. *Journal of the Indian Society of Soil Science* **49**: 324-327.

Yaduvanshi NPS (1998). Sulphur fertilization in sugarcane. *Sugar Cane* **6**: 6-8.

Yaduvanshi NPS and Swarup A (2005). Effect of continuous use of sodic irrigation water with and without gypsum, farm yard manure, pressmud and fertilizer on soil properties and yields of rice and wheat in a long term experiment. *Nutrient Cyclic in Agroecosystems.* **73:** 111-118.

Yoshida S and Chaudhury MR (1979). Sulphur nutrition of rice. *Soil Science Plant Nutrition*. **25**:121.

Received: February, 2015; Accepted April, 2015

Journal of Soil Salinity and Water Quality 7(1), 40-44, 2015

Salinity Induced Changes in Chlorophyll Pigments and Ionic Relations in Bael (*Aegle marmelos* Correa) Cultivars

Anshuman Singh*, PC Sharma, A Kumar, MD Meena and DK Sharma

ICAR-Central Soil Salinity Research Institute, Karnal-132001, Haryana
**Email- anshumaniari@gmail.com*

Abstract

Bael (*Aegle marmelos*) cultivars NB-5, NB-9, CB-1 and CB-2 were grown in normal (EC_e 1.3 dS m^{-1}), moderate (6.5 dS m^{-1}) and high (10.7 dS m^{-1}) saline soils. The cultivars, evaluated for changes in appearance, leaf chlorophyll pigments and ionic relations, exhibited salt stress symptoms as yellowing, scorching and chlorosis of the leaves. Majority of the affected leaves subsequently abscised from the plants. Salinity significantly increased membrane injury and caused reduction in relative water content in all the cultivars. Accumulation of total soluble sugars in salt treated plants showed genotypic differences with NB-5 plants recording their maximum accumulation. Leaf chlorophyll (a, b and total) values showed a consistent decrease with increase in salinity except for NB-5 plants which exhibited slightly higher chlorophyll contents at moderate salinity. All the cultivars except NB-5 exhibited significantly higher leaf Na^+ concentrations with increasing salinity while the plants of cultivar NB-5 maintained a favourable ionic balance in terms of low Na^+/K^+ ratio resulting in good plant performance under salinity. The plants of NB-9 and CB-2 varieties did not survive at high salinity. Based on overall performance, NB-5 exhibited tolerance to moderately saline soils (EC_e ~6.5dS m^{-1}) and was successfully established when irrigated with normal water.

Key words: *Aegle marmelos*, Cultivars, Mineral nutrition, Salinity tolerance, Salt-affected soils

Introduction

A sustainable approach for the productive utilization of salt-affected soils (SAS), which cover approximately 6.73 m ha area in India, relates to the use of salt tolerant crop genotypes (Singh *et al.*, 2010). Many plants of economic importance exhibit salt tolerance and are adapted to grow in salt-affected environments. Similarly, many improved crop genotypes have been developed and/or identified for commercial cultivation in SAS (Flowers, 2004). A number of fruit crops perform well under salinity stress and may be commercially grown in saline and sodic soils (Dagar, 2009). Bael (*Aegle marmelos* Correa) is an indigenous underutilized fruit crop valued for its medicinal and processing values and tolerance to different biotic and abiotic stresses. In spite of these strengths, there is no organized cultivation of this fruit in India. Bael cultivation in SAS could be a good option for alternate land use and crop diversification (Dagar, 2009). Salt stressed bael plants suffer from nutrient deficiencies (N, P, K and Ca) which may account for poor plant establishment and growth under salt stress (Shukla and Singh, 1996). The available reports on salinity tolerance in bael provide least information on important physiological and biochemical parameters of the tolerant and susceptible accessions which may explain plant behaviour in relation to salinity and may be correlated with salinity tolerance mechanism in certain cultivar(s). In this backdrop, one-year old plants of four improved bael genotypes were evaluated in saline soils for assessing their salt tolerance so as to appraise their suitability for cultivation in SAS.

Material and Methods

The present experiment was carried out during 2013-2014 at the experimental facility of ICAR-Central Soil Salinity Research Institute (CSSRI), Karnal, India. One-year-old, grafted plants of four bael cultivars, namely, Narendra Bael-5 (NB-5), Narendra Bael-9 (NB-9), CISH Bael-1 (CB-1) and CISH Bael-2 (CB-2) procured from the ICAR-Central Institute of Subtropical Horticulture, Lucknow, India were used. The saline soils used in this experiment were obtained from the CSSRI-Nain Experimental Farm, Panipat, India; while control soil was obtained from the crop fields. The soil was filled in large, metallic

Table 1. Initial physico-chemical properties of the experimental soil

Type of soil/soil properties	Control	Moderately saline	Highly saline
pH_s	7.6	8.0	8.1
EC_e (dS m^{-1})	1.3	6.5	10.7
HCO_3* (meq l^{-1})	0.60	0.40	0.60
Organic carbon (%)	0.74	0.34	0.77
Available N (kg ha^{-1})	43.12	39.2	54.88
Available P (kg ha^{-1})	33.60	13.44	38.80
Available K (kg ha^{-1})	100.7	92.50	117.5

*Carbonates were not present in experimental soil.

experimental columns of approximately 74 cm length, 44 cm width and 166 cm circumference (each column containing approximately 76 kg soil). There were three salinity treatments: control (soil EC_e 1.3 dS m^{-1}), moderate (EC_e 6.5 dS m^{-1}) and high (EC_e 10.7 dS m^{-1}). After transplanting, the plants were irrigated with normal water (EC_{IW} 0.5 dS m^{-1}) till the time of data recording.

Soil pH_s and EC_e were determined by a glass electrode pH meter and electrical conductivity meter, respectively in the supernatant. The organic carbon content in soil was determined by wet oxidation method of Nelson and Sommer (1982). Carbonate and bicarbonate in soil water extract were determined using 0.01N H_2SO_4 as described by Richards (1954). The available N in soil was determined by alkaline permanganate method (Subbiah and Asija, 1956), available P by colorimetric method (Olsen *et al.*, 1954) and available K by flame photometry (Jackson, 1973).

One-year after salt treatment, the leaves were collected and analysed for estimating salinity induced physio-biochemical changes. The membrane injury index and relative water content in leaves were estimated using the methods of Blum and Ebercon (1981) and Barrs and Wheatherly (1962), respectively. Total soluble sugars were measured by the colorimetric method with antrone reagent (Yemm and Wills, 1954). Total soluble protein content was determined according to Bradford (1976). The leaf chlorophyll (chlorophyll a, b, and total) values were estimated using the method of Hiscox and Israelstam (1979). For ionic relations, leaves were dried in a forced-draft oven at 60 ºC for 48 h, weighed and crushed in a hammer mill and stored at the room temperature. Approximately 50 mg of dried and powdered leaf material was extracted with 1 M HNO_3 at 100 ºC. Na^+ and K^+ contents were determined by using the flame photometer (Systronics, India).

Results and Discussion

Selected soil properties

The initial physico-chemical properties of the experimental soil (Table 1) indicated its low organic carbon (0.34-0.77 %) status, extreme deficiency of available nitrogen (39.2-54.88 kg ha^{-1}), moderate quantities of available P (13.44-38.8 kg ha^{-1}) and low to moderate available K (92.5-117.5 kg ha^{-1}). The pH_s in saturation extract was in range of 7.6-8.1. The electrical conductivities of experimental soils in soil saturation paste extract were 1.3, 6.5 and 10.7 and the soils were accordingly categorized as normal, moderately saline and highly saline. The saturation extract of soils used had measurable amount of HCO_3^- but CO_3^{2-} was not detectable. Plants growing in such saline soils face osmotic stress and nutrient toxicities (primarily due to excess accumulations of Na^+ and Cl^- ions) which result in poor growth (Flowers, 2004). The traditional practice of leaching the excess soluble salts below root zone to facilitate crop production in saline soils requires huge amounts of good quality water. Given the high environmental footprint of this technology and limited availability of fresh water, identification of salt tolerant genotypes can greatly help in their productive utilization (Dagar, 2009; Sharma *et al.*, 2014).

Morphological symptoms of salt stress

Morphological symptoms (data not shown) revealed that salt stressed plants initially showed yellowish appearance and marginal scorching in leaves as compared to their non-salinized counterparts. With increase in duration of salt treatment, these symptoms spread to entire leaf which eventually became chlorotic and abscised from the plants. At 6.5 dS m^{-1} salinity, NB-9 and CB-2 plants were severely affected while those of CB-1 recorded relatively lesser injury but salt treated NB-5 plants maintained growth comparable to their non-salinized counterparts. At high salinity (10.7 dS m^{-1}), all the cultivars exhibited severe reduction in growth and those of NB-9 and CB-2 did not survive. These results are consistent with previous salinity studies in bael (Pandey *et al.*, 1985). Salt stressed bael plants suffer from nutritional deficiencies and ion toxicities which seem to cause injury symptoms such as scorching, chlorosis and necrosis of leaves and in extreme cases eventual abscission from the plants (Shukla and Singh, 1996) resulting in poor plant growth and establishment.

Membrane injury index and relative water content

Salt stressed bael plants exhibited significant cultivar differences for membrane injury index and relative water content (Table 2). At moderate (6.5 dS m^{-1}) salinity the membrane injury ranged from 38% (CB-2) to 74% (NB-9) as compared to control plants. Similarly differences were also observed among the cultivars for relative water content (RWC). Among cultivars, moderate salinity caused the maximum decrease (23.8%) in RWC in CB-2 while the minimum (7.8%) decrease occurred in CB-1. In citrus, cultivar differences have earlier been reported for salinity induced membrane damage and reduction in RWC in leaves. Salt stressed plants exhibit damage of lipid membranes which often results in increased cell permeability and electrolyte leakage from cells (Singh *et al.*, 2014). High salt concentration in root zone, which causes osmotic stress, restricts water absorption by the plants and causes cellular dehydration, seems to be primarily responsible for decrease in RWC (Greenway and Munns, 1980). These results are in agreement with findings of Singh *et al.* (2014) in citrus.

Table 2. Effect of salinity on membrane injury index (MII), relative water content (RWC) and total soluble sugars (TSS) in bael cultivars

Cultivar	Soil salinity (dS m^{-1})	MII	RWC (%)	TSS (mg g^{-1} DW)
NB-5	1.3	14.46g	77.78a	13.36f
	6.5	21.61e	71.08b	22.4c
	10.7	37.03b	59.89c	31.43a
NB-9	1.3	16.3fg	78.37a	13.1f
	6.5	28.35c	64.04c	21.69cd
	10.7	PNS	PNS	PNS
CB-1	1.3	14.52g	79.53a	14.08f
	6.5	24.46d	73.34b	18.4e
	10.7	42.71a	55.25d	28b
CB-2	1.3	17.44f	79.96a	13.39f
	6.5	24.08de	60.94c	20.26d
	10.7	PNS	PNS	PNS

Means with at least one letter common in each column are not statistically significant using Duncan's Test at 5% level of significance. PNS= Plants not survived (NB-9 and CB-1 plants did not survive at 10.7 dS m^{-1} salinity).

Total soluble sugars

Salt treated bael cultivars exhibited different accumulation patterns of total soluble sugars (TSS) in leaves (Table 2). Although TSS concentration in leaves increased with salinity in all the cultivars, NB-5 plants had significantly higher TSS at both moderate and high salinity as compared to other cultivars. It suggested the salt tolerant nature of NB-5 plants as soluble sugars accumulate in higher concentrations in salt stressed plants and contribute to osmotic adjustment (Bolarín *et al.*, 1995).

Chlorophyll pigments

All the cultivars showed significant reductions in chlorophyll (a, b and total) values with increasing salt stress except NB-5 which showed slightly higher chlorophyll contents at moderate salinity (Table 3). At 6.5 dS m^{-1} salinity, decrease in chlorophyll 'a' was 30% in NB-9, 56% in CB-1 and 47% in CB-2 as compared to respective control plants. Similarly, chlorophyll 'b' content decreased by 13% in NB-9, 35% CB-1 and 22.45% in CB-2 as compared to control. In general, high salinity causes a decrease in chlorophyll in both tolerant and susceptible genotypes in different crop (Misra *et al.*, 1997; Singh *et al.*, 2014) but in certain cases low-to-moderate salt concentrations may favour preferential accumulation of these pigments in tolerant types (Misra *et al.*, 1997). The effects of salt stress on chlorophyll degradation, presumably due to increased activity of the enzyme chlorophyllase (Misra *et al.*, 1997), were characterized as the yellowing of leaves which failed to produce the optimum amounts of photosynthates leading to reduced plant growth and vigour.

Table 3. Effect of salinity on chlorophyll pigments in bael cultivars

Cultivar	Soil salinity ($dS\ m^{-1}$)	Chlorophyll 'a' ($mg\ g^{-1}$ FW)	Chlorophyll 'b' ($mg\ g^{-1}$ FW)	Total chlorophyll ($mg\ g^{-1}$ FW)
NB-5	1.3	2.02d	1.38b	3.41b
	6.5	2.4bc	1.59a	4a
	10.7	0.85g	1.12d	1.97d
NB-9	1.3	2.32c	1.56ab	3.87a
	6.5	1.63e	1.36bc	2.99c
	10.7	PNS	PNS	PNS
CB-1	1.3	2.69a	1.17cd	3.86a
	6.5	1.17f	0.76e	1.93d
	10.7	0.68h	0.49f	1.17e
CB-2	1.3	2.46b	0.98d	3.44b
	6.5	1.3f	0.76e	2.06d
	10.7	PNS	PNS	PNS

Means with at least one letter common in each column are not statistically significant using Duncan's Test at 5% level of significance. PNS= Plants not survived (NB-9 and CB-1 plants did not survive at 10.7 $dS\ m^{-1}$ salinity).

Sodium, potassium and sodium: potassium ratio

At both salinity levels, there was a significant increase in leaf Na^+ accumulation irrespective of the cultivar (Table 4). At moderate salinity, there was a three-fold increase in Na^+ concentration in leaves of NB-5 relative to control while the corresponding increase was five-times in NB-9 and four-times in both CB-1 and CB-2 cultivars. Cultivar NB-5 not only prevented the accumulation of Na^+ to toxic levels but also exhibited higher K^+ concentrations and thus maintained a favourable ionic balance in terms of low Na^+/K^+ ratio resulting in good plant performance.

Table 4. Ionic relations in bael cultivars under salinity stress

Cultivar	Soil salinity ($dS\ m^{-1}$)	Na^+ (% DW)	K^+ (% DW)	Na^+/K^+ ratio
NB-5	1.3	0.06e	0.27g	0.22a
	6.5	0.18d	1e	0.18cd
	10.7	0.29b	1.46b	0.2bc
NB-9	1.3	0.06e	0.45f	0.13e
	6.5	0.3b	1.35c	0.22a
	10.7	PNS	PNS	PNS
CB-1	1.3	0.06e	0.42f	0.14e
	6.5	0.24c	1.07d	0.23a
	10.7	0.35a	1.65a	0.21ab
CB-2	1.3	0.06e	0.46f	0.12e
	6.5	0.24c	1.41bc	0.17d
	10.7	PNS	PNS	PNS

Means with at least one letter common in each column are not statistically significant using Duncan's Test at 5% level of significance. PNS= Plants not survived (NB-9 and CB-1 plants did not survive at 10.7 $dS\ m^{-1}$ salinity).

The plants of NB-9 and CB-2 varieties, due to Na^+ toxicity, did not survive at high salinity. Most of the fruit crops are sensitive to excessive concentrations of Na^+ ions in the growing medium. Excessive Na^+ concentration reduces the uptake of K^+ and Ca^{2+} by plants. Available reports in citrus point to genotypic differences which may explain better performance by some scions and/or rootstocks as compared to others (Levy and Syvertsen, 2004; Murkute *et al.*, 2005).

Conclusions

The bael cultivars tested in this experiment exhibited tolerance to low and moderate salinity. Cultivar NB-5 exhibited relatively higher salinity tolerance and showed better performance as compared to other cultivars. Although salinity adversely affected some of the physiological traits in NB-5 plants, they showed better salt tolerance owing to favourable chlorophyll concentration, restricted uptake of Na^+ ions and higher K^+ accumulation in leaves. In concluding remarks, the commercial cultivation of NB-5 is feasible in moderately saline soils (EC_e ~6.5).

References

Barrs HD and Weatherley PE (1962). A re-examination of the relative turgidity technique for estimating water deficits in leaves. *Australian Journal of Biological Science* **15:** 413-28.

Blum A and Ebercon A (1981). Cell membrane stability as a measure of drought and heat tolerance in wheat. *Crop Science* **21:** 43-47.

Bolarín MC, Santa-Cruz A, Cayuela E and Perez-Alfocea F (1995). Short-term solute changes in leaves and roots of cultivated and wild tomato seedlings under salinity. *Journal of Plant Physiology* **147:** 463-468.

Bradford M (1976). A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein dye binding. *Annals of Biochemistry* **72:** 248-254

Bray RH and Kurtz LT (1945). Determination of total, organic and available forms of phosphorus in soils. *Soil Science* **59:** 39-45.

Dagar JC (2009). Opportunities for alternate land uses in salty and water scarcity areas. *International Journal of Ecology and Environmental Sciences* **35:** 53-66.

Flowers, T. J. 2004. Improving crop salt tolerance. *Journal of Experimental Botany* **55**: 307-319.

Greenway H and Munns R (1980). Mechanisms of salt tolerance in non-halophytes. *Annual Review of Plant Physiology* **31:** 149-90.

Hiscox JD and Israelstam GF (1979). A method for the extraction of chlorophyll from leaf tissue without maceration. *Canadian Journal of Botany* **57:** 1332-34.

Jackson ML (1973). *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi.

Levy Y and Syvertsen J (2004). Irrigation water quality and salinity effects in citrus trees. *Horticultural Reviews* **30:** 37-82.

Misra AN Sahu SM Misra M Singh P Meera I Das N Kar M and Sahu P (1997). Sodium chloride induced changes in leaf growth, and pigment and protein contents in two rice cultivars. *Biologia Plantarum* **39:** 257-262.

Murkute AA Sharma S and Singh SK (2005). Citrus in terms of soil and water salinity: A review. *Journal of Scientific and Industrial Research* **64:** 393-402.

Nelson DW and Sommers LE (1982). Total carbon, organic carbon and organic matter. In: (Page AL, Miller RH, Keeney D.R. (eds.) *Methods of Soil Analysis*, Agron. Monogr. 2nd Edition, Madison, **12(2)**: 101-129.

Olsen SR, Cole CV, Watarabe FS and Dean LA (1954) Estimation of available phosphorus in soil by extraction with sodium bicarbonate (US Department of Agriculture Circular No. 939). Washington DC. US Government Printing Office.

Pandey G, Pathak RK and Om H 1985. Effect of sodicity on mineral composition, chlorophyll content and injury symptoms in bael (*Aegle marmelos* Correa) leaves. *Progressive Horticulture* **17:** 5-8.

Richards LA (1954). Diagnosis and improvement of saline and alkali soils. Agric. Hand Book No.60, USDA, U.S. Govt. Printing Office, Washington D.C. p160.

Sharma DK, Chaudhari SK and Singh A (2014). In salt-affected soils agroforestry is a promising option. *Indian Farming* **63:** 19-22.

Shukla SK and Singh GN (1996). Nutrient imbalances in bael (*Aegle marmelos* Correa) leaves as induced by salinity and sodicity. *Indian Journal of Plant Physiology* **1:** 293-294.

Singh A Prakash J Srivastav M Singh SK Awasthi OP Singh AK Chaudhari SK and Sharma D K (2014). Physiological and biochemical responses of citrus rootstocks under salinity stress. *Indian Journal of Horticulture* **71:** 162-167.

Singh G Bundela DS Sethi M Lal K and Kamra SK (2010). Remote sensing and geographic information system for appraisal of salt-affected soils in India. *Journal of Environmental Quality* **39:** 5-15.

Subbiah BV and Asija GL (1956). A rapid procedure for the determination of available nitrogen in soils. *Current Science* **25:** 259-60.

Yemn EW and Willis AJ (1954). The estimation of carbohydrates in plant extracts by anthrone. *Biochemistry Journal* **57:** 508-514.

Received: January, 2015; Accepted March, 2015

Journal of Soil Salinity and Water Quality 7(1), 45-53, 2015

Screening of Chilli (*Capsicum annuum* L.) Genotypes under Saline Environment of Sundarbans in West Bengal, India

Chandan Kumar Mondal[1]*, Ashim Datta[2#], Prabir Kumar Garain[1], Pinaki Acharyya[3] and Pranab Hazra[4]

[1]*Ramkrishna Ashram Krishi Vigyan Kendra, Nimpith Ashram, South 24 Parganas-743338, West Bengal*
[2]*Division of Soil and Crop Management, Central Soil Salinity Research Institute, Karnal-132 001, Haryana*
[3]*Department of Horticulture, Institute of Agricultural Science, University of Calcutta, 51/2, Hazra Road, Kolkata-700019*
[4]*Department of Vegetable Crops, Faculty of Horticulture, BCKV, Mohanpur, Nadia-741252, West Bengal*
**Author for Correspondence: drchandanmondal@gmail.com*

Abstract

Agriculture in the Sundarban region is literally backward due to the problems of soil salinity, poor drainage there by late release of land for *rabi* crop and poor irrigation facility for *rabi* crop because of ground water salinity. Here, farmers have a very limited crop choice option. Chilli *(Capsicum annuum* L.) is an important commercial crop of this region as it can tolerate higher levels of salinity and have good storability of the harvested dry produce. But the productivity of the crop is declining now-a-days due to use of local undescribed land races for a long period. Chilli leaf curl complex is another major problem whose prevalence is quite high. In this backdrop a study was made to find out genotypes having tolerance to both salinity and leaf curl complex. Twelve genotypes were collected and evaluated at three locations having salinity gradients (EC_e) of 6.68 dS m^{-1}, 10.46 dS m^{-1} and 15.25 dS m^{-1}, respectively in three Sundarban Blocks. Seven genotypes (CUCH-1, CUCH-4, CUCH-6, CUCH-29, CUCH-31, CUCH-34 and CUCH-35) performed satisfactorily in all the three situations with good stability parameters coupled with higher leaf curl tolerance. Among these, best two performers were CUCH-31 and CUCH-34 recording a fresh yield of 218.17 and 190.54 g/plant; 175.56 and 159.77 g/plant; 139.68 and 148.19 g/plant, respectively at low, medium and high salinity levels.These genotypes can be promoted for commercial cultivation at varied salinity environments. Yield reduction at higher salinity level was lowest for CUCH-34 (22.23%), so this genotype will be a better choice over CUCH-31.

Key words: Chilli, Soil Salinity, Leaf Curl, Stability, Sundarban

Introduction

Soil salinity is a major factor limiting plant productivity affecting about 323 million ha worldwide (Brinkman, 1980). One of such salt affected area is Sundarbans of great Gangetic Delta. High soil salinity is of great concern in this area. According to agro-ecosystem analysis, Sundarbans belongs to CDR System which implies Critical, Diversified and Risk prone area. The agrarian system in Sundarbans faces the problems of salinity in both soil and water, poor drainage system during rainy season and poor irrigation opportunity. Here, chilli *(Capsicum annuum* L.) proved to be a good choice by the farmers over the decades. Chilli can be grown in saline soils because they can accumulate the salt which can be useful for osmotic adjustment against water stress due to salinity (Kaliappan and Rajagopal, 1970); although the germination and early vigour of the plants are affected by the salinity in the soil. Most of the regions where cultivation of chilli was predominant are characterized by the presence of moderately high level of salts and high water table (Kameswari and Prasad, 2005). Inspite of soil and climatic problems, chilli still now, is the first choice of the Sundarban farmers. There are many genotypes of chilli normally grown by the farmers. However, introduction of chilli genotypes tolerant to both soil salinity and leaf curl complex will be a boon for the farming community of Sundarbans. Therefore, an attempt has been made to screen suitable chilli genotypes resistant to both soil salinity and leaf curl complex disease under the Sundarban region of West Bengal.

#presently at the Department of Agricultural Chemistry and Soil Science, BCKV, Mohanpur, Nadia-741252, West Bengal

Table 1. Physico-chemical characteristics of soil of the experimental field

Experimental area	pH	EC_edS/m	OC (%)	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
Farmers' plot (Kaikhali)	6.94	4.08	0.61	171.94	81.37	987.4
Farmers' plot (Kakdwip)	6.88	6.38	0.38	185.22	76.22	962.3
Farmers' plot (PatharPratima)	7.25	9.30	0.53	176.38	73.13	1054.8

Twelve elite chilli genotypes (CUCH-1, CUCH-4, CUCH-5, CUCH-6, CUCH-11, CUCH-7, CUCH-16, CUCH-15, CUCH-29, CUCH-31, CUCH-34 and CUCH-35) were grown in natural saline soil condition having three levels of soil salinity (EC_e) of 6.68 dS m^{-1}, 10.46 dS $m^{-1}$and 15.25 dS m^{-1} to identify promising genotypes for salinity conditions of Sundarbans.

Material and Methods

Multi-location trials of the selected genotypes were carried out at the farmers plot in three coastal blocks of South 24 Parganas falling under Sundarban region of West Bengal, namely Kultali (Kaikhali village), Kakdwip (Kamarhat village) and Pathar Pratima (Kamdebpur village). Agro-climatic situation of the experimental site comes under coastal saline zone of West Bengal. Soil is clay-loam and almost neutral in reaction. Physico-chemical properties of the soil of experimental sites are presented in Table 1.

Agro-climatic condition

The experimental site falls under subtropical region, the average temperature of which ranged from 23.19^{0}C – 37.58^{0}C during summer months and between 10.78^{0}C – 27.74^{0}C during winter months, with a relative humidity range of 32.54% – 97.48%. The average rainfall is in between 1600 to 1800 mm with the maximum precipitation occurring from June to October.

Assemblage of plant materials for the study

Twelve chilli genotypes including many local types of 24 Parganas (South) were collected from different sources (Regional Institutes, Government agencies, Universities, authorized seed vendors etc. of West Bengal as well as from neighbouring states) comprised the plant material for the present study. Name and source of the germplasm have been presented in Table 2.

Crop husbandry

Pre-soaked seeds of all the genotypes were sown in seedbed in the first week of November each year. Seedlingsof 45 days old were transplanted in the main field in the individual plots with a spacing of 45cm × 45cm between row-to-row and plant-to-plant, respectively ensuring 40 plants in each plot. Transplanting was done by second fortnight of December each year. Chemical fertilizer was applied @ 72:58:46 kg NPK/ha. Essential intercultural operations (weeding, staking, time bound irrigation etc.) were carried out as and when required.

Table 2. Name and source of chilli germplasm under study

Accession No.	Name at source	Source/Place of collection
CUCH-1	BCC–12 (sel)	AICRP-Vegetable Crops, Directorate of Research, B.C.K.V., Kalyani, WB
CUCH-4	BCC–28 (18)	-do-
CUCH-5	BCC–28 (int)	-do-
CUCH-6	BCC–30	-do-
CUCH-7	BCC–49(var)	-do-
CUCH-11	Guntur-002	Horticultural Research Station, Lam, Guntur, A.P.- 522034
CUCH-15	PusaJwala	IARI, Pusa, New Delhi - 110012
CUCH-16	Pant-C-1	G. B. Pant University Of Agriculture & Technology, Pantnagar, Udham Singh Nagar, Uttarakhand - 263145
CUCH-29	Ankur-228	Amtala Seed Stores, Amtala, South 24 PGS, W.B.
CUCH-31	Roshni	Amtala Seed Stores, Amtala, South 24 PGS, W.B.
CUCH-34	Canning Bullet	Local collection from Canning, 24 Pgs.(S) W.B.
CUCH-35	Damkal	Local collection from Damkal island, South 24 PGS

Table 3. Scale of classifying disease reaction of Chilli to leaf curl complex

Symptom	Symptom severity grade	Response value	Coefficient of infestation	Reaction*
Symptom absent	0	0.00	0-4	HR
Very mild curling upto 25% leaves	1	0.25	5-9	R
Curling and puckering of 26-50% leaves	2	0.50	10-19	MR
Curling and puckering of 51-75% leaves	3	0.75	20-39	MS
Severe curling and puckering of >75% leaves	4	1.00	40-69	S
			70-100	HS

* R = resistant, HR - highly resistant, MR - moderate resistant, MS - moderate susceptible, S - susceptible, HS - highly susceptible

Observations recorded

Five random plants per replication (plot) were sampled for recording data on different quantitative characters *viz.* plant height (cm), number. of primary branches/plant, days to 50 % flowering, fruit length (cm), fruit girth (mm), number of fruits per plant, fresh and dry fruit weight (g), and fruit yield per plant (g).

Evaluation of the collected genotypes against leaf curl complex

The assessment of chilli leaf curl complex was done as per Banerjee and Kaloo (1987). Individual plants were evaluated for leaf curl disease reaction. Forty plants of each genotype were grown in every replication. No insecticide or acaricide was applied in these plots. Disease reaction data was recorded during the peak period of fruiting which was usually at 60 – 70 days after transplanting. The percent disease severity and disease intensity grade was calculated by using the following formula:

Percent Disease Intensity (PDI) =

$$\frac{\text{Number of diseased plant(s)}}{\text{Total number of plants observed}} \times 100$$

The coefficient of infection was calculated by multiplying the PDI with the Response value assigned to each severity grade. The overall disease reaction was assigned to the coefficient of infection range as given in the Table 3.

Statistical analysis

Plot Means were used for standard analysis. Statistical analysis for various parameters was executed using the statistical package SPSS 16.0. Analysis of variance was calculated as per Gomez and Gomez (1984).

Results and Discussion

Mean performance

Mean values for nine growth and yield related characters *viz.*, plant height, number of primary branches per plant, days to 50% flowering, fruit length, fruit girth, fruits per plant, fresh fruit weight, dry fruit weight and fresh fruit yield per plant were recorded in all the genotypes (Table 4). All the nine quantitative characters varied considerably with the salinity level. High salinity level drastically reduced the manifestation of all the characters including fruit yield in all the genotypes compared to low and medium salinity level. However, such reduction was more conspicuous for plant height, number of fruits per plants and fruit yield per plant. Average plant height in all the 12 genotypes reduced by 15.9 to 36.8% when they were grown in the higher salinity conditions compared to low salinity condition (Table 5). Similarly, number of fruits per plant and average fruit yield per plant also declined by 13.1 to 45.2% and 22.2 to 52.5%,respectively under similar situation. Extent of fruit yield loss in all the genotypes with rising salinity levels in the present investigation agreed well to the earlier work of Goldberg (2004) who advocated that rising electrical conductivity having an EC_e value of 5^+dS/m lead to 50% yield loss with an additional 10-12% reduction in yield for every additional unit increase in EC_e. However, such reduction in different set of characters in the present investigation varied with the genotypes.

Variance

Mean sum of squares presented in Table 6 clearly suggested significant difference of the genotypes for all the characters even at 1% level of significance which clearly depicted the justification of studying genetic variability employing these genotypes and characters for these three locations. This finding

Table 4. Mean values of traits of interest from multi-locational trial

Characters	Plant height (cm)			No. of primary branches			Days to 50% flowering			Fruit length (cm)			Fruit girth (cm)			No. of fruits per plants			Individual fruit wt (g)			Fruit dry wt(g)			Fresh yield / plant (g)		
Salinity levels	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L
CUCH-1	32.62	40.29	51.59	5.50	6.13	7.67	76.67	70.00	63.67	6.80	7.57	8.30	6.67	7.33	7.83	29.61	36.91	43.77	2.73	2.88	3.11	0.75	0.79	0.84	79.38	106.98	142.86
CUCH-4	38.46	44.04	51.62	5.48	6.03	6.47	57.33	54.67	49.67	7.43	7.77	8.50	8.17	8.33	8.50	41.60	50.40	55.17	2.56	2.66	2.91	0.72	0.74	0.81	104.81	135.11	158.46
CUCH-5	32.11	40.59	45.87	5.17	5.37	6.20	74.00	70.67	64.33	7.10	7.70	8.17	8.00	8.33	9.00	31.37	36.30	43.38	2.49	2.64	2.85	0.71	0.75	0.81	78.05	96.71	132.20
CUCH-6	36.64	41.47	48.61	7.22	8.25	8.22	51.67	48.67	46.00	7.00	7.57	7.93	7.50	8.00	8.50	40.50	52.17	55.63	2.45	2.55	2.80	0.68	0.71	0.77	99.93	134.75	151.73
CUCH-7	35.62	44.29	51.26	5.73	6.53	8.07	76.00	69.33	61.33	5.73	6.43	7.33	8.67	9.33	10.83	31.88	38.21	44.93	2.30	2.43	2.58	0.59	0.61	0.64	74.44	95.20	128.81
CUCH-11	31.68	39.42	48.77	5.00	5.70	5.73	81.33	72.00	64.67	6.60	7.37	8.50	7.83	8.33	9.00	28.06	33.91	51.24	2.32	2.51	2.59	0.65	0.69	0.72	64.98	85.74	136.89
CUCH-15	34.11	37.25	43.88	5.11	5.81	5.89	63.33	57.67	49.67	6.67	7.37	8.03	5.67	6.00	6.33	31.70	38.87	49.00	2.51	2.62	2.77	0.70	0.72	0.77	81.18	102.80	136.48
CUCH-16	34.71	41.03	46.08	5.17	5.73	5.90	64.67	61.33	57.33	5.80	6.43	7.83	6.50	7.00	7.17	33.22	36.62	46.19	2.40	2.54	2.68	0.64	0.67	0.71	79.05	92.52	128.85
CUCH-29	33.52	36.63	42.48	4.63	4.81	5.02	59.00	55.00	50.67	7.87	8.43	9.47	7.50	8.00	8.33	33.40	40.13	42.80	3.19	3.42	3.68	0.89	0.94	1.01	106.00	141.22	156.34
CUCH-31	36.45	40.48	45.47	6.47	6.81	7.14	58.00	55.33	51.33	7.03	7.47	8.60	10.00	10.33	10.67	40.00	46.67	55.03	3.53	3.68	3.98	0.88	1.01	1.10	139.68	175.56	218.17
CUCH-34	40.63	44.75	48.31	5.33	6.03	6.51	54.33	53.67	51.00	6.57	6.70	7.03	16.00	16.83	17.00	42.60	46.00	49.03	3.15	3.48	3.90	0.88	0.97	1.08	148.19	159.77	190.54
CUCH-35	39.27	44.89	49.10	5.44	6.11	6.56	69.00	67.00	62.33	7.57	7.77	7.93	10.50	10.67	11.00	58.43	62.50	68.00	2.53	2.59	2.79	0.70	0.71	0.77	133.85	159.79	190.33
SEm	1.31	1.14	1.23	0.34	0.31	0.37	2.03	1.98	1.67	0.23	0.15	0.19	0.36	0.29	0.32	1.65	1.45	1.48	0.03	0.03	0.04	0.05	0.02	0.02	3.44	3.74	3.14

Note: Salinity levels (EC_e) – High (H): 9.3 dS/m; Medium (M): 6.4 dS/m; Low (L): 4.1 dS/m

Table 5. Percent reduction in the values of parameters due to salinity (as compared to data of low salinity level)

	Plant height (cm)		No. of primary branches		Days to 50% flowering		Fruit length (cm)		Fruit girth (cm)		No. of fruits per plants		Individual fruit wt (g)		Fruit dry wt(g)		Fresh yield / plant (g)	
Salinity levels	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H
CUCH-1	21.90	36.77	20.08	28.29	-9.94	-20.42	8.80	18.07	6.39	14.81	15.67	32.35	7.40	12.22	5.95	10.71	25.12	44.44
CUCH-4	14.68	25.49	6.80	15.30	-10.07	-15.42	8.59	12.59	2.00	3.88	8.65	24.60	8.59	12.03	8.64	11.11	14.74	33.86
CUCH-5	11.51	30.00	13.39	16.61	-9.86	-15.03	5.75	13.10	7.44	11.11	16.32	27.69	7.37	12.63	7.41	12.35	26.85	40.96
CUCH-6	14.69	24.62	-0.36	12.17	-5.80	-12.33	4.54	11.73	5.88	11.76	6.22	27.20	8.93	12.50	7.79	11.69	11.19	34.14
CUCH-7	13.60	30.51	19.08	29.00	-13.04	-23.92	12.28	21.83	13.85	19.94	14.96	29.05	5.81	10.85	4.69	7.81	26.09	42.21
CUCH-11	19.17	35.04	0.52	12.74	-11.33	-25.76	13.29	22.35	7.44	13.00	33.82	45.24	3.09	10.42	4.17	9.72	37.37	52.53
CUCH-15	15.11	22.27	1.36	13.24	-16.11	-27.50	8.22	16.94	5.21	10.43	20.67	35.31	5.42	9.39	6.49	9.09	24.68	40.52
CUCH-16	10.96	24.67	2.88	12.37	-6.98	-12.80	17.88	25.93	2.37	9.34	20.72	28.08	5.22	10.45	5.63	9.86	28.20	38.65
CUCH-29	13.77	21.09	4.18	7.77	-8.55	-16.44	10.98	16.90	3.96	9.96	6.24	21.96	7.07	13.32	6.93	11.88	9.67	32.20
CUCH-31	10.97	19.84	4.62	9.38	-7.79	-12.99	13.14	18.26	3.19	6.28	15.19	27.31	7.54	11.31	8.18	20.00	19.53	35.98
CUCH-34	7.37	15.90	7.37	18.13	-5.24	-6.53	4.69	6.54	1.00	5.88	6.18	13.11	10.77	19.23	10.19	18.52	16.15	22.23
CUCH-35	8.57	20.02	6.86	17.07	-7.49	-10.70	2.02	4.54	3.00	4.55	8.09	14.07	7.17	9.32	7.79	9.09	16.05	29.67

Note: Salinity levels (EC_e) – as depicted in Table 4 amply suggests the possibility of selection of promising genotypes suitable for cultivation under enhanced soil salinity conditions.

Disease reaction of the promising genotypes tolerant to soil salinity

Twelve genotypes were grown in three salinity levels following Randomized Block Design with 3 replications without any application of either insecticides or acaricides. Data pertaining to reaction to leaf curl complex disease was recorded during the peak period of fruiting which was usually at 60–70 days after transplanting. The percent disease severity and disease intensity grade was calculated as per Banerjee and Kaloo (1987).

Mean percent disease index and coefficient of infection for leaf curl complex disease of the 12 genotypes expressed quite differently under varied salinity levels (Table 7). It was found that soil salinity increased the susceptibility of the genotypes to leaf curl disease complex which might have happened due to impaired nutrient uptake under such stress condition. Disease reaction in the genotypes CUCH-4, CUCH-31, CUCH-34 and CUCH-35 did not change with the level of soil salinity, so these genotypes may be considered better performing with respect to leaf-curl problem.

Selection of promising genotypes tolerant to soil salinity

It has already been recorded that different genotypes responded differently to salinity gradient. Out of these 12 genotypes, 6 genotypes (CUCH-4, CUCH-6, CUCH-29, CUCH-31, CUCH-34, and CUCH-35) showed comparatively low yield reduction (Table 5) at higher salinity level. Also, coefficient of infection in these genotypes was low ranging between 13.13 and 28.13 at all the salinity levels (Table 7).Under high salinity level,4 out of these 6 genotypes (CUCH-4, CUCH-31, CUCH-34, and CUCH-35) recorded 'Moderately Resistant' disease reaction.

However, no consistency was recorded by these genotypes for reduction in yield at both the salinity levels. Lowest yield reduction at medium salinity level was recorded in the genotype CUCH-29 (9.67%) while in the high salinity level it was recorded in the genotype CUCH-34 (22.23%). It was quite expected because different studies have come-up with the view that influence of environment on

Table 6. ANOVA for multilocational trial in three locations (Mean sum of squares of nine characters for three salinity levels)

Source	Salinity (Environment)	DF	Character-1	Character-2	Character-3	Character-4	Character-5	Character-6	Character-7	Character-8	Character-9
Replication	High (E_1)		6.589	0.260	30.195*	0.072	0.063	1.267	0.000	0.002	7.185
	Medium(E_2)	2	7.600*	0.554*	0.693	0.051	0.271	0.476	0.002	0.001	6.283
	Low(E_3)		0.857	0.336	8.083	0.021	0.361	4.368	0.002	0.001	42.177
Genotype	High (E_1)		25.187**	1.474**	288.202**	1.237**	21.992**	212.918**	0.466**	0.029**	2365.155**
	Medium(E_2)	11	23.245**	2.112**	197.808**	1.048**	23.214**	216.675**	0.566**	0.049**	2869.553**
	Low(E_3)		27.339**	2.894**	144.303**	1.179**	22.840**	159.426**	0.772**	0.066**	2515.311**
Error	High(E_1)		2.557	0.170	6.194	0.077	0.191	4.087	0.002	0.004	17.758
	Medium(E_2)	22	1.964	0.141	5.907	0.036	0.127	3.154	0.001	0.003	21.006
	Low(E_3)		2.260	0.207	4.205	0.051	0.149	3.284	0.002	0.005	14.766

* significant at 5% level ** significant at 1% level

Table 7. Evaluation of genotypes against leaf curl complex under varied salinity levels

Genotypes*	Severity Grade '0'			Severity Grade '1'			Severity Grade '2'			Severity Grade '3'			Severity Grade '4'			Disease Reaction	
	RV	No. of plants	PDI	RV	No. of plants	PDI	RV	No. of plants	PDI	RV	No. of plants	PDI	RV	No. of plants	PDI	CI	Reaction
Location: Low salinity (EC- 4.08 dS/m)																	
CUCH-1	0	10	25	0.25	22	55	0.5	8	20	0.75	0	0	1	0	0	23.75	MS
CUCH-4	0	23	57.5	0.25	13	32.5	0.5	4	10	0.75	0	0	1	0	0	13.13	MR
CUCH-5	0	9	22.5	0.25	21	52.5	0.5	9	22.5	0.75	1	2.5	1	0	0	26.25	MS
CUCH-6	0	17	42.5	0.25	16	40	0.5	7	17.5	0.75	0	0	1	0	0	18.75	MR
CUCH-7	0	6	15	0.25	27	67.5	0.5	7	17.5	0.75	0	0	1	0	0	25.625	MS
CUCH-11	0	0	0	0.25	28	70	0.5	9	22.5	0.75	3	7.5	1	0	0	34.38	MS
CUCH-15	0	6	15	0.25	27	67.5	0.5	7	17.5	0.75	0	0	1	0	0	25.63	MS
CUCH-16	0	6	15	0.25	28	70	0.5	6	15	0.75	0	0	1	0	0	25	MS
CUCH-29	0	15	37.5	0.25	20	50	0.5	5	12.5	0.75	0	0	1	0	0	18.75	MR
CUCH-31	0	13	32.5	0.25	27	67.5	0.5	0	0	0.75	0	0	1	0	0	16.88	MR
CUCH-34	0	17	42.5	0.25	23	57.5	0.5	0	0	0.75	0	0	1	0	0	14.38	MR
CUCH-35	0	19	47.5	0.25	21	52.5	0.5	0	0	0.75	0	0	1	0	0	13.13	MR
Location: Moderate salinity (EC- 6.38 dS/m)																	
CUCH-1	0	6	15	0.25	25	62.5	0.5	9	22.5	0.75	0	0	1	0	0	26.88	MS
CUCH-4	0	16	40	0.25	19	47.5	0.5	5	12.5	0.75	0	0	1	0	0	18.13	MR
CUCH-5	0	1	2.5	0.25	28	70	0.5	11	27.5	0.75	0	0	1	0	0	31.25	MS
CUCH-6	0	11	27.5	0.25	22	55	0.5	7	17.5	0.75	0	0	1	0	0	22.5	MS
CUCH-7	0	1	2.5	0.25	27	67.5	0.5	10	25	0.75	2	5	1	0	0	33.13	MS
CUCH-11	0	2	5	0.25	27	67.5	0.5	6	15	0.75	5	12.5	1	2	5	38.75	MS
CUCH-15	0	3	7.5	0.25	28	70	0.5	9	22.5	0.75	0	0	1	0	0	28.75	MS
CUCH-16	0	0	0	0.25	31	77.5	0.5	7	17.5	0.75	2	5	1	0	0	31.88	MS
CUCH-29	0	8	20	0.25	26	65	0.5	6	15	0.75	0	0	1	0	0	23.75	MS
CUCH-31	0	14	35	0.25	23	57.5	0.5	3	7.5	0.75	0	0	1	0	0	18.13	MR
CUCH-34	0	17	42.5	0.25	22	55	0.5	1	2.5	0.75	0	0	1	0	0	15	MR
CUCH-35	0	16	40	0.25	24	60	0.5	0	0	0.75	0	0	1	0	0	15	MR
Location: High salinity (EC- 9.30 dS/m)																	
CUCH-1	0	0	0	0.25	31	77.5	0.5	7	17.5	0.75	2	5	1	0	0	31.88	MS
CUCH-4	0	17	42.5	0.25	16	40	0.5	7	17.5	0.75	0	0	1	0	0	18.75	MR
CUCH-5	0	0	0	0.25	28	70	0.5	9	22.5	0.75	3	7.5	1	1	2.5	36.88	MS
CUCH-6	0	4	10	0.25	27	67.5	0.5	9	22.5	0.75	0	0	1	0	0	28.13	MS
CUCH-7	0	0	0	0.25	30	75	0.5	8	20	0.75	2	5	1	0	0	32.5	MS
CUCH-11	0	0	0	0.25	27	67.5	0.5	9	22.5	0.75	4	10	1	4	10	45.63	S
CUCH-15	0	0	0	0.25	27	67.5	0.5	11	27.5	0.75	2	5	1	2	5	39.38	MS
CUCH-16	0	0	0	0.25	30	75	0.5	8	20	0.75	2	5	1	0	0	32.5	MS
CUCH-29	0	6	15	0.25	26	65	0.5	8	20	0.75	0	0	1	0	0	26.25	MS
CUCH-31	0	11	27.5	0.25	28	70	0.5	1	2.5	0.75	0	0	1	0	0	18.75	MR
CUCH-34	0	11	27.5	0.25	29	72.5	0.5	0	0	0.75	0	0	1	0	0	18.13	MR
CUCH-35	0	14	35	0.25	26	65	0.5	0	0	0.75	0	0	1	0	0	16.25	MR

*Total number of plants per plot in each genotype = 40, RV = Response value, PDI = (No. of diseased plant / total no of pl(40))*100, CI (Coefficient of Infection) = Σ [(Response Value $_{0.00-1.00}$) × Respective PDI; R = Resistant, MR = Moderately Resistant, MS = Moderately Susceptible, S = Susceptible, HS = Highly Susceptible the genotypes for the expression of quantitative characters is neither uniform nor consistent.

Analysis of adaptability under differential soil salinity conditions

Primary objective of applied biological research is the improvement of plant adaptation. The term adaptation has been applied to both process and condition. On one hand, it is used to refer to the action or process of becoming modified to suit new circumstances and on the other hand, it may be used to refer to the state or condition of adaptation. Whatever may be the outcome of the term, it clearly implies the genetic change as the basic principle and environmental pressure as the driving force of such change.

The importance of 'Genotype x Environment' interactions in most investigations of quantitative genetics has been widely discussed (Comstock and Moll, 1963). The significance of linear regression analysis of 'Genotype x Environment' interactions in crop breeding programme has been understood much later (Wright, 1976). In the present investigation, an attempt was made to examine the adaptability of 12 genotypes under three distinct soil salinity levels through the analysis of 'Genotype x Environment' interactions by adapting the approach of regression analysis of Eberhart and Russell (1966). The analysis of variance indicated that differences between the genotypes and environments were highly significant for all the 9 characters including fruit yield (Table 8). The 'Genotype x Environment' interaction was found highly significant for the characters namely number of fruits per plant, fresh fruit weight and fruit yield per plant indicating that the genotypes showed differential response in different salinity levels with respect to these characters. However, the magnitude of 'Genotype x Environment' variance was smaller as compared to genotype and environmental variances for these characters. Both the environment (linear) and 'Genotype x Environment' (linear) components of variance were highly significant for all the nine characters which indicated that the genotypes responded differently in varying environments. Deviation from regression i.e. pooled deviation was significant for number of fruits per plant and fruit yield per plant. However, linear component was relatively greater than non-linear component for all the characters indicating that the performance of the genotypes could be predicted.

Table 8. ANOVA for parameters of stability analysis

Source	DF	Plant height (cm)	No. of primary branches	Days to 50% flowering	Fruit length (cm)	Fruit girth (cm)	No. of fruits per plants	Fresh fruit weight (g)	Dry fruit weight (g)	Fresh yield / plant (g)
Genotypes (G)	11	18.126**	1.933**	201.289**	1.001**	22.550**	183.042**	0.591**	0.046**	2493.434**
Environment (E)	3	452.043**	3.619**	268.849**	5.033**	2.598**	545.984**	0.421**	0.033**	9748.877**
G X E	22	3.566	0.114	4.408	0.077	0.066	6.648*	0.005**	0.001	44.948**
Environment (Linear)	1	904.093**	7.238**	537.655**	10.066**	5.196**	1091.974**	0.843**	0.066**	19497.633**
G X E (Linear)	11	6.286**	0.163**	8.323**	0.141**	0.110**	9.224*	0.010**	0.001**	51.067
Pooled deviation	12	0.775	0.059	0.455	0.012	0.020	3.732**	0.001	0.000	35.603**
Pooled error	66	2.260	0.173	5.435	0.055	0.156	3.509	0.002	0.002	17.843

* significant at 5% level ** significant at 1% level

Table 9. Stability parameters of twelve genotypes at three locations for nine vital traits

Genotypes	Plant height (cm)			No. of primary branches			Days to 50 % flowering			Fruit length (cm)			Fruit girth (cm)		
	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di
CUCH-1	41.50	1.55	1.05	6.43	1.95	0.19	70.11	1.37	0.57	7.56	1.15	0.01	7.28	1.25	0.01
CUCH-4	44.71	1.07	0.25	5.99	0.91	0.00	53.89	0.82	0.34	7.90	0.84	0.01	8.33	0.36	0.00
CUCH-5	39.52	1.12	2.66	5.58	0.92	0.08	69.67	1.03	0.57	7.66	0.81	0.02	8.44	1.08	0.02
CUCH-6	42.24	0.98	0.44	7.90	0.93	0.14	48.78	0.60	0.16	7.50	0.71	0.02	8.00	1.07	0.00
CUCH-7	43.72	1.27	1.13	6.78	2.10	0.14	68.89	1.55	0.02	6.50	1.24	0.00	9.61	2.33	0.11
CUCH-11	39.96	1.39	0.06	5.48	0.68	0.06	72.67	1.75	2.59	7.49	1.48	0.00	8.39	1.25	0.00
CUCH-15	38.41	0.80	1.41	5.61	0.74	0.06	56.89	1.45	0.08	7.36	1.05	0.01	6.00	0.72	0.00
CUCH-16	40.61	0.92	0.62	5.60	0.68	0.02	61.11	0.78	0.00	6.69	1.60	0.03	6.89	0.71	0.02
CUCH-29	37.54	0.73	0.82	4.83	0.36	0.00	54.89	0.88	0.07	8.59	1.25	0.01	7.94	0.89	0.01
CUCH-31	40.80	0.74	0.03	6.80	0.61	0.00	54.89	0.71	0.05	7.70	1.23	0.03	10.33	0.72	0.00
CUCH-34	44.56	0.62	0.17	5.96	1.07	0.00	53.00	0.36	0.43	6.77	0.37	0.00	16.61	1.07	0.08
CUCH-35	44.42	0.80	0.65	6.03	1.04	0.00	66.11	0.71	0.58	7.76	0.28	0.00	10.72	0.54	0.00
POP Mean	41.50			6.08			60.91			7.46			9.05		
SE	0.62			0.17			0.48			0.08			0.10		

Genotypes	Number of fruits per plants			Fresh fruit weight (g)			Dry fruit weight (g)			Fresh yield / plant (g)		
	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di
CUCH-1	36.76	1.05	0.26	2.91	1.02	0.00	0.79	0.89	0.00	109.74	1.12	0.01
CUCH-4	49.06	1.00	3.84	2.71	0.95	0.00	0.76	0.82	0.00	132.79	0.93	32.24
CUCH-5	37.02	0.89	0.35	2.66	0.98	0.00	0.75	0.99	0.00	102.32	0.96	15.79
CUCH-6	49.43	1.11	13.66	2.60	0.93	0.00	0.72	0.87	0.00	128.81	0.96	5.52
CUCH-7	38.34	0.97	0.02	2.44	0.75	0.00	0.62	0.48	0.00	99.48	0.89	100.23
CUCH-11	37.74	1.73	17.21	2.47	0.69	0.00	0.69	0.66	0.00	95.87	1.28	73.19
CUCH-15	39.86	1.29	0.66	2.64	0.69	0.00	0.73	0.74	0.00	106.82	0.87	117.73
CUCH-16	38.67	0.97	4.92	2.54	0.74	0.00	0.67	0.63	0.00	100.14	0.89	44.44
CUCH-29	38.78	0.69	3.52	3.43	1.30	0.00	0.95	1.18	0.00	134.52	0.98	3.88
CUCH-31	47.23	1.12	0.12	3.73	1.23	0.00	1.00	2.09	0.00	177.80	1.38	2.02
CUCH-34	45.88	0.48	0.09	3.51	2.00	0.00	0.98	1.97	0.00	161.32	0.99	1.25
CUCH-35	62.98	0.71	0.13	2.64	0.71	0.00	0.73	0.68	0.00	166.17	0.76	30.96
POP Mean	43.48			2.86			0.78			126.32		
SE	1.37			0.02			0.01			4.22		

bi – regression coefficient; S^2di- deviation from regression; POP- Population

Out of 12 genotypes, CUCH-6, CUCH-29, CUCH-31 and CUCH-34 exhibited b_i value close to 1.00 with very low S^2di value (Table 9) for most of the characters particularly fruit yield per plant.

Eberhart and Russell (1966) classified a variety to be stable which showed high mean, unit regression coefficient ($b_i = 1$) and the deviation from regression as small as possible ($S^2di = 0$). In the present study, the genotypes CUCH-29, CUCH-31 and CUCH-34 could therefore, be considered as stable since these genotypes registered high mean fruit yield with unit regression coefficient close to 1.00 and very low S^2di values. Two genotypes *viz.*, CUCH-4 and CUCH-35 showed high mean values for fruit yield with b_i values nearer to 1.00 but S^2di values were high, thus suggesting that these two genotypes are fit to be adapted only under specific favourable environment (below average stability).

Conclusion

Twelve better performing genotypes were put in multilocational salinity stress trial and only three genotypes *viz*. CUCH-29, CUCH-31 and CUCH-34 expressed stability under varying stress levels. The genotypes CUCH-4 and CUCH-35 showed high mean values for fruit yield but their S^2di values were high suggesting that these genotypes are suited for specific favourable environment. With respect to dual stress tolerance for salinity and leaf curl complex, only the genotypesCUCH-31 and CUCH-34 performed better as their ranking for disease reaction did not change with the level of soil salinity. So, these genotypes can be promoted for commercial cultivation at varied salinity environments. Yield reduction at higher salinity level was lowest for CUCH-34 (22.23%)among all the twelve genotypes, so this genotype will be a better option over CUCH 31.

References

Banerjee MK and Kalloo G (1987). A scale for classifying disease reaction of *Lycopersicon* species to tomato leaf curl virus. *Theor. Appl. Genet.***73**: 707-710.

Brinkman R (1980). Saline and sodic soils. In: *Land Reclamation and Water Management*. International Institute for Land Reclamation and Improvement (ILRI), Wageningen, The Netherlands. pp. 62-68.

Comstock RE and Moll RH (1963). *Genotype-environment Interactions in Statistical Genetics and Plant Breeding.* NAS-NRC Publ. USA **982**: 164-196.

Eberhart SA and Russell WA (1966). Stability parameters for comparing varieties.*Crop Sci*. **6**: 36-40.

Goldberg NP (2004). *Chile Pepper Disorders Caused by Environmental Stress*. New Mexico State University College of Agriculture and Home Economics, H-249.

Gomez KA and Gomez AA (1984).*Statistical Procedures in Agricultural Research*, Wiley, New York, Chichester, etc., 2nd edition, pp. 680.

Kaliappan R and Rajagopal A (1970). Effect of salinity on the south Indian field crops: germination and early vigour of chillies (*Capsicum annuum*, Linn.). *Madras Agric. J.* **57**(4): 231-233.

Kameswari PL and Prasad DM (2005). Evaluation of chilli genotypes for salt tolerance. *Indian J. Hort*. **62**(1): 46-48.

Wright AJ (1976). The significance for breeding of linear regression analysis of genotype-environment interactions. *Heredity.***37**: 83-93.

Received: January, 2015; Accepted March, 2015

Journal of Soil Salinity and Water Quality 7(1), 54-57, 2015

Consumptive Use, Water Use Efficiency, Soil Moisture Use and Productivity of Fenugreek (*Trigonella foenum-graecum* L.) under Varying IW-CPE Ratios and Fertilizer Levels on Calcareous Alkali Soils of South West Rajasthan

RC Dhaker*, RK Dubey[2], RC Tiwari[3] and SK Dubey[4]

Department of Agronomy, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur-313 001, Rajasthan

**Corresponding author E-mail: rameshagro2011@gmail.com*

Abstract

Field experiment was conducted at Udaipur (*rabi* seasons of 2011-12 and 2012-13) with objective to optimize the productivity and water use in fenugreek through use of appropriate IW-CPE ratio and fertility level. It revealed that IW-CPE ratio of 1.0 registered significantly higher of pooled yield and an enhancement of 45.48, 27.50 and 11.90% in seed yield and 41.42, 23.72 and 10.26% in haulm yield at IW-CPE ratio of 1.0 over IW-CPE ratios of 0.4, 0.6 and 0.8, respectively. The IW-CPE ratio of 1.0 also recorded significantly higher residual soil moisture at 0-15 cm (36.41%) and 15-30 cm (23.94%) soil depths after 40 days of sowing over different lower IW-CPE ratios. However, WUE at IW-CPE ratio of 1.0 (11.58 kg mm ha^{-1}) was significantly lower than lower IW-CPE ratios of 0.8 (9.34 kg mm ha^{-1}), 0.6 (8.63 kg mm ha^{-1}) and 0.4 (8.61 kg mm ha^{-1}). Results further showed that 40 kg N + 40 kg P_2O_5 ha^{-1} recorded significantly higher pooled seed yield (8.38 and 20.69% higher), haulm yield (5.57 and 17.60% higher) and biological yield (6.30 and 18.39% higher) under 40 kg N + 40 kg P_2O_5 ha^{-1} over 20 kg N + 20 kg P_2O_5 ha^{-1} and control, respectively. Application of 40 kg N + 40 kg P_2O_5 ha^{-1} recorded significantly higher consumptive use over different lower fertility levels but WUE under each lower fertility levels up to 40 kg N + 40 kg P_2O_5 ha^{-1} recorded significantly higher WUE over it higher fertility level.

Key words: Consumptive use, Fenugreek, Residual soil moisture, Water use efficiency, Seed yield

Introduction

Fenugreek (*Trigonella foenum-graecum* L.) is an important multipurpose *rabi* season seed spice crop mainly grown in Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Haryana, Punjab, Bihar and Andhra Pradesh. The seeds of fenugreek are used as a condiment and seasoning agent for garnishing and flavoring dishes. Being a leguminous crop, the root nodules enrich the soil with atmospheric nitrogen. Intensive agriculture involving use of high input for increasing production resulted heavy removal of nutrients from the soil. Thus, there is wide gap between nutrients removed from soil and nutrient supplied. This gap can be bridged with use of chemical fertilizers along with application of low-cost inputs like bio-fertilizers. Water is scarce commodity, which if judiciously used along with suitable agro-techniques, would substantially increase yield, consumptive use and water use efficiency. With the introduction of high yielding varieties coupled with increased use of fertilizers and irrigation, weed problem has increased manifolds. Recently irrigation is being scheduled on the basis of climatologically-approach which is now considered as most scientific, since it integrate all weather parameters giving them natural weightage in a given climate-plant continuum (Datta and Chatarjee, 2006). The highest seed yield of fenugreek was obtained with irrigation at IW-CPE ratio of 1.0 at Nadia, West Bengal as compared to other lower ratios tested. Phosphorus (P) is an important element that significantly affects plant growth and metabolism. P is a component of DNA and RNA, involved in cell division and is important for plant growth (Brady and Weil, 2004). Expansion of leaves under P stress becomes limited by the number of cell divisions, which implies control of cell division by a common regulatory factor; symbiotic N_2 fixation has a higher P requirement for maximum activity than growth supported by nitrate assimilation because of high energy requirements in the reduction of atmospheric N_2 by the nitrogenase system and P deficiency conditions also result in reduced nodule number and mass (Rotaru and Sinclair, 2009).

Material and Methods

Twenty treatments comprising of five IW-CPE (Irrigation water-cumulative pan evaporation) ratios i.e. (0.4, 0.6, 0.8, 1.0 and 1.2) (in main plots) and four fertility levels i.e. control; 20 kg N + 20 kg P_2O_5 ha^{-1}; 40 kg N + 40 kg P_2O_5 ha^{-1}; and 60 kg N + 60 kg P_2O_5 ha^{-1} (in sub-plots) were evaluated in the split plot design having three replications during *rabi* 2011 and 2012 at the Instructional Farm of Rajasthan College of Agriculture, Udaipur (altitude: 582.17 m above mean sea level; location 23^{0}35' N and 72^{0}42' E). The mechanical analysis of soil and bulk density were done as described by Piper (1967); pH by using pH meter; EC as described by Richards (1968); organic carbon by rapid titration method (Walkley and Black, 1934); available nitrogen by alkaline $KMnO_4$ method (Subbiah and Asija, 1956); available P by Olsen's method (Olsen *et al.,* 1954); and available K by using Flame Photometer (Richards, 1968). Soil of the study site at 0-15 cm depth was slightly alkaline (pH: 8.1); clay loam in texture (sand: 38.5 %, silt: 26.0 % and clay: 35.5 %) having bulk density of 1.38 mg cm^{-3} and 5.6 g kg^{-1} organic carbon. The soil was medium in state of N and P_2O_5 (283 and 20 kg ha^{-1}, respectively). Full dose of phosphorus and half dose of nitrogen were applied as basal dressing at sowing through DAP and urea, respectively (adjusting N from DAP).

Results and Discussion

Results (Table 1) showed that consumptive use of fenugreek crop significantly improved at increasing levels of IW-CPE ratios up to 1.0 but IW-CPE ratios of 1.0 and 1.2 were indifferent during both the years and on pooled basis. Consumptive use almost linearly increased up to IW-CPE ratio of 1.0 as variations recorded between IW-CPE ratios of 0.4; 0.6 and 0.6; 0.8 corresponded to pool values of 27.55 and 49.16 ha mm^{-1} respectively. Between IW-CPE ratio of 0.8 and 1.0, consumptive use values depicted a curvilinear trend as pooled difference corresponded to only 36.71 ha mm^{-1}. However, consumptive use declined between IW-CPE ratios of 1.0 and 1.2 as pooled variation corresponded just to 5.22 ha mm^{-1}. As such, IW-CPE ratio of 1.0 was also most effective from consumptive use point of view since it avoided soil moisture deficit as well as excessive soil moisture regimes to a legume crop fenugreek. This is also well supported by data on growth and yield performance. Significant enhancement in consumptive use at each higher IW-CPE ratio up to 1.0 clearly reveals that water uptake by fenugreek profoundly depended on soil moisture availability. Higher root biomasses of fenugreek at

Table 1. Effect of IW-CPE ratios and fertility levels on consumptive use, water use efficiency and moisture content of fenugreek

Treatment	Consumptive use (mm ha^{-1})			Water use efficiency (kg grain mm ha^{-1})			Moisture (%) at 40 DAS					
							0-15 cm depth			15-30 cm depth		
	2011	2012	Pooled	2011	2012	Pooled	2011	2012	Pooled	2011	2012	Pooled
IW-CPE ratios												
I_0 (0.4)	97.85	100.20	99.03	11.18	14.33	12.75	34.49	35.10	34.79	22.39	23.09	22.74
I_1 (0.6)	123.79	129.36	126.58	10.62	12.54	11.58	35.97	36.85	36.41	23.54	24.33	23.94
I_2 (0.8)	173.93	177.55	175.74	8.55	10.13	9.34	37.29	38.69	37.99	24.57	25.95	25.26
I_3 (1.0)	208.59	215.22	211.91	7.84	9.43	8.63	39.63	41.10	40.37	25.63	27.39	26.51
I_4 (1.2)	214.21	220.06	217.13	7.82	9.39	8.61	39.69	41.23	40.46	26.10	27.82	26.96
SEm.±	1.86	3.00	1.76	0.15	0.18	0.11	0.36	0.48	0.30	0.29	0.33	0.22
LSD (p= 0.05)	6.07	9.77	5.29	0.47	0.57	0.34	1.18	1.57	0.90	0.96	1.07	0.66
Fertility levels (N : P_2O_5 kg ha^{-1})												
F_0 (0:0)	151.52	153.62	152.57	8.80	10.82	9.81	36.93	38.26	37.59	24.43	25.36	24.90
F_1 (20 : 20)	161.45	163.80	162.62	9.12	11.31	10.22	37.34	38.30	37.82	24.24	25.76	25.00
F_2 (40 : 40)	170.00	177.17	173.59	9.46	11.34	10.40	37.67	38.90	38.28	24.54	25.87	25.20
F_3 (60 : 60)	171.73	179.32	175.52	9.43	11.18	10.31	37.72	38.92	38.32	24.57	25.86	25.22
SEm.±	1.30	1.56	1.02	0.06	0.08	0.05	0.31	0.26	0.20	0.20	0.14	0.12
LSD (p= 0.05)	3.75	4.51	2.88	0.18	0.22	0.14	NS	NS	NS	NS	NS	NS

IW-CPE ratio of 1.0 over lower IW-CPE ratios have also been reported by Mehta et *al*. (2010), Datta and Chatarjee (2006) and Lakpale *et al.* (2004).

Data (Table 1) clearly showed that consumptive use of fenugreek crop significantly enhanced on each increment in higher fertility level up to 40 kg N + 40 kg P_2O_5 ha^{-1} during both the years and on pooled basis but variations between 40 kg N + 40 kg P_2O_5 ha^{-1} and 60 kg N + 60 kg P_2O_5 ha^{-1} were indifferent. Use of 40 kg N + 40 kg P_2O_5 ha^{-1} recorded 6.74 and 13.78% higher consumptive use over fertility levels of 20 kg N + 20 kg P_2O_5 ha^{-1} and control, respectively. Increase in consumptive use at each higher fertility level can again be attributed to significantly higher growth and resultant higher plant transpiring surface and transpiration losses by fenugreek crop. The increase in consumptive use at higher fertility levels can also be attributed due to increase in root biomass/ length/ ramification and to higher turgidity of plant which is well supported by findings of Lakpale *et al.* (2004).

Water use efficiency was also significantly influenced under different fertility levels during both the years and on pooled basis. The fertility level of 40 kg N + 40 kg P_2O_5 ha^{-1} recorded maximum water use efficiency (at par with 60 kg N + 60 kg P_2O_5 ha^{-1}) which was significantly higher than pooled water use efficiency under 20 kg N + 20 kg P_2O_5 ha^{-1} and control that corresponded to 1.76 and 6.01%, respectively. This can be ascribed to fact that addition of nutrients/ fertilizer normally improve crop nutrition, growth and productivity and thereby water use efficiency at a given soil moisture level which critically controls nutrient uptake. Nutrients favorably influence different physiological and metabolic processes of plants on account of variety of cellular, structural and other roles. This is clearly evidenced and each higher fertility level up to 40 kg N + 40 kg P_2O_5 ha^{-1} recorded significantly higher water use efficiency over the immediately lower fertility level while pooled variations in water use efficiency corresponded to 4.18% between control and 20 kg N + 20 kg P_2O_5 ha^{-1} and 1.76% between 20 kg N + 20 kg P_2O_5 ha^{-1} and 40 kg N + 40 kg P_2O_5 ha^{-1}. Increase in consumptive use and decrease in water use efficiency of fenugreek at each higher fertility level up to 40 kg N + 40 kg P_2O_5 ha^{-1} have also been reported by Kumar *et al.* (2009).

Results appended in Table 2 reveal that statistically identical IW-CPE ratios of 1.0 and 1.2 recorded significantly higher performance of seed, haulm and biological yield over lower IW-CPE ratios of 0.8, 0.6 and 0.4 during 2011, 2012 and on pooled basis. This shows the sufficiency of soil moisture to fenugreek crop at IW-CPE ratio of 1.0 over all lower IW-CPE ratios. The data on performance of various growth parameters also recorded significantly higher values up to IW-CPE ratio of 1.0 (Datta and Chatarjee, 2006). This reveals that IW-CPE ratio of 1.0 maintained sufficient soil moisture during entire

Table 2. Effect of IW-CPE ratios and fertility levels on seed, haulm yields, net return and B-C ratio of fenugreek

Treatment	Seed yield (kg ha^{-1})			Haulm yield (kg ha^{-1})			Biological yield (kg ha^{-1})		
	2011	2012	Pooled	2011	2012	Pooled	2011	2012	Pooled
IW-CPE ratios									
I_0 (0.4)	1095	1425	1260	3223	4005	3614	4318	5430	4874
I_1 (0.6)	1316	1622	1469	3782	4480	4131	5098	6102	5600
I_2 (0.8)	1484	1792	1638	4254	5015	4635	5738	6807	6272
I_3 (1.0)	1638	2028	1833	4653	5569	5111	6291	7597	6944
I_4 (1.2)	1678	2069	1873	4751	5681	5216	6429	7750	7089
SEm.±	31	48	28	93	133	81	106	169	100
LSD (p= 0.05)	100	157	85	303	434	243	347	551	299
Fertility levels (N : P_2O_5 kg ha^{-1})									
F_0 (0:0)	1270	1582	1426	3746	4378	4062	5016	5960	5488
F_1 (20 : 20)	1406	1769	1588	4088	4962	4525	5494	6731	6112
F_2 (40 : 40)	1545	1896	1721	4346	5207	4777	5892	7103	6497
F_3 (60 : 60)	1547	1902	1725	4351	5253	4802	5898	7155	6526
SEm.±	17	21	14	34	45	28	35	48	30
LSD(p= 0.05)	48	62	38	99	131	80	100	138	84

crop period particularly during critical stages (flowering and pod formation) that resulted in significantly higher performance of growth, yield attributes and yield components. Datta and Chatarjee, (2006) reported at Nadia, West Bengal the highest seed yield of fenugreek at IW-CPE ratio of 1.0. Irrigation scheduling on basis of climatological approach like IW-CPE ratio is considered to be most scientific since it integrates all weather parameters giving them natural weightage in a given climate-plant continuum.

Results clearly indicate that each higher fertility level from control to 40 kg N + 40 kg P_2O_5 ha^{-1} recorded significantly higher seed, haulm and biological yield over its immediately lower level. Use of 20 kg N + 20 kg P_2O_5 ha^{-1} recorded 162 and 463 kg ha^{-1} higher pooled seed and haulm yield over control. However, variations in pooled seed, haulm and biological yields between 60 kg N + 60 kg P_2O_5 ha^{-1} and 40 kg N + 40 kg P_2O_5 ha^{-1} was just marginally higher (not significant) and corresponded to only 4, 25 and 29 kg ha^{-1}, respectively. The result well corroborate with findings of Kumar *et al.* (2009).

References

Brady NC and Weil RR (2004). *The Nature and Properties of Soils*. 13th Ed. Pearson Educ. Inc. pp.580.

Datta S and Chatarjee R (2006). Effect of irrigation regimes on moisture extraction pattern, evaporation and yield of fenugreek *(Trigonella foenum-graecum* L). *Journal of Spices and Aromatic Crops* **15** (2):125-129.

Kumar S, Singh D and Nepalia V (2009). Performance of fenugreek (*Trigonella foenum-graecum*) varieties at various fertilizer levels and bio-fertilizer inoculations. *Indian Journal of Agricultural Sciences* **79** (1): 80-83.

Lakpale R, Shrivastava GK and Tripathi RS (2007). Effect of irrigation schedule on growth, yield and economics of spice crops. *Indian Journal of Agricultural Sciences* **77**(3): 170-173.

Mehta RS, Meena SS and Lal G (2010). Effect of irrigation levels and weed control methods on dry matter accumulation, growth dynamics and yield of fenugreek. *Indian Journal of Horticulture* **67** (2): 219-224.

Olsen SR, Cole CV, Watarabe FS and Dean LA (1954) Estimation of available phosphorus in soil by extraction with sodium bicarbonate (US Department of Agriculture Circular No. 939). Washington DC. US Government Printing Office.

Piper CS (1967) *Soil and Plant Analysis*. Asia Publishing House, New Delhi, India.

Richards LA (1954). Diagnosis and improvement of saline and alkali soils. Agric. Hand Book No.60, USDA, U.S. Govt. Printing Office, Washington D.C. p160.

Rotaru V and Sinclair TR (2009). Interactive influence of phosphorus and iron on nitrogen fixation by soybean. *Environmental Experimental Biotechnology* **66**: 94-99.

Subbiah BV and Asija GL (1956). A rapid procedure for the determination of available nitrogen in soils. *Current Science* **25:** 259-60.

Walkley A and Black IA (1934) An examination of the Digital method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37**: 29-38.

Received: December, 2014; Accepted March, 2015

Journal of Soil Salinity and Water Quality 7(1), 58-60, 2015

Study of Different Genotypes of Groundnut (*Arachis hypogaea* L.) and their Relative Salt Tolerance Under Simulated Saline Soil Condition

Shalini Kumari*, Pamu Swetha and MS Solanki

Department of Soil Science and Agriculture Chemistry , College of Agriculture,
Junagadh Agricultural University, Junagadh-362001, Gujarat
Email:-shalinikumari136@gmail.com

Abstract

A greenhouse experiment was conducted at Junagadh during 2012-2013 in galvanized pots (75 x 60 x 30 cm) containing 120 kg soil to evaluate the salt tolerance of three spreading (GG-12,GG-13 and JSP-11391), three semi-spreading (GG-20,TG-26 and JSSP-22302) and four bunch (GG-6,GG-7,GG-5 and J-33533) genotypes of groundnut (*Arachis hypogaea* L.) using four levels of salinity (control,4,8 and 12 EC dS m^{-1}) using RBD with three replications. The results showed that as the salinity levels increased the germination count, plant height and pod and haulm yield decreased significantly but reverse was true in case of Na/K ratio. The varieties GG-12 (spreading), GG-20 (semi-spreading) and J-33533 (bunch) showed better performance at all the salinity levels than the other varieties tested in their respective groups.

Key words: Groundnut genotypes, Salt tolerance, Galvanized pots, Simulated salinity

Introduction

Groundnut is the most important oil seed crop in Gujarat in general, and in Saurashtra region particular with 66 per cent of salt-affected soil of the State (Patel *et al*., 1992). Groundnut crop has been reported to be salt sensitive, however, the limit of salt tolerance would depend on nature of ionic species, crop species, stage of growth, environmental factors and physico-chemical properties of soil. Some farmers in the region of groundnut are also growing in the salt-affected soils. Information on relative performance of commonly cultivated varieties of groundnut in respect to their salt tolerance is lacking. Therefore, the present investigation was undertaken to investigate the relative salt tolerance of different groundnut genotypes under simulated saline soil condition.

Material and Methods

Development of salt-tolerant plant materials will require selection at several stages of plant growth. Selection for salt tolerance of different genotype in the field has proven to be very difficult and often not effective, because of lack of uniformity of most salt affected fields. In order to develop simple screening methodology for salt tolerance, initially, three genotypes of spreading, three semi-spreading and four bunch genotypes of groundnut using four levels of salinity in a completely randomized block design with three replications was taken under study in a greenhouse at Junagadh.

Experimental site

A greenhouse study in big galvanized iron pots (75 × 60 × 30 cm) containing 120 kg medium black calcareous clay soil (Typic Ustochrepts) was conducted during *kharif*-2012 -2013 at junagadh to evaluate the salt tolerance of three spreading (GG-12, GG-13 and JSP-11391), three semi-spreading (GG-20, TG-26 and JSSP-22302) and four bunch (GG-6, GG-7, GG-5 and J-33533) genotypes of groundnut using four levels of salinity (control, 4, 8 and 12 EC dS m^{-1}) in a completely randomized block design (RBD) with three replications.

Treatments

Salinity levels: S_0: control, S_1: 4 ECe, S_2:8 ECe, S_3: 12 ECe

Varieties: V_1:GG-12(S),V_2:GG-13(s), V_3:JSP-11391(S),V_4:GG-20(SS),V_5:TG-26(SS),V_6:JSSP-

22302(SS), V_7:GG-6, V_8:GG-7(B), V_9:GG-5(B), V_{10}:J-33533(B)

Soil analysis

The experimental soils were clayey in texture, EC-0.85 dS m^{-1}, pH 2.5-7.8, $CaCO_3$-16.6 %, Organic carbon-6.2g kg^{-1}, Olsen's available P-11.0 kg ha^{-1} and available K-190 kg ha^{-1}. The saline water 4.0, 8.0, and 12.0 EC dS m^{-1} were prepared by dissolving sulphate and chloride of Na, Ca and Mg so as the ratio of Na: Ca: Mg was maintained at 5:1:2 and of Cl: SO_4 at 4:1. Soil analysis was done using standard methods (Jackson, 1973).

Sowing, irrigation and harvesting

The calculated amount of N and P as urea and diammonium phosphate was applied in furrow per pot as basal @25 kg N and 50 kg P_2O_5 ha^{-1}. Following this, 15 seeds of each variety were shown in line in each pot and they were covered with soil. Fourty-two liters of solution as per the treatments were applied uniformly in each pot in order to attain slightly higher moisture than that of field capacity. Irrigation was given at appropriate time to maintain the EC and moisture content in the soil. Finally 10 seedlings were allowed to grow up to maturity. Plant height and pod and haulm yield at harvest were recorded and haulm samples were analyzed for Na and K content using standard methods (Richards, 1954).

Results and Discussion

Salinity level

The data presented in (Table-1) indicated that pod and haulm yield and mature pods per plant found significantly highest under S_0 level i.e. control and lowest under EC 12 dS m^{-1} i.e S_3 level. As the height and germination percentage play important role under groundnut yield, so while examining this observation climatic condition should be taken in consideration. The plant height and germination percentage under different genotype is significantly influenced by simulated salinity levels and were recorded higher under S_0 level i.e. control, whereas the corresponding values were significantly lowest under S_3 level i.e. 12 dS m^{-1}.

In most plants, the accumulation of Na in shoot brings about deleterious effect, and the plant strategy is to limit the Na build-up in the shoot tissues.

Table 1. Effect of simulated salinity levels on yield, yield attributes and nutrient content in haulm of different varieties of groundnut

Treatment	Yield (g/plant)		Mature	Plant height	Germination	Haulm		
	Pod	Haulm	pods/ plant	(cm)	(%)	Na (%)	K (%)	Na/K ratio
Salinity levels								
S_0: control	4.22	11.26	5.16	40.4	77.4	0.15	0.81	0.19
S_1: 4 EC	3.92	3.92	10.34	4.73	34.2	73.6	0,16	0.20
S_2:8 EC	3.61	3.61	9.25	4.42	30.2	70.8	0.17	0.21
S_3: 12 EC	2.82	2.82	7.47	3.64	26.9	66.6	0.17	0.23
S.Em±	0.09	0.20	0.08	0.68	0.83	0.002	0.02	0.003
C.D at 5%	0.25	0.56	0.21	0.20	2.4	0.01	0.02	0.01
Variety								
V_1:GG-12(S)	4.14	10.89	5.01	33.9	77.4	0.17	0.81	0.21
V_2:GG-13(S)	4.01	10.48	4.74	33.5	67.0	0.17	0.81	0.21
V_3:JSP-11391(S)	3.06	8.49	3.74	30.6	77.4	0.16	0.79	0.20
V_4:GG-20(SS)	5.69	13.95	6.78	32.5	79.3	0.16	0.79	0.20
V_5:TG-26(SS)	1.61	4.17	2.28	28.9	73.5	0.16	0.76	0.21
V_6:JSSP-22302(SS)	4.93	12.59	5.73	37.8	71.8	0.17	0.79	0.23
V_7: GG-6	3.62	10.08	4.58	33.6	70.0	0.17	0.79	0.21
V_8:GG-7(B)	2.51	6.83	3.35	33.3	68.6	0.16	0.78	0.21
V_9:GG-5(B)	3.03	7.85	3.84	31.6	70.6	0.16	0.79	0.20
V_{10}:J-33533(B)	3.86	9.94	4.81	31.5	72.0	0.15	0.78	0.20
S.Em±	0.14	0.31	0.12	1.08	1.32	0.003	0.01	0.003
LSD (p=0.05)	0.40	0.88	0.34	3.1	3.8	0.01	NS	0.01

S=Spreading, SS=Semi spreading, B=bunch

Although it was found that the Na concentration in shoot increased with the salt treatment. It was also found in sorghum (*Sorghum bicolor*) that plants under salinity store a large amount of Na in the stem, as compared to leaves and young leaves (Netondo *et al.,* 2004). It was found in sorghum that there was a highly significant correlation between the salinity tolerance and the stem/leaves ratio (our on-going unpublished work in sorghum). The same turned out to be true in groundnut, where stems could be used as Na storage. Nautiyal *et al.* (1989, 2000) and Mensah *et al.* (2006) also observed salinity tolerance in genotypes of groundnut. Further investigation is needed to dissect the precise localization of Na in the shoot parts of tolerant and sensitive groundnut genotypes. Thus, the result showed that the Na content and Na/K ratio in haulm were found significantly lowest and K content significantly highest under S_0 level and were remains at par with simulated salinity level S_1.

Varieties

Among the spreading varieties, variety V_1 (GG-12) produced significantly highest pod (4.14g) and haulm yield (10.89 g) mature pods per plant (5.01) and plant height (33.88cm) but was at par with variety V_2 (GG-13), while germination percentage was recorded significantly higher under variety V_1 (GG-12) and V_3 (Sp-11391). All the three varieties of spreading groundnut had almost similar Na and K content and Na/K ratio. In case of semi spreading varieties, pod (5.69 g) and haulm (13.45 g) yield per plant, mature pods per plant (6.78) and germination percentage (79.25) found significantly higher under variety V_4 (GG-20) of groundnut, while plant height and Na/K ratio under variety V_6 (JSSP-22302). Significantly highest pod yield (3.86 g), mature pods per plant (4.81) and germination percentage (72.0) was recorded under variety V_{10} (J-33533) of bunch groundnut, which was at par with variety V_7 (GG-6), but reverse was true in case of haulm yield per plant. The significantly highest Na content was recorded under variety V_7 (GG-6), while all the four varieties of bunch groundnut were similar with respect to plant height, K content and Na/K ratio.

Conclusions

The foregoing discussion revealed that as the salinity levels increased the germination count, plant height and pod and haulm yield decreased significantly but reverse was true in case of Na/K ratio. The varieties GG-12 (spreading) GG-20 (semi- spreading) and J-33533 (bunch) were found salt tolerance at all the salinity levels.

References

Jackson ML (1973) *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi.

Mensah JK, Akomeah PA, Ikhajiagbe B and Ekpekurede EO (2006) Effect of salinity on germination, growth and yield of five groundnut genotypes. *African Journal of Biotechnology* **5**: 1973-1979.

Nautiyal PC, Ravindra V and Joshi YC (1989) Germination and early seedling growth of some groundnut (*Arachis hypogaea* L.) cultivars under salt stress. *Indian Journal of Plant Physiology* **32**: 251-253.

Nautiyal PC, Bandyopadhyay A, Koradia VG and Makad M (2000) Performance of groundnut germplasm and cultivars under saline water irrigation in the soils of Mundra in Gujarat, India. *International Arachis Newsletter* **20**: 80-82.

Netondo GW, Onyango JC and Beck E. (2004). Sorghum and salinity: I. Response of growth, water relations, and ion accumulation to NaCl salinity. *Crop Science* **44**:797–805.

Patel MS, Gundalia JD and Polara KB (1992) Evaluation of salt tolerance of different groundnut (*Arachis hypogaea* L.) genotypes. *Gujarat Agricultural University Res J* **18**: 17-23.

Received: December, 2014; Accepted April, 2015

Journal of Soil Salinity and Water Quality 7(1), 61-63, 2015

Impact of Organic Mulch, Soil Configuration and Soil Amendments on Yield of Onion and Soil Properties under Coastal Saline Condition

Shalini Kumari*, Pamu Swetha and MS Solanki

Department of Soil Science and Agriculture Chemistry, College of Agriculture, Junagadh Agricultural University, Junagadh -362001, Gujarat
Email: shalinikumari136@gmail.com

Abstract

A field experiment was conducted in a coastal saline region of Saurashtra of Gujarat state at Junagadh district during 2010-2013 designed in a RBD with four replication on the impact of surface organic mulch, soil configuration and soil amendment on yield of onion crop. Pearl millet husk was applied as surface organic mulch at 3 t ha^{-1}. Gypsum was broadcast at 5 t $ha^{-1}$and incorporated before sowing. The result revealed that the treatment of flat bed with surface organic mulch gave significantly higher onion bulb yield. The effect of the gypsum and soil configuration were found non-significant on the yield of onion bulb in the pooled data. At the end of the experiment soil analysis data indicated that significantly lower EC and ESP was recorded with mulch treatment in flat bed or ridge and furrow method. The mulch treatment was effective for reducing soil salinity. The maximum net return of Rs 22220 per ha with net CB ratio 1: 22 was also noted with flat bed with mulch treatment.

Key words: Onion bulb, Flat bed, Ridge furrow, mulch, ESP

Introduction

Onion (*Allium cepa* L.) is one of the major cash crops grown in Mahuva and Talaja under Shentruji command area. During last decade there was no facility of canal water, therefore, farmers are using ground water, which is over exploited in this area. Hence the quality of ground water is deteriorating rapidly. Under such condition the soil properties and thereby crop yields are adversely affected. With a proper management practices it could be possible to better harvest of crops under such condition. There is no any information available on this aspect in this area; therefore, a field experiment was planned on farmers' fields of Mahuvataluka to study the effect of soil configuration, organic mulch and soils amendments on yield of onion and soil properties under saline condition.

Material and Methods

Experimental site

A field experiment was conducted on coastal saline soil of Saurashtra for the three years during Rabi season from the year 2010 to 2013 in a RBD with four replications at the farmers' field (Village: Vadli, Taluka: Mahuva, Dist: Bhavnagar, State: Gujarat) cultivating onion, Cv, Talaja red (Local variety). The observations on growth and yield attributes were recorded from 5 randomly selected plants from each plot. The data were recorded for bulb yield on net plot basis and then converted on hectare basis and subjected to statistical analysis.

Treatments

The treatments were T_1: Flat bed (Fb, Control), T_2: Fb+ Mulch (3 t ha^{-1}), T_3: Fb + Gypsum (5 t ha^{-1}), T_4: Fb + Mulch (3 t ha^{-1}) + Gypsum (5 t ha^{-1}), T_5: Ridge and furrow (R&F), T_6: R&F + Mulch (3 t ha^{-1}), T_7: R&F +Gypsum (5 t ha^{-1}), T_8: R&F +Mulch (3 t ha^{-1}) + Gypsum (5 t ha^{-1}).

Soil and plant analysis

Soil samples were analyzed following methods described by Jackson (1973). Potassium contents were determined according to the method mentioned by Jackson (1973). After drying, a sample of bulbs and leaves from onion plants from each plot were used to measure potassium levels (%) using flam photometer.

Table 1. Effect of different treatment on bulb yield of onion (t ha^{-1})

Sr. no.	Treatment	Bulb yield (t ha^{-1})			Pooled
		2010-11	2011-12	2012-13	
T_1	Fb (Control)	42.73	63.20	47.69	51.21
T_2	Fb+Mulch (M)	46.09	76.63	65.75	62.82
T_3	Fb +Gypsum (G)	44.89	66.44	56.02	55.78
T_4	Fb+M+G	48.99	64.59	53.71	55.76
T_5	R & F	43.92	55.79	50.47	50.06
T_6	R & F+ Mulch	51.07	68.76	50.93	56.92
T_7	R & F +Gypsum	44.26	61.81	49.08	51.72
T_8	R & F +M+ G	49.80	63.20	51.16	54.72
	S.Em±	1.69	1.64	2.04	2.20
	LSD (p=0.05)	4.94	4.81	6.01	6.66
	C.V.%	7.23	5.03	7.69	6.54

Depictions: Fb-flat bed, M-mulch, G- gypsum, R & F- ridge and furrow

The experiment soil had texture silty loam, EC (dS m^{-1}) 1.3, pH 8.2, $CaCO_3$ 28 g kg^{-1}, ESP 8.5, OC 4.3 g kg^{-1}, available P_2O_5 35.4 kg ha^{-1} and available K_20 510 kg ha^{-1}.

Fertilizer doses

The half N and full P_2O_5 and K_2O of RD-recommended dose (75.0:60.0:50.0 N + P_2O_5 +K_2O kg ha^{-1}) were applied as basal and remaining half dose of N of RD as split at 30 days after planting of onion seedling.

Spacing

The plant spacing of 15 cm by 10 cm adopted for onion seedling.

Irrigation

The mean annual rainfall of the area is about 400 mm of an erratic distribution. The slope of the study area was less than 2 per cent, with little variation in physiography. The onion crop grown in plots was subjected to irrigation by flood system. Irrigation application was scheduled to ensure that the crops moisture sensitive periods were covered and sufficient water supplied. The value of EC (dS m^{-1}) and pH of the irrigation water were 2.3 and 7.9, respectively.

Results and Discussion

Effect on crop yield

The onion bulb yields were significantly affected due to different treatments and mentioned in Table 1. The pooled results revealed that the treatment of flat bed with surface organic mulch gave significantly higher onion bulb yield and was at par with the treatment of ridge and furrow with mulch. The surface organic mulch under irrigated conditions resulted in higher initial infiltration rates (Singh and Sachhan, 1998; Arika and Lenga, 2000). Such an improved trend in the onion bulb yield, fallowing mulching, could be attributed to moderated soil hydrothermal regime (Sharma and Parmar, 1998) which resulted in an enhanced growth and activity of roots and shoots. The effects of the gypsum and soil configuration were found non-significant on the yield of onion bulb in the pooled data. Wong and Ho (1991) also observed encouraging results due to gypsum application.

Table 2. Effect of different treatment on soil properties

Sr. no.	Treatment	Soil analysis (last year)		
		$EC_{2.5}$ dS/m	pH (1:2.5)	ESP
T_1	Fb (Control)	0.53	7.95	17.38
T_2	Fb+Mulch (M)	0.50	7.95	16.88
T_3	Fb +Gypsum (G)	0.88	7.78	16.43
T_4	Fb+M+G	0.78	7.68	16.30
T_5	R & F	0.56	8.00	19.03
T_6	R & F+ Mulch	0.55	7.98	18.75
T_7	R & F +Gypsum	1.58	7.63	15.23
T_8	R & F +M+ G	1.03	7.80	15.10
	S.Em±	0.072	0.079	0.689
	LSD (p=0.05)	0.213	0.232	2.026
	C.V.%	18.11	2.01	8.16

Depictions as in Table 1

Table 3. Economic of treatments for *rabi* onion crop.

Sr. no.	Treatment	Bulb yield (t ha^{-1})	Additional bulb yield over control (t ha^{-1})	Additional bulb yield income over control (Rs. ha^{-1})	Total additional expenditure over control (Rs ha^{-1})	Total additional income over control (Rs ha^{-1})	NET CBR
T_1	Fb (Control)	51.21	-	-	-	-	-
T_2	Fb+Mulch (M)	62.82	11.61	23220	1000	22220	1:22.22
T_3	Fb+Gypsum (G)	55.78	4.57	9140	1250	7890	1:6.31
T_4	Fb+M+G	55.76	4.55	9100	2250	6850	1:3.04
T_5	R & F	50.06	-1.15	-2300	1000	-3300	-
T_6	R & F+ Mulch	56.92	5.71	11420	2000	9420	1:4.71
T_7	R & F +Gypsum	51.72	0.51	1020	2250	-1230	-
T_8	R & F +M+ G	54.72	3.51	7020	3250	3770	1:1.16

Depictions as in Table 1
Price of the materials considered and application charge
Onion bulb: 2.00 Rs kg^{-1} Husk of pearl millet (mulch): 1000 Rs t^{-1}
Gypsum: 250 Rs t^{-1} Cost of ridge and furrow : 1000 Rs ha^{-1}

Yield and bulb quality

After harvesting and curing of onion bulbs, another sample were taken to measure bulb physical characteristics such as bulb weight (g), diameter (cm), and length (cm). In the same above sample bulb quality were evaluated by measuring total soluble solids (TSS %) which determined using a hand-held refractometer.

Effect on soil properties

At the end of the experiment soil analysis data (Table 2) indicated that significantly lower EC was recorded with mulch treatment in flat bed or/and in ridge and furrow method. Whereas, significantly lower ESP was recorded under the treatment of ridge and furrow + mulch + gypsum. Thus the mulch treatment was effective for reducing soil salinity.

Economy

The perusal of data presented (Table-3) revealed that the treatment of flat bed with mulch gave significantly higher bulb yield of onion. Similarly, the maximum net return of Rs 22220 per ha with net CBR 1: 22 was also noted with flat bed with mulch treatment.

Conclusion

The study revealed that addition of gypsum and organic amendments acted as ameliorant to coastal saline soils. In this study, individual or combined effect of gypsum and organic mulch was more effective in changing EC and ESP. Gypsum application in combination with organic amendments improved the soil chemical properties by reducing the EC, ESP and pH, than the applying gypsum alone.It is therefore, inferred from the experiment that by the application of surface organic mulching, the onion bulb yield can be increased by 22.69 per cent over traditional cultivation practices of the coastal saline area of Saurashtra.

References

Arika CN and Lenga FK (2000). Effect of mulch application method on soil moisture characteristics and maize yield in a semiarid region of Kenya *Journal of Indian Society Soil Science* **48**: 9-15.

Jackson ML (1973). *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd. New Delhi.

Singh SR and Sacchan BA (1998). Response of different bulb size and spacing combinations on seed yield and yield attributing traits on onion (*Allium cepa* L) *Haryana Journal of Horticultural Science*. **21(1):** 56-58.

Sharma PK and Parmer DK (1998). Effect of phosphorus and mulching on the uptake of secondary nutrients and productivity of wheat at different growth stages on Alfisol from Western Himalayas. *Journal of Indian Society of Soil Science*. **46**: 67-70.

Wong JWC and Ho GH. (1991). Effect of gypsum and sewage sludge amendment on physical properties of fine bauxite refining residue. *Soil Science* **152:** 326-332.

Received: December, 2014; Accepted April, 2015

Journal of Soil Salinity and Water Quality 7(1), 64-67, 2015

Comparative Efficacy of Different Crop Residues, Green Manures and Gypsum in Improving Biological Properties of Sodic Vertisols

AO Shirale[1]*, VK Kharche[1], RN Katkar, RS Zadode and AB Aage

[1]Department of Soil Science and Agril. Chemistry, [2] Department of Agronomy
Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra
**E-mail: abhayshirale@gmail.com*

Abstract

The field experiments on cotton followed by green gram in *kharif* (2011) and chickpea in *rabi* season (2012) were conducted on farmers' fields in Kutasa village of Purna valley of Vidarbha region of Maharashtra. The treatments comprised of five different green manures (sunhemp, dhaincha, cowpea, green gram and leucaena loppings), two crop residues (cotton stalk and farm waste as bio-mulch), gypsum and control. There were nine treatments replicated on three farmers' fields on Vertisols treating each farmer as one replication. Application of crop residues and green manures significantly enhanced the CO_2 evolution, soil microbial biomass carbon, permanganate oxidizable carbon and dehydrogenase activity over the application of gypsum and control. The application of dhaincha and sunhemp *in situ* green manuring showed highest potential to improve biological properties of soils. The different treatments of organic amendments followed the sequence dhaincha > sunhemp > cowpea > leucaena loppings > green gram > cotton stalk > bio-mulch for improving biological properties. The results thus suggest the potential of different crop residues and green manures of improving biological properties in sodic Vertisols.

***Key words*:** Biological properties, Crop residues, Green manures, Microbial biomass carbon, Reclamation, Sodic Vertisols.

Introduction

Salt- affected soils are an important ecological entity in the landscape of semi-arid and arid regions of the world. The soil degradation due to salinity and sodicity has affected larger areas of fertile tracts, particularly in arid and semi-arid regions of the country and caused significant losses to crop productivity. In sodic soils there is low biological activity including enzyme activity, nitrogen mineralization and microbial biomass carbon, due to high pH, exchangeable Na^+, excessive CO_3^{2-} and HCO_3^- and low organic matter and N status (Rao and Pathak, 1996). The Application of green manure enhances the reclamation action of organic manures by improving physical and chemical properties of soil and by markedly decreasing soil pH. Plant litter incorporation improves aggregation and lead to better aeration and water relationship, creating favorable environment for better establishment of microbial activities. Purna valley in Vidarbha region of Maharashtra is such an area having major problems like native salinity/sodicity, poor hydraulic conductivity, high degree of swell shrink potential, compact and dense sub-soil, incomplete leaching of salts from soil due to severe drainage impairments and low biological activities. It is therefore necessary to identify cost effective and site specific management options for improvement of these soils. In this context the present study was carried out in representative village Kutasa District Akola in Purna valley and the field experiments were conducted for two years on farmers fields in order to ascertain the comparative efficacy of different crop residues, green manures and gypsum in improving biological properties of sodic Vertisols.

Material and Methods

The field experiments on cotton (2011) followed by green gram and chickpea (2012) were conducted on selected farmers'fields in Purna valley. The treatments comprised of five different green manures (sunhemp-*Crotalaria juncea*, dhaincha-*Sesbania aculeata*, cowpea - *Cajanus cajan*, green gram -*Vigna radiata* and leucaena-*Leucaena leucocephala,* green leaf), two kinds of mulch (composted cotton stalk residue and bio-mulch (mulching with farm waste)),

Table 1. Effect of crop residues, green manuring and gypsum application on soil microbial biomass carbon (SMBC) and CO_2 evolution

Tr. No.	Treatment		SMBC (µg g^{-1} soil)			CO_2 evolution (mg 100 g^{-1} soil)		
			2011-12	2012-13	2012-13	2011-12	2012-13	2012-13
	Cotton	Green gram-Chickpea	Cotton	Green gram	Chickpea	Cotton	Green gram	Chickpea
T_1	Control (no residue no green manure)	Residual effect	68.93	88.92	92.04	29.70	28.60	31.90
T_2	Sunhemp *in situ* green manuring	Residual effect	115.10	143.74	171.29	55.73	57.20	63.43
T_3	Dhaincha *in situ* green manuring	Residual effect	124.24	148.23	174.97	59.40	62.70	64.90
T_4	Leucaena loppings green leaf manuring	Residual effect	113.02	141.75	168.99	52.80	52.80	58.30
T_5	Cow pea *in situ* green manuring	Residual effect	113.46	139.57	168.57	49.70	51.43	55.37
T_6	Green gram *in situ* green manuring	Residual effect	110.11	139.67	168.51	49.50	49.17	53.53
T_7	Composted cotton stalk residue	Residual effect	101.69	134.33	160.60	47.30	53.90	55.73
T_8	Biomulch (Mulching with farm waste)	Residual effect	102.12	132.32	160.51	46.20	47.30	53.53
T_9	Gypsum @ 2.5 t ha^{-1}	Residual effect	95.80	102.13	119.19	42.90	40.70	46.93
	SE (m) ±	2.78 5.17	3.96	1.38	2.21	1.99		
	LSD (p=0.05)	8.34 15.49	11.88	4.15	6.61	5.97		

gypsum (@ 2.5 t ha^{-1}) and control. The field experiments were conducted on three different farmers' fields in Purna valley. The design of experiments was randomized block design, replicated three times, where one farmer was treated as one replication. During first year cotton was grown in *kharif* and various green manuring crops were sown in between two rows of cotton which were buried subsequently in soil. The cotton stalk residues were decomposed using decomposing culture and applied to the soil before sowing. Gypsum application was made to the respective treatment plots uniformly by mixing in the top soil layer. During second year green gram was grown in *kharif* followed by chickpea in *rabi* season. The crop residues from both the crops grown in second year were incorporated into soil of respective treatments after harvest of the crops so as to ascertain their residual effect. The initial pH of experimental sites varied from 8.27 - 8.34, the electrical conductivity (EC_2) between 0.20 - 0.25 dS m^{-1}, the organic C content between 5.23 - 5.71 g kg^{-1}, the $CaCO_3$ content between 9.67 - 10.60%, clay content from 50 to 51%, the cation exchange capacity between 52.17-53.47 cmol(p^+) kg^{-1}) and ESP between 10.39 - 11.29.

The treatment wise soil samples from each site were collected (2011-12 and 2012-13) and analyzed on same day for biological properties. Soil microbial biomass carbon was determined by chloroform fumigation extraction method as described by Jenkinson and Powlson (1976). Dehydrogenase activity was determined by TTC method as described by Klein *et al.* (1971). CO_2 evolution was determined by alkali trap method as described by Anderson (1982). The active carbon (permanganate oxidizable carbon) was determined by oxidation of C with 20 mM $KMnO_4$ as described by Blair *et al.* (1995).

The data were analyzed using analysis of variance (ANOVA) (Gomez and Gomez, 1990).

Results and Discussion

Soil microbial biomass carbon

The soil microbial biomass carbon (SMBC) was observed to significantly increased in the treatments of organic amendments as compared to gypsum and control (Table 1). The significantly highest value of SMBC was observed under dhaincha in situ green manuring (T_3) (124.24 and 174.97 µg g^{-1} soil) and sunhemp *in situ* green manuring (T_2) (115.10 and 171.29 µg g^{-1} soil). Among different organics dhaincha *in situ* green manuring (T_3) increased SMBC by 86.84 per cent over control. On an average all organic treatments increased SMBC by 82.13 per cent over control and 40.64 per cent over gypsum amended plot. Kaur *et al*. (2008) and Choudhary *et al*. (2013) reported that the soils amended with organic materials maintained significantly higher SMBC values compared to those without organic amendments under sodic water or canal water irrigation treatment with or without gypsum. The increase in microbial growth with the addition of carbon substrate and declined with the exhaustion of available C, as microbial C was positively correlated with organic matter (Fig.1). The increase in microbial C might also be due to increased biological activity as indicated by increased dehydrogenase activity in different treatments (Table

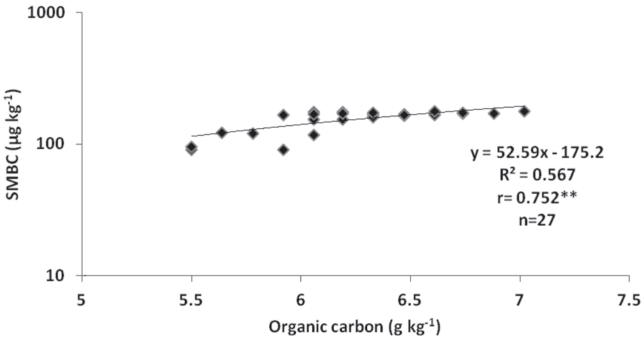


Fig. 1. Relationship between organic carbon and SMBC

2). Dalal *et al.* (2011) also reported Increase in microbial biomass carbon due to reduction in pH and ESP of soil on account of addition of organic matter.

CO_2 evolution

The significant improvement in CO_2 evolution under dhaincha (T_3) (64.90 mg 100 g^{-1} soil) and sunhemp in situ green manuring (T_2) (63.43 mg 100 g^{-1} soil) (Table 1). Pathak and Rao (1998) reported that addition of sesbania residues recorded higher CO_2 evolution. This might be attributed to fast reclamation and creation of favorable environment for microbial multiplication and overall activities. The treatment of organic amendments (53.53 to 64.90 mg 100 g^{-1} soil) showed higher values of CO_2 evolution over gypsum amended plot (46.93 mg 100 g^{-1} soil) and control plot (31.90 mg 100 g^{-1} soil). The results revealed the significance of green manuring and crop residues incorporation for improving biological soil health which is normally deteriorated in sodic soils. The increased microbial biomass and metabolically active substances could have resulted in increased soil respiration rate (Rao and Pathak. 1996).

The treatments of gypsum recorded comparatively lower CO_2 evolution while control showed lowest values. The practice involving use of various organic amendments however recorded higher values of CO_2 evolution, which thus suggest that very low biological activity under absence of organics renders the soil poor in biological health.

Dehydrogenase activity

The dehydrogenase activity showed significant improvement due to dhaincha *in-situ* green manuring (T_3) during both the years (70.90, 78.22 and 90.79 µg TPF g^{-1} 24 h^{-1}). It was lowest under control (T_1) (average, 22.39 µg TPF g^{-1} 24 h^{-1}), which improved slightly with gypsum application (T_9) (40.93, 40.55 and 48.93 µg TPF g^{-1} 24 h^{-1}) (Table 2). The application of sunhemp *in situ* green manuring (T_2) and leucaena loppings showed significant improvement in dehydrogenase activity over control and on par with dhiancha *in situ* green manuring (T_3) during chickpea (2012-13). The stronger effects of dhaincha, sunhemp and leucaena on dehydrogenase activity might be due to the more easily decomposable components of crop residues on the metabolism of soil microorganisms and due to the increase in microbial growth with addition of carbon substrate. The results are in conformity with the findings of Rao and Pathak (1996) and Kharche *et al.* (2010).

The findings thus indicate that, the soils are greatly hampered due to sodicity which hinders the microbial activity under restricted use of organic amendments which necessitates application of organic manure in sufficient quantity. Being chief carbon source, it provides energy for soil microorganisms, and increases number of pores, which are considered important in soil-water–plant relationships and maintain good soil structure accompanied by better dehydrogenase activity (Marinari *et al.,* 2000).

The improvement in dehydrogenase activity of gypsum amended plots over control (no residue no green manure) was observed which might be due to reduction in pH and ESP. Similar results were also reported by Batra (1998) who studied dehydrogenase activity of three different sodic soils showing improvement in DHA by application of gypsum (50% GR) over no gypsum treatment.

Permanganate oxidizable carbon

The significantly highest value of POC was observed under dhaincha *in situ* green manuring (T_3) (277.50 mg kg^{-1}) followed by sunhemp *in situ* green manuring (T_2) (262.50 mg kg^{-1}). The lowest POC (174.75 mg kg^{-1}) was observed under control (T_1). Highly significant improvement under dhaincha and sunhemp (T_3 and T_2) might be due to rapid reclamation potential of dhaincha and sunhemp which reduces pH, ESP along with improvement in physical environment of soil which decreased its loss of carbon by oxidation losses as against other organic amendments under study. The higher POC observed under all organic amendments (T_2-T_8) over gypsum (T_9) showed higher carbon sequestering potential of

Table 2. Effect of crop residues, green manuring and gypsum application on Dehydrogenase activity (DHA) and permanganate oxidizable carbon (POC)

Tr. No.	Treatment		DHA (µg TPF g^{-1} 24 h^{-1}) 2011-12	2012-13	2012-13	POC (mg kg^{-1} soil) 2011-12	2012-13	2012-13
	Cotton	Green gram-Chickpea	Cotton	Green gram	Chickpea	Cotton	Green gram	Chickpea
T_1	Control (no residue no green manure)	Residual effect	20.10	22.24	24.85	111.00	121.50	174.75
T_2	Sunhemp *in situ* green manuring	Residual effect	63.59	69.33	90.79	204.75	217.50	262.50
T_3	Dhaincha *in situ* green manuring	Residual effect	70.90	78.22	90.79	216.75	231.00	277.50
T_4	Leucaena loppings green leaf manuring	Residual effect	48.97	53.64	88.18	182.25	198.00	242.75
T_5	Cow pea *in situ* green manuring	Residual effect	60.21	65.14	80.85	198.00	208.50	256.50
T_6	Green gram *in situ* green manuring	Residual effect	50.43	55.21	76.66	179.25	181.50	224.33
T_7	Composted cotton stalk residue	Residual effect	43.49	62.01	74.05	165.00	160.50	213.00
T_8	Biomulch (Mulching with farm waste)	Residual effect	42.76	49.97	71.95	152.25	152.25	204.00
T_9	Gypsum @ 2.5 t ha^{-1}	Residual effect	40.93	40.55	48.93	118.50	143.25	194.25
	SE (m) ±	2.98	2.35	2.07	9.39	7.85	5.81	
	LSD (*p*=0.05)	8.92	7.03	6.21	28.15	23.53	17.43	

organic amendments. Tirol-Padre *et al*. (2007) reported the application of FYM or green manure (*Sesbania*) recorded higher status of POC than unfertilized and unamended plots. Similar results were also reported by Lakaria *et al.* (2012) who noticed that the application of 6 t FYM ha^{-1} recorded highest POC than unfertilized and fertilized plots.

The results thus suggest that crop residue recycling and green manuring is more effective in improving biological properties of sodic black calcareous soils over gypsum.

References

Anderson JPE (1982) Soil respiration. In: Page AL, Miller RH and Keeney DR (eds) *Methods of Soil Analysis*. Part 2. *Chemical and Microbiological Properties, Agronomy Monograph* No. 9, ASA-SSSA Publisher, Madison, Wisconsin, USA, pp. 831-871.

Batra L (1998). Effect of different cropping sequences on dehydrogenase activity of three sodic soils. *Journal of the Indian Society of Soil Science* **46**(3): 370-375.

Blair GJ, Lefroy RDB and Lisle L (1995). Soil cabon fractions based on their degree of oxidation and the development of a carbon management index for agricultural systems. *Aus. J. Agric. Res*. **46**:1459-1466.

Choudhary OP, Gill JK and Bijay Singh (2013) Water extractable carbon pools and microbial biomass carbon in sodic water irrigated soil amended with gypsum and organic manures. *Pedospher*e **23(1):** 88-97.

Dalal RC, Wong VNL and Sahrawat KL (2011) Salinity and sodicity affect organic carbon dynamics in soil. *Bulletin of the Indian Soc. of Soil Sci*. **28**: 95-117.

Gomez KA and Gomez AA (1990) *Statistical Procedures for Agricultural Research*, Second edn. John Willy and Sons New york.

Jenkinson, D.S. and Powlson, D.S. 1976. The effect of biological treatments on metabolism in soil. V.A. method for measuring soil biomass. *Soil Biol. Biochem*. **8:** 209-213

Kaur J, Choudhary OP and Singh B (2008) Microbial biomass carbon and some soil properties as influenced by long term sodic water irrigation, gypsum and organic amendments. *Aust. J. of Soil Res*. **46**:141-151.

Kharche VK, Patil SR, Belur SV and. Ghogare NS (2010) Integrated use of gypsum, spent-wash press-mud compost and bio-inoculants for reclamation of sodic swell shrink soils of Maharashtra. *J. of Soil Salinity and Water Quality* **2(2):** 110-115

Klein DA, Loh TC and Goulding R L (1971) A rapid procedure to evaluate dehydrogenase activity of soils low in organic matter. *Soil Biol. Biochem*. **3**: 385-387

Lakharia BL, Patne MK, Jha P and Biswas AK (2012) Soil organic carbon pools and indices under different land use systems in Vertisols of Central India. *J. Indian Soc. Soil Sci.* **60 (2):** 125-131.

Marinari S, Masciandaro G, Ceccanti B and Grego S (2000) Influence of oragnic and mineral fertilizers on physical properties. *Bioresour. Technol*. **72**: 9-17.

Pathak H and Rao DLN (1998) Carbon and nitrogen mineralization from added organic matter in saline and alkali soils. *Soil Biol. Biochem*. **6**: 695-702.

Rao DLN and Pathak H (1996) Ameliorative influence of organic matter on biological activity of salt affected soils. *Arid Soil Research and Rehabilitation* **10**: 311-319.

Tirol-Padre A, Ladha JK, Regmi AP, Bhandari AL and Inubushi K (2007) Organic amendments affect soil parameters in two long term rice wheat experiments. *Soil Sci. Soc. Am. J.* **71:** 442–452.

Received: January, 2015; Accepted April, 2015

Journal of Soil Salinity and Water Quality 7(1), 68-76, 2015

Reducing Farm Income Losses through Land Reclamation: A Case Study from Indo-Gangetic Plains

K Thimmappa*[1], Yashpal Singh[1], R Raju[1], Sandeep Kumar[2], RS Tripathi[1], Govind Pal[3] and A Amarender Reddy[4]

[1]ICAR-Central Soil Salinity Research Institute, Zarifa Farm, Kachhwa Road, Karnal-132 001, Haryana
[2]Uttar Pradesh Land Development Corporation, Lucknow-226 001, Uttar Pradesh
[3]Directorate of Seed Research, Mau-275 101, Uttar Pradesh
[4]ICAR-Indian Agricultural Research Institute, New Delhi-110 012
*E-mail:thimpu@rediffmail.com

Abstract

Soil sodicity is a major problem in arid and semi-arid regions of Indo-Gangetic plains in India. A large proportion of sodicity-affected soils in Indo-Gangetic areas occur on land inhibited by resource poor farmers. Several efforts have been made by the Central and State governments to check soil degradation and increase agricultural productivity through land reclamation programmes in salt-affected regions of India. The present study is an attempt to measure the impact of land reclamation on reduction in farm income losses. The study sourced data from published records and survey from farm households in Uttar Pradesh, India. Analysis revealed that land reclamation has contributed substantially to improve the soil health, crop productivity and farm income. All uncultivated degraded lands in pre-reclamation period have been put under cultivation in post-reclamation period and cropping intensity has significantly increased. The farm income losses were reduced substantially in post-reclamation period. The study has concluded that sodic land reclamation technology has made a significant contribution to livelihood security of resource-poor farmers in salt-affected regions. The study has suggested that a large part of agricultural land is being abandoned in India due to severe sodicity related problems and need to be reclaimed on priority basis to improve land productivity and farm income of resource poor farmers.

Key words: Gypsum, Farm income, Land degradation, Sodic soil, Land reclamation

Introduction

Land degradation due to sodicity is a major threat to agriculture in Indo-Gangetic plains. The sodic soils are widely distributed across the globe and occupy nearly 357.2 million hectares (Pessarakli and Szabolcs, 1999). India has 6.73 Mha of salt-affected soils, of which 3.72 Mha is sodic soils predominantly present in Indo-Gangetic plains (Mandal *et al*., 2010). Sodic soils are characterized by the occurrence of excess Na^+ that adversely affects soil structure and crop growth (Qadir and Schubert, 2002). The weathering of alumino-silicate minerals produces a continuous supply of sodium, potassium, calcium and magnesium salts in the catchment area. Due to arid and semi-arid climate, the water evaporates in post-rainy months leave sodium carbonates (Na_2CO_3) and bi-carbonates ($NaHCO_3$) on soil surface, which contribute to the formation of sodic soils in Indo-Gangetic plains (Chhabra, 1996). Indo-Gangetic plain lies between 21^0 55' to 32^0 39' N and 73^0 45' to 88^0 25' E comprising of the states of Punjab, Haryana, Uttar Pradesh and part of Bihar (North), West Bengal (South) and Rajsthan (North) is having about 2.7 Mha salt affected soils (NRSA, 1996).

Soil sodicity creates an inordinately high soil pH ranging from 8.5 to 11 in addition to the ion toxicity and high osmotic pressure (Bing-Sheng *et al.,* 2013). A high pH condition causes deficiencies of several important minerals which in turn inhibits the plant growth (Guan *et al*., 2009) and adversely affects the growth of early seedlings, grain yield (Chhabra, 1996; Sharma *et al*., 2010) and grain quality (Rao *et al.*, 2013).

India's foodgrain demand projections (Radhakrishna and Ravi, 1990; Kumar, 1998; Kumar *et al*., 2009) suggest that the need to produce more food to an expanding human population, which will result in an increase in the use of poor-quality waters and soils for foodgrain production (Yadav, 1981; Oster and Jayawardane, 1998; Qadir *et al.*, 2001). Plant growth in sodic soils is affected by high osmotic stress, ion toxicity and nutritional disorders which ultimately reduces crop yield (Qadir and Schubert, 2002).

A significant advancement in sodic land reclamation technology has been made at Central Soil Salinity Research Institute (CSSRI), Karnal (India) to use the degraded sodic soils with the addition of soil amendments to meet the food grains demand for growing population. The successful application of sodic soil reclamation technology at the farmers' fields has encouraged many states to launch ambitious programmes of land reclamation through Land Reclamation and Development Corporations by providing necessary inputs to augment the food and livelihood security of resource poor farmers.

However, studies on yield and income of major crops in sodic soils before and after soil reclamation has been very limited which is most important to determine measures for improving crop production practices and for long term sustainability of agriculture. Hence, this study was focused on assessing the impact of land reclamation on crop productivity improvement and reduction in farm income losses in sodicity affected regions of Indo-Gangetic plains.

Material and Methods

Study site

An intensive study was conducted in Santaraha village in Hardoi district of Uttar Pradesh, India. It is located at an elevation of 139 meters above mean sea level. Temperature in summer goes as high as 44 °C and in winter comes down to as low as 4°C. The rainy season prevails from mid-June to mid-September and annual rainfall varies from 629 to 818 mm.

The average size of land holding was 0.62 ha and the majority of the farmers were marginal category (Table 1). The crop production was an important activity contributing 68 per cent to the total household income. Many farmers (27%) supplemented their household income by engaging themselves or their family members as farm laborers. Farmers grew crops in *kharif* season (June–October) and *rabi* seasons (November–March). Transplanted rice (*Oryza sativa*) crop was most popular in *kharif* season. Wheat (*Triticum aestivum*) was grown after rice in *rabi* season. In 'moderate' soil sodicity (ESP 15–40), rice was grown in *kharif* season and land remained barren in *rabi* season. There was no crop cultivation in the severe soil sodicity condition due to extreme sodicity (ESP >40).

Table 1. Socio-economic profile of sample farmers

Particulars	Percentage / value
(I) General information	
(a) Family size (No.)	7
(b) Literacy level (%)	40
(c) Age (years)	48
(d) Average farm size (ha)	0.62
(e) Annual rainfall (mm)	629 - 818
(f) Temperature (°C)	4 - 44
(II) Classification of farm holdings (%)	
(a) Marginal (<1 ha)	84
(b) Small (1 to 2 ha)	16
(c) Medium (>2 to 10 ha)	0
(d) Large (> 10 ha)	0
(III) Sources of family income (%)	
(a) Crop production	68
(b) Livestock	2
(c) Service	1
(d) Business	2
(e) Others	27

Source: Survey data.

Field survey

The village has total agricultural land of 123 ha owned by approximately 197 farmers. The degraded land constituted 39 per cent of the total land holdings and has varying levels of soil sodicity. The land holdings have been classified into 'normal', 'slightly affected', 'moderately affected' and 'severely affected' by sodicity based on the extent of sodicity hazard (Table 2). Soil sodicity is usually quantified by the exchangeable sodium percentage (Van der Zee *et al.*, 2010). It also can be quantified by soil pH. Sodic soils have pH greater than 8.5. Several studies have shown that there is an intimate relationship between ESP and pH of the saturation paste (Kanwar *et al.*, 1963; Kolarkar and Singh, 1970; Abrol *et al.*, 1980). Since pH of the saturation paste can be easily determined in laboratory, this property can be used as an approximate measure of ESP, which is otherwise a cumbersome determination (Chhabra, 1996). The sodicity hazards were low in 'slight' sodicity soil category. Farmers grew both rice and

Table 2. Distribution of landholdings under different sodicity classes in Santaraha village

Soil sodicity category*	pH*	Approximate ESP*	Area (ha)	Area (%)
Normal	<8.5	<15	74.98	60.96
Slight	8.5-9.0	< 15	3.13	2.55
Moderate	9.1-9.8	15-40	13.53	11.00
Severe	>9.8	>40	31.36	25.49
Total	-	-	123	100.00

Source: * Mandal *et al*. (2010).

wheat in this category of the land. The sodicity hazards were high in 'moderate' sodicity soil class and farmers grew only rice crop. Farm lands were left fallow in 'severe' sodicity soil category lands due to extremely high pH and ESP. Out of total agricultural land of 123 ha, 74.98 ha (60.96%) was under 'normal' category, 3.13 ha (2.55%) was 'slight' category, 13.53 ha (11%) was 'moderate' category and 31.36 ha (25.49%) was categorized as 'severe' soil sodicity land category based on pH and ESP (Table 2). Hence, in this village, 48.03 ha (39.04%) of agricultural land were under varying levels of degradation due to sodicity.

Soil samples were collected within a soil depth of 0 – 15 cm before application of the soil amendments in 2011-12. Another set of soil samples was collected from each plot after two years of reclamation in 2013-14. The samples were air dried and ground to pass through a <2 mm sieve. The exchangeable sodium percentage (ESP) and pH were determined following the methods outlined in the USDA Handbook No 60 (Richards, 1954). Soil samples were analyzed at the Regional Research Station, Central Soil Salinity Research Institute, Lucknow, India and crop yields were recorded after harvesting of the crops from each selected plots.

The data on land holdings were collected from the registers of village level Water Users Associations maintained with the assistance of gross root officers of Uttar Pradesh Land Development Corporation, Government of Uttar Pradesh (Anonymous, 2012). One hundred fifty farm households were surveyed. The sample households comprised of 76% of the total farm households in the village. Information on various aspects of crop production and cropping intensity were collected from the selected farm households on standardized questionnaire. The costs and returns have been estimated based on 2013-14 prices. The cost of cultivation included all expenses incurred for crop production such as human labour, machine labour, seeds, fertilizers, irrigation, plant protection measures, overhead charges and imputed value of family labour. The overhead charges included repair, maintenance and depreciation of fixed assets, interest on working capital and fixed capital and land revenue paid to the state government. Gross income included the total value of main crop and by-products. Net income was calculated as the difference between gross income and cost of production.

The farm income losses caused by sodicity were estimated by subtracting the net income per ha in each soil sodicity class from the net income of 'normal' soil class for each crop. The potential farm income losses per ha were calculated by multiplying estimated farm income loss values with corresponding proportional areas of sodicity classes. The actual farm income loss per ha in *kharif* and *rabi* seasons has been estimated by multiplying potential farm income loss with the corresponding cropping intensities.

Results and Discussion

Sodic land reclamation technology

Reclamation of sodic land requires the removal of most of the exchangeable sodium ion and its replacement by calcium ion in the root zone (Abrol *et al.,* 1988). For successful crop growth in alkali soils, the ESP of the soil must be lowered by the application of soil amendments (Chhabra, 1996). In India, gypsum is the major source of soil amendment used to reclaim alkali soils. The use of other amendments like calcium chloride, sulphuric acid, phosphogypsum, press-mud, acid wash and molasses are limited (Chhabra *et al.,* 1980). CSSRI has developed a low cost technology to reclaim the sodic soils by adding only 25% gypsum requirement (GR) value combined with 10 t ha^{-1} press-mud which is a waste product of sugar factories and recommended fertilizer doses (Swarup and Yaduvanshi, 2004). This technology not only improves the productivity of rice based cropping system but also maintains soil fertility to an optimum level. Since, the degraded area was located near a sugar mill, the combination of 10 t ha^{-1} press-mud along with gypsum (25% GR value) were used to reclaim the degraded soils of Santaraha village.

The investment on reclamation depends on the quantity of gypsum required for reclamation, which depends on the amount of exchangeable sodium to be replaced in the soil. The actual quantity of gypsum required is calculated on the basis of laboratory tests carried out on the surface soil (0-15 cm). The total investment required to reclaim one hectare sodic land was varied between Rs 45755 in 'slight' sodic category land to Rs 54530 in 'severe' sodic category land. A sizable amount of money is required to reclaim severely affected land. It also requires larger quantity of gypsum due to higher ESP. The severely degraded lands were left uncultivated for many years and more investment required for farm development activities as farmers have to clear naturally grown trees and bushes on these lands. To level the land and make suitable for cultivation, 2-3 times extra ploughing is required as compared to 'slight' and 'moderate' land categories. The investment on amendments application, irrigation and flushing of salts was highest in severely affected sodic lands. If there are no canal or tube-well irrigation facilities, an additional amount of Rs. 25000 per ha investment on tube-well is required to create irrigation facility. This indicates that a large amount of capital is required to reclaim sodic land.

The marginal and small holders may not be able to invest a huge amount of money in reclaiming soidic land due to their low investment capacity. Hence, central and state governments provide subsidies to farmers ranged from 50 per cent to 90 per cent through different land improvement, sodic land reclamation and anti-poverty programmes. After the application of amendments and leaching of salts, a standard pakage of agronomic practices recommended by CSSRI needs to be followed to make the soil free from sodicity hazard. Rice is recommended for inclusion in crop rotation. The rice–wheat–sasbania or rice–berseem crop rotation continuously for 4 to 5 years is recommended for successful reclamation of alkali soils (CSSRI, 1998).

Effect of reclamation on sodicity level

Soil samples were analyzed in pre and post-reclamation periods to know the extent of reduction in soil pH and ESP (Table 3). The values of soil pH varied from 8.9 to 10.30 and ESP values ranged from 31 to 85 in pre-reclamation period. The high pH of these soils has been attributed to the presence of carbonate which is present in the soils affected with sodium carbonate (Abrol *et al.*, 1980). The main purpose of sodic soil reclamation is to reduce their exchangeable sodium content and make the soils suitable for crop production. Results indicated that amendments improved the soil properties in two years of reclamation when compared with the pre-reclamation period. The soil pH values were reduced by 8.09%, 8.82% and 11.75% in 'slight', 'moderate' and 'severe' sodicity land categories respectively, in post-reclamation period. Similarly, compared with pre-reclamation period, addition of amendments reduced the ESP values by 25.81% to 63.53% in post-reclamation period indicating remarkable reduction in sodicity level. However, previous studies showed that complete reclamation of sodic soils takes several years depending on status of surface soil and the crops grown in post-reclamation phase (Abrol and Bhumbla, 1979; Mehta *et al.*, 1980; Chhabra, 1996).

Table 3. Impact of amendments application on sodicity

Sodicity parameters	Slight	Moderate	Severe
Pre-reclamation period (2011-12)			
pH	8.90	9.30	10.30
ESP	31	42	85
Post-reclamation period (2013-14)			
pH	8.18	8.48	9.09
ESP	23	27	31
pH reduction (%)	8.09	8.82	11.75
ESP reduction (%)	25.81	35.71	63.53

Cropping intensity

Cropping intensity shows the extent of cultivated area used for crop production out of total net area sown in a year. The average cropping intensity during 2009-2012 was 122.93 per cent (Table 4). The cropping intensity in *rabi* season was low (47.95%) in pre-reclamation period because land under 'moderate' and 'severe' categories were left fallow due to high level of sodicity. Hence, cropping intensity decreased with increase in soil sodicity levels. All uncultivated degraded lands in pre-

Table 4. Cropping intensity (%) by soil sodicity classes

Soil sodicity class	Pre-reclamation period				Post-reclamation period		
	2009-10	2010-11	2011-12	Average	2012-13	2013-14	Average
Normal	198.57	198.47	198.47	198.50	198.47	198.47	198.47
Slight	196.86	191.44	191.44	193.25	199.73	199.73	199.73
Moderate	99.96	99.96	99.96	99.96	199.93	199.93	199.93
Severe	0.00	0.00	0.00	0.00	200.00	200.00	200.00
Average in *kharif*	74.47	73.73	73.73	73.98	99.77	99.77	99.77
Average in *rabi*	49.38	48.74	48.74	48.95	99.77	99.77	99.77
Annual average	123.85	122.47	122.47	122.93	199.54	199.54	199.54

reclamation period have been put under cultivation in post-reclamation period. Hence, the cropping intensity was 199.54 per cent and increased by 62.32%. The increased cropping intensity contributed to higher total farm production and income.

Crop yield

Yield loss is detrimental at a local scale because salt-affected soils are not uniformly distributed. The degree of sodicity varied across the farms with in the village. It was observed that the salt concentration in soil has steeply reduced the crop yield (Table 5). The rice yield decreased from 4.87 t/ha in 'normal' soils to 2.95 t/ha in 'slight' soil sodicity class, indicating 39.43 per cent decline. Several studies have shown that crop yield decreases with increase in the level of sodicity (Abrol and Bhumbla, 1979; Chhabra, 2002; Dwivedi and Qadar, 2011). The yield reduction was drastic (74.95%) in 'moderate' soil sodicity class. A large number of studies indicated that the sodicity inhibits shoot and root growth of rice seedlings and had less biomass when grown under sodic conditions (Chhabra, 1996; Van Aste *et al.*, 2003; Wang *et al.*, 2011).

Wheat yield decreased from 3.65 t ha^{-1} in 'normal' soil to 2.82 t/ha in 'slight' land class, depicting 22.74 per cent yield loss (Table 5). The yield loss of wheat was greater at the higher sodicity levels (Sharma *et al.*, 2010). Yield of wheat is highly dependent on the number of spikes produced by each plant. Sodic conditions negatively affect number of spikes produced per plant (Maas and Grieve, 1990) and the fertility of the spikelets (Seifert *et al.*, 2011; Fatemeh *et al.*, 2013). Sodic soils usually have poor availability of most micronutrients, which is generally attributed to high soil pH (Naidu and Rengasamy, 1993). In addition, poor physical properties of sodic soils, which directly limit crop growth through poor seedling emergence and root growth, also exhibit indirect effects on plant nutrition by restricting water and nutrient uptake and gaseous exchange (Curtin and Naidu, 1998) which ultimately result in reduced crop yield and quality (Grattan and Grieve, 1999).

There was no wheat production in 'moderate' and 'severe' soil sodicity classes. A high pH condition damages plants directly and causes deficiencies of nutritional minerals such as iron and phosphorus (Guan *et al.*, 2009). The 'severe' category of soil sodicity class remained barren in both the seasons due to high sodicity as ESP ranged from 65 to 90 and pH varied from 9.5 to 11. Heavy salt stress generally leads to reduced growth and even plant death (Qadar, 1998; Parida and Das, 2005).

The rice-wheat rotation is most common in Indo-Gangetic plains. It was noticed that land reclamation had a profound impact on productivity of rice and wheat. Before reclamation, the productivity of rice was 2.95 t ha^{-1} in 'slight' and 1.22 ha^{-1} in 'moderate' land categories. The productivity of rice increased to 4.71 t ha^{-1} in 'slight' soil sodicity category, depicting a gain of 60%. In 'moderate' soil sodicity category, rice productivity increased to 4.40 t ha^{-1}, indicating a remarkable increase of 261%. Hence, a significant yield gain was observed in rice after land reclamation. In the 'severe' soil sodicity category, rice production was 3.90 t ha^{-1}, which was barren in pre-reclamation period.

Before reclamation, wheat production was 2.82 t ha^{-1} in 'slight' land category and increased to 3.49 t ha^{-1} in post-reclamation period. The wheat yield was 3.17 t ha^{-1} in 'moderate' and 2.75 t ha^{-1} in 'severe' land sodicity categories in post-reclamation period which were uncultivated in pre-reclamation period. It suggested that a significant yield gain was observed

Table 5. Average yield (t ha^{-1}) of rice and wheat in the different sodicity classes

Year	Soil sodicity class			
	Normal	Slight	Moderate	Severe
Rice				
Pre-reclamation period				
2009 - 2010	4.81	2.92	1.21	0
2010 - 2011	4.94	2.98	1.25	0
2011 - 2012	4.86	2.95	1.20	0
Average	4.87	2.95	1.22	0
Yield loss (%)	-	39.43	74.95	100
Post-reclamation period				
2012-2013	4.94	4.63	4.30	3.83
2013-2014	4.99	4.78	4.49	3.97
Average	4.97	4.71	4.40	3.90
Yield loss (%)	-	5.24	11.48	21.45
Mean Difference between post and pre reclamation periods	-	1.76*	3.18*	-
Wheat				
Pre-reclamation period				
2009 - 2010	3.57	2.76	0	0
2010 - 2011	3.70	2.85	0	0
2011 - 2012	3.67	2.84	0	0
Average	3.65	2.82	0	0
Yield loss (%)	-	22.74	100	100
Post-reclamation				
2012-2013	3.67	3.43	3.02	2.63
2013-2014	3.81	3.54	3.32	2.86
Average	3.74	3.49	3.17	2.75
Yield loss (%)	-	6.82	15.24	26.60
Mean Difference between post and pre reclamation periods	-	0.67*	-	-

*Significant at (p=0.05)

Note: In pre-reclamation period, the severely sodicity affected lands were left fallow in both seasons and no crop production in 'moderate' classes during *rabi* season.

after land reclamation. The yield gain was highest in 'moderate' class (3.17 t ha^{-1}) followed by 'severe' (2.75 t ha^{-1}) and 'slight' (0.67 t ha^{-1}) sodicity classes.

The rice yield losses were ranged from 39.43% to 100% in pre-reclamation period compared with normal land. The yield losses were reduced and ranged from 5.24% to 21.45% in post-reclamation period. Similarly, wheat yield losses were varied from 22.74% to 100% in pre-reclamation period. The losses were substantially reduced and ranged from 6.82% to 26.60% after reclamation.

Hence, uncultivated degraded land could be used for crop production by application of amendments. The higher crop productivity in post-reclamation period was due to better soil condition for crop production. Several studies have proved that the application of gypsum decreases Na toxicity and improves soil structures which contribute to crop productivity improvement to a greater extent (Chhabra, 1996; Rasouli *et al.,* 2013). Therefore, soil reclamation played a great role in augmenting rice and wheat yields in degraded sodic soils.

Gross and net returns

Rice (k*harif* season crop) and wheat (*rabi* season crop) production costs and returns were estimated for each sodicity class (Table 6). The gross income of rice and wheat decreased with increase in soil quality deterioration. Net income decreased more sharply compared to gross income with increase in sodicity level, because the total cost of production remained almost uniform throughout the soil sodicity classes.

The net income from 'slight' land class was lower (Rs 6769 ha^{-1}) compared to net income (Rs 35575

Table 6. Costs and returns (Rs ha^{-1}) per season

Sodicity class	Gross return		Total cost		Net returns		Total net returns
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	
Pre-reclamation period							
Normal	77290	58320	41715	34614	35575	23706	59281
Slight	47120	45032	40351	31707	6769	13324	20094
Moderate	19470	-	37597	-	-18127	-	-18127
Post-reclamation period							
Normal	79278	59740	44442	34396	34836	25344	60180
Slight	75143	55548	44366	33732	30777	21815	52592
Moderate	68958	50670	44214	33088	24743	17582	42325
Severe	62275	43558	42964	31342	19311	12216	31527

Note: 'Moderate' sodicity category lands were kept fallow only in *rabi* season. 'Severe' sodicity category lands were kept fallow in both the seasons.

ha^{-1}) from 'normal' land during *kharif* season, depicting a loss of 80.97 per cent. The farmers incurred income loss (Rs 18127 ha^{-1}) in 'moderate' soil sodicity class. In *rabi* season, decline in the net income was 43.79 per cent in 'slight' soil sodicity class and the 'moderate' sodicity affected lands were kept fallow. The rate of income loss increased with higher levels of sodicity. Hence, it was clear that the soil sodicity adversely affected net income across soil sodicity classes and income losses were greater in higher sodicity levels.

The net return was Rs 20094 ha^{-1} in 'slight' soil sodicity category in pre-reclamation period and increased to Rs 52592 ha^{-1} in post-reclamation period, indicating a gain of 161.73%. Farmers incurred a loss in 'moderate' soil sodicity category during pre-reclamation period and income has steeply increased to Rs 42325 ha^{-1} after reclamation. The increased productivity contributed to higher net income across the soil sodicity categories. In the 'severe' soil sodicity category, net income was Rs 31527 ha^{-1} which was left fallow in pre-reclamation period. It indicated that income could be generated by reclamation of severely degraded barren land. Hence, land reclamation benefited farmers in terms of reduction in income losses and enhanced farm income.

Estimation of farm income losses

Farm income losses data are essential for management of degraded lands and planning agricultural policy. Such losses can influence livelihood and food security of resource poor farmers. The farm income losses were estimated by subtracting net income per ha in each soil sodicity class from net income of 'normal' soil class for each crop. The potential farm income losses per ha has been calculated by multiplying estimated farm income loss values with corresponding proportional areas of sodicity classes in accordance with Table 2.

The actual farm income losses per ha in *kharif* and *rabi* has been estimated by multiplying potential farm income losses with the corresponding cropping intensities. The average cropping intensities in *kharif* and *rabi* were 73.98 and 48.95 per cent, respectively, accordance with the cropping intensity data of Table 4. To estimate the actual income loss per ha in pre-reclamation period, the potential income losses figures for *kharif* and *rabi* were multiplied by the factors 0.7398 and 0.4895, respectively. In post-reclamation period, factors were 0.9977 both for *kharif* and *rabi* seasons.

The total potential and actual farm income losses per agricultural year per ha has been estimated by summing up *kharif* and *rabi* seasons income loss values (Table 7). The annual potential and actual losses per ha due to sodicity were Rs 24629 and Rs 15988, respectively. The potential annual farm income loss in Santaraha village was Rs 1182800 due to soil sodicity.

The scenario has changed after reclamation. The per hectare potential income loss was reduced by 61.58% and per hectare actual income loss was reduced by 40.95%. This indicates that at the village level, community income loss was reduced due to reduction in the barren land and improved crop productivity.

Table 7. Potential and actual income (Rs ha^{-1}) in pre and post reclamation periods

Year	*Kharif*		*Rabi*		Agricultural	
	Potential income loss	Actual income loss	Potential income loss	Actual income loss	Potential income loss	Actual income loss
Pre-reclamation period						
2009-10	15851	11805	8763	4327	24614	16132
2010-11	15879	11707	8884	4330	24763	16037
2011-12	15408	11360	9102	4436	24509	15796
Average	15712	11624	8916	4364	24629	15988
Post-reclamation period						
2012-13	5248	5236	4435	4425	9683	9661
2013-14	5095	5083	4147	4137	9242	9221
Average	5172	5160	4291	4281	9463	9441

Conclusion

Land reclamation made a remarkable impact on crop productivity and farm income. The crop yield gap and income loss were substantially reduced after reclamation due to reduction in the sodicity level and land became suitable for crop production. Several efforts have been made by the Central and State governments to check soil degradation and increase agricultural productivity through land reclamation programmes in salt-affected regions of India. Still, a large part of agricultural land is being abandoned in India due to severe sodicity related problems and need to be reclaimed on priority basis to improve land productivity and farm income of resource poor farmers.

References

Abrol IP and Bhumbla DR (1979). Crop response to differential gypsum application in a highly sodic soil and tolerance of several crops to exchangeable sodium under field conditions. *Soil Science* **127(1):** 79-85.

Abrol IP, Chhabra R and Gupta RK (1980). A fresh look at the diagnostic criteria for sodic soils. In: *Proceedings of International Symposium on Salt Affected Soils*, Central Soil Salinity Research Institute, Karnal, India, pp 142-147.

Abrol IP, Yadav JSP and Massoud FI (1988). *Salt-affected soils and their management*. FAO Soils Bulletin 39. Food and Agriculture Organization of the United Nations, Rome.

Anonymous (2012). Santaraha Water User Group Register, Water Users Association, Santaraha, Hardoi district, Uttar Pradesh.

Bing-Sheng LV, Xiao-Wei Li, Hong-Yuan Ma, Yang Sun, Li-Xing Wei, Chang-Jie Jiang and Zheng-Wei L (2013). Differences in growth and physiology of rice in response to different saline-alkaline stress factors. *Agronomy Journal* **105(4):** 1119-1128.

Chhabra R (1996). *Soil Salinity and Water Quality*. Oxford and IBH Publication, New Delhi.

Chhabra R (2002). Salt-affected soils and their management for sustainable rice production-key management issues: a review. *Agriculture Review* **23(2):** 110-126.

Chhabra R, Singh A and Abrol IP (1980). Fluorine in sodic soil. *Soil Science Society of America Journal* **44:** 33-38.

CSSRI (1998). Reclamation and management of alkali soils, In: Minhas PS, Sharma, OP and Patil SG (eds) *25 Years of Research on Management of Salt-affected Soils and Use of Saline Water in Agriculture.* Central Soil Salinity Research Institute, Karnal. pp. 64-84.

Curtin D and Naidu R (1998). Fertility constraints to plant production. In: Sumner ME and Naidu R (eds) *Sodic Soil: Distribution, Management and Environmental Consequences.* Oxford University Press, New York, pp 107–123.

Dwivedi RS and Qadar A (2011). Effect of sodicity on physiological traits. In: Sharma DK, Rathore RS, Nayak AK and Mishra VK (eds) *Sustainable Management of Sodic Lands.* Central Soil Salinity Research Institute, Karnal, Haryana.

Fatemeh R, Pouya AK and Karimian N (2013). Wheat yield and physico-chemical properties of a sodic soil from semi-arid area of Iran as affected by applied gypsum. *Geoderma* **193–194:** 246-255.

Grattan SR and Grieve CM (1999). Salinity–mineral nutrient relations in horticultural crops. *Scientia Horticulturae* **78:** 127–157.

Guan B, Zhou D, Zhang H, Tian Y, Japhet W and Wang P (2009). Germination responses of *Medicago ruthenica* seeds to salinity, sodicity and temperature. *Journal of Arid Environment* **73:**135–138.

Kanwar JS, Sehgal J and Bhumbla DR (1963). Relationship between some indices of saline sodic soils. *Journal of India Society of Soil Science* **11:** 39-44.

Kolarkar AS and Singh N (1970). Diagnosis of sodic conditions in saline alkali soils of Western Rajastan. *Annals of Arid Zone* **9(1):** 31-35.

Kumar P (1998). *Food Demand and Supply Projections for India.* Agricultural Economics Policy Paper 98-01, Indian Agricultural Research Institute, New Delhi.

Kumar P, Joshi PK and Pratap SB (2009). Demand projections for food grains in India. *Agricultural Economics Research Review* **22 (2):** 237-243.

Maas EV and Grieve CM (1990). Spike and leaf development in salt-stressed wheat. *Crop Science* **30:** 1309–1313.

Mandal AK, Sharma RC, Singh G and Dagar JC (2010). *Computerized Database on Salt Affected Soils in India.* Technical bulletin 2/2010, Central Soil Salinity Research Institute, Karnal, 28p.

Mehta KK, Yadav JSP and Sharma DP (1980). Effect of gypsum on the reclamation of alkali soils and crop growth in the farmers' fields in Karnal District of Haryana. In: *International Symposium on Salt Affected Soils*, February 18-21. Central Soil Salinity Research Institute. pp. 525-531.

Naidu R and Rengasamy P (1993). Ion interactions and constraints to plant nutrition in Australian sodic soils. *Australian Journal of Soil Research* **31:** 801–819.

NRSA (1996). Mapping salt-affected soils of India on 1:250,000. National Remote Sensing Agency, Hyderabad, India.

Oster JD and Jayawardane NS (1998). Agricultural management of sodic soils. In: Sumner ME and Naidu R (eds) *Sodic Soil: Distribution, Management and Environmental Consequences.* Oxford University Press, New York, pp 126–147.

Parida AK and Das AB (2005). Salt tolerance and salinity effects on plants: A review. *Ecotoxicology Environmental Safety* **60:** 324–349.

Pessarakli M and Szabolcs I (1999). Soil salinity and sodicity as particular plant stress factors. In: Pessarakli M and Marcell Dekker (eds) *Handbook of Plant and Crop Stress.* New York, pp 3-11.

Qadar A (1998). Alleviation of sodicity stress on rice genotypes by phosphorus fertilization. *Plant and Soil* **203:** 269–277.

Qadir M and Schubert S (2002). Degradation processes and nutrient constraints in sodic soils. *Land Degradation and Development* **13:** 275–294.

Qadir M, Schubert S, Ghafoor A and Murtaza G (2001). Amelioration strategies for sodic soils: a review. *Land Degradation & Development* **12:** 357–386.

Radhakrishna R and Ravi C (1990). *Food Demand Projections for India.* Centre for Economic and Social Studies, Hyderabad, India.

Rao PS, Mishra B and Gupta SR (2013). Effects of soil salinity and sodicity on grain quality of tolerant, semi-tolerant and sensitive rice genotypes. *Rice Science* **20(4):** 284-291.

Rasouli F, Ali KP and Karimian N (2013). Wheat yield and physico-chemical properties of a sodic soil from semi-arid area of Iran as affected by applied gypsum. *Geoderma* **193–194:** 246–255.

Richards LA (1954). *Determination of the properties of saline and alkali soils.* Agriculture Handbook No 60, USDA, Washington D.C: 7-40.

Seifert C, Ivan Ortiz-Monasterio and David BL (2011). Satellite based detection of salinity and sodicity impacts on wheat production in the Mexicali Valley. *Soil Science Society of America Journal* **75(2):** 699-707.

Sharma PK, Sharma SK and Choi IY (2010). Individual and combined effects of waterlogging and sodicity on yield of wheat (*Triticum aestivum L.*) imposed at three critical stages. *Physiology and Molecular Biology of Plants* **16(3):** 317–320.

Swarup A and Yaduvanshi NPS (2004). Response of rice and wheat to organic and inorganic fertilizers and soil amendment under sodic water irrigated conditions. *International Rice Research Notes* 29.1: 49-51.

Van Aste PJA, Wopereisl MCS, Haefelel S, Quid Isselmou, M and Kropff MJ (2003). Explaining yield gaps on farmer-identified degraded and non-degraded soils in a Sahelian irrigated rice scheme. *Net Journal of Agricultural Sciences* **50(3/4):** 277-296.

Van der Zee SEATM, Shah SHH, Van Uffelen CGR, Raats PAC and Dal Ferro N (2010). Soil sodicity as a result of periodical drought. *Agricultural Water Management* **97:** 41-49.

Wang H, Wu Z, Chen Y, Yang C and Shi D (2011). Effects of salt and alkali stresses on growth and ion balance in rice (*Oryza sativa L.*). *Plant Soil and Environment* **57:** 286-294.

Yadav, JSP (1981). Reclamation and crop production in alkali soils. *Current Science* **50(9):** 387-393.

Received: February, 2015; Accepted May, 2015

Journal of Soil Salinity and Water Quality 7(1), 77-78, 2015

Short Note

Assessment of Nutrient Status of Soil from Cashew Orchard of Coastal Lateritic Soil of Konkan

JJ Palkar, NB Gokhale, KD Patil, MC Kasture, PR Parte and VD Cheke

Department of Soil Science and Agricultural Chemistry
Dr. B.S. Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri-415712, Maharashtra
Email: jjpalkar@gmail.com; kashinath_111@yahoo.com

Cashew is one of the most important commercial crops among the horticultural and plantation crops in the country. It requires minimum rainfall of 50 cm per annum but can withstand it up to 300-400 cm. It is cultivated on wide variety of soils in India, including, soils of marginal lands of coastal belts of the poor and sandy soils, fairly steep sloped lateritic and red soils. It is also found growing in saline coastal areas. In spite of the high yielding varieties of cashew the yield levels are quite low and are stagnated around 1-1.2 tones ha^{-1}. Introduction of new potential high yielding varieties have forced to have a relook at the nutrient levels in soils of the existing old orchards. Therefore, to get the status of soils of cashew orchard, the present experiment was carried out in coastal areas of Konkan region.

Representative surface soil samples (0-15 cm soil depth) were collected at three stages (viz. before fertilizer application, after fertilizer application and at harvest) for analyzing their nutrient status in cashew orchard. The soil pH and EC (in water suspension soil: water ratio 1:2) were determined using digital pH and EC meters, respectively. The organic carbon was determined by Walkley and Black (1934) method. Soil physic-chemical properties were analysed following standard methods (Jackson, 1967). The DTPA extractable micro-nutrients were determined (Lindsay and Norvell, 1978) using Atomic Absorption Spectrophotometer. The initial soil properties are shown in Table 1.

The soil was slightly acidic in reaction. The electrical conductivity showed variation at all stages, it increases after fertilizer application and declines at harvest stages. Similar results are reported by Palsande *et al.,* (2013). Organic carbon content of soil at different stages showed a slight increase up to fertilizer application stage, but it decreased at harvest stage. The N, P_2O_5, and K_2O content in cashew orchard after fertilizer application stage was found to significantly increase. The highest average mean N content *i.e.* 828 kg ha^{-1} observed after fertilizer application stage. Thereafter, decreasing trend of available N at harvest stage was observed in all the samples. The average P_2O_5 content *i.e.* 32 kg ha^{-1} was recorded after fertilizer application and decrease gradually 25 kg ha^{-1} at harvest. This can be ascribed to solubilization of soil P by organic acids produced during decomposition of FYM and due to release of P contained in it. Similar trend were observed in available K_2O content in soil and showed highest availability content after fertilizer application. Ghosh *et al*. (1986) and Aikpokpodion *et al*. (2009) also emphasized the importance of nutrients in cashew plantations. The DTPA extractable (Fe, Mn, Zn and Cu) micronutrient status of the soil at different stages showed similar maximum availability after fertilizer application and thereafter it decreases at harvest stage

Table 1. Chemical properties of the experimental field

Chemical properties	Contents
pH (1 : 2.5)	5.64
Electrical conductivity (dS m^{-1})	1.0
Organic Carbon (g kg^{-1})	19.34
Available N (kg ha^{-1})	248
Available P_2O_5 (kg ha^{-1})	7
Available K_2O (kg ha^{-1})	125
DTPA extractable Fe (mg kg^{-1})	36
DTPA extractable Mn (mg kg^{-1})	45
DTPA extractable Zn (mg kg^{-1})	0.5
DTPA extractable Cu (mg kg^{-1})	3.4

Table 2. pH, electrical conductivity, organic carbon content, available nutrients and total micro-nutrients in soil at different growth stages of cashew orchard (n= 25)

Sample	pH			Electrical conductivity EC_2 (dS m^{-1})			Organic Carbon (%)		
	BFA	AFA	At Harvest	BFA	AFA	At Harvest	BFA	AFA	At Harvest
Mean	6.2	5.4	5.0	0.1	0.3	0.2	0.8	1.3	1.5
S. Em ±	0.1	0.08	0.15	0.2	0.1	0.1	0.01	0.01	0.015
LSD (p≤0.01)	0.28	0.23	0.43	0.1	1.0	0.1	0.016	0.025	0.041

Available nutrients (N, P_2O_5 and K_2O) contents

Samples	N			P_2O_5			K_2O		
	BFA	AFA	At Harvest	BFA	AFA	At Harvest	BFA	AFA	At Harvest
Mean	494	828	176	10.0	32.0	24.7	531	689	429
S. Em ±	2.4	2.6	1.3	0.25	0.69	0.86	0.64	10.47	0.65
LSD (p≤0.01)	6.64	7.42	3.69	0.70	1.95	2.44	1.81	29.72	1.84

Total micronutrient (Fe, Mn, Zn and Cu) contents

Sample	Fe (mg kg^{-1})			Mn (mg kg^{-1})			Zn (mg kg^{-1})			Cu (mg kg^{-1})		
	BFA	AFA	At Harvest	BFA	AFA	At Harvest	BFA	AFA	At Harvest	BFA	AFA	At Harvest
Mean	49.75	63.25	50.41	38.74	22.97	49.79	0.24	0.61	0.37	3.45	3.97	2.40
S. Em ±	0.026	0.479	0.461	0.321	0.581	0.589	0.010	0.006	0.006	0.032	0.325	0.017
LSD (p≤0.01)	0.074	1.362	1.308	0.910	1.649	1.673	0.028	0.018	0.016	0.091	0.924	0.048

BFA-before fertilizer application, AFA-after fertilizer application

in all micronutrient. The details of the nutrient parameters and status of micro-nutrients are shown in Table 2. Badrinath *et al*. (1990) also studied the role of micro-nutrients in cashew plantations.

The results indicate that both major and micro-nutrients decline after application showing that these are absorbed by the trees and need to be applied at regular basis. We must analyze the soil of all the plantation orchards and apply FYM and other nutrients at regular interval to get optimum yield of cashew nut.

References

Aikpokpodion P E, Uloko B and Edibo G (2009). Nutrients dynamics in soil and cashew leaf and kernel in Kogi State, Nigeria. *J. Appl. Biosci.V.* **25**: 1573-1578.

Badrinath,, Chidanandappa HM, Ramakrishna PVR, Sudhir K and Kumar DP (1990) Distribution of DTPA, Mn in costal soil profiles of existing cashew plantation at Mangalore. *The Cashew* **4** (3): 13 -14.

Ghosh SN and Bose TK (1986). Nutritional requirement of cashew in laterite tract of West Bengal. *Indian Cashew J.* **18**: 11-17.

Jackson ML (1967) *Soil Chemical Analysis* . Asia Publishing House, New Delhi.

Lindsay WL and Norvell WA (1978) Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal* **42**: 421-428.

Palsande VN, Dabke DJ and Kasture MC (2013) Influence of foliar sprays of urea and potassium nitrated on macro and micronutrient content of cashew nut leaves in lateritic soils of Konkan. *Asian J Soil Science* **8** (2): 393-396.

Walkley A and Black IA (1934) An examination of the Digital method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37**: 29-38.

Received: December, 2014; Accepted May, 2015

Guidelines for authors for submitting manuscript for publication in the "Journal of Soil Salinity and Water Quality"

The authors are advised to follow the guidelines given in latest issue of journal for preparation of manuscript. The authors are required to submit one electronic copy in the form of CD or email (salinitysocietykarnal@gmail.com; pcsharma.knl@gmail.com) and one hard copy completed in all respects to General Secretary, Journal of Soil Salinity and Water Quality, Central Soil Salinity Research Institute, Kachhwa Road, Karnal-132001, Haryana, India. The receipt of manuscript as well as subsequent correspondences regarding the manuscript will be done electronically only.

Manuscript

- The article should be as concise as possible. All the full length papers should comprise of Short title, Title, Author(s)' name(s), Affiliations, email ID of corresponding author, Abstract, Key words, Introduction, Material and Methods, Results and Discussion, Conclusions, Acknowledgement (if any), References, Tables and Figures (if any). The text under each section should throughout have 12 fonts in MSW, Times New Roman, justified with 1.5 line spacing. However in the Abstract part, text should be 11 font with 1.5 line spacing and should not exceeds 250 words.
- The total length of article should not exceed 15 typed pages (2.5 cm. margin on each side of A4 paper) including Tables and Figures.
- All headings should be bold in capital letters with 12 fonts except Title which should be in Title Case and have 14 fonts. However, the subheadings within each section wherever necessary should be in title case bold in 14 font, further headings should be in Sentence case and bold; whereas further sub-sub titles should be bold italic. All main and subheadings should be aligned left.

Title Page

It should be a separate page and comprise of following:

Short Title : It should have a short title (not exceeding five words in italics) on the top of right hand corner.

Title : It should not exceed 15 words and should reflect the contents of paper. It should be in title case like "Alleviation of Sodicity Stress on Rice Genotypes by Phosphorous Fertilization".

Author(s) : Name of author(s) should be 12 font bold (without their official designations), aligned in center and in the title case like "AK Aggarwal and MK Tiwari".

Address : Each author's name should have number as superscript to indicate the address. The corresponding author's name should have number as superscript to indicate more than one address. The corresponding author's name should have asterisk (*) mark as superscript e.g. AK Aggarwal[*1] and MK Tiwari[2]. The address should be written in italics as shown below:

[*1] Central Soil Salinity Research Institute, Zarifa Farm, Kachhwa Road, Karnal-132001, Haryana, India

[2] Indian Institute of Soil Science, Nabibagh,, Berasia Road, Bhopal-462038, Madhya Pradesh, India.

All addresses should be complete indicating state/ province, PIN/ postal code and country etc. The email ID of corresponding author should be given after the address. The total number of pages, tables and figures of the manuscript should also be mentioned on title page.

First Page

Actual paging (on right lower corner) of the manuscript should start from this page. It should have full title of paper followed by Abstract, Keywords and Introduction, etc. To ensure anonymity of the author(s), author's names and addresses should not be indicated on this page.

Abstract : Its contents should be in 11 font, single space and single paragraph with justified alignment.

Key words : Key words should appear just after the abstract and to be written as key words (11 fonts). These may be up to 7 in alphabetic order each separated by a comma. The scientific names (if any) should be italicized. e.g.

Key words : Agroforestry model, Biodrainage, Gypsum, *Oryza sativa* L., Salt tolerance

Tables and figures

Each table and figure should have 12 font and be given on separate page after References part. Table 1 and Figure 1 should be written as **Table 1** (bold) and **Fig. 1** (bold), respectively. Table caption should appear on the top of table whereas figure caption should be just below the figure. Figures captions and matter should be legible with 8-12 font size. Maximum size of tables and figures should be such that these can be conveniently accommodated in A4 size page. Approximate position of the tables and figures should be indicated in the text of the manuscript.

References

References should be in alphabetic and chronological order and should not be serial numbered. The author(s) names should start with surname, comma after initials. If first author has two publications in a year, single author paper should appear first. Year should be bracketed. The journal names should be in full without abbreviation and should be italicized. Volume No. should be in bold. Few examples are given below:

Journal : Dagar JC, Tomar OS, Minhas PS and Kumar M (2013). Lemon grass productivity as affected by salinity of irrigation water, planting methods and fertilizer doses on a calcareous soil in a semi-arid region of northwest India. *Indian Journal of Agricultural Sciences* **83(7):** 734-738.

Book : Singh NT (2005). *Irrigation and Soil Salinity in the Indian Subcontinent- Past and Present.* Lehigh University Press, Bethlehem, USA, p 404.

Book Chapter: Tyagi NK (1998) Management of salt-affected soils. In: Singh GB and Sharma BR (eds) *50 Years of Natural Resource Management Research*. Indian Council of Agricultural Research, New Delhi, India, pp 363-401.

Online Reference: Rhoades JD, Kandiah A and Mashali AM (1992). The use of saline waters for crop production-FAO irrigation and drainage paper 48. Food and Agriculture Organization, Rome. (http://www.fao.org/docrep/t0667e00.HTM.)

Conference/Symposium Proceedings: Suarez DL and Lebron I (1993) Water quality criteria for irrigation with highly saline water. In: Lieth H and Al Masoom AA (eds) *Towards the Rational Use of High Salinity Tolerant Plants*, Vol 2-*Agriculture and Forestry under Marginal Soil Water Conditions*. Proceedings of the first ASWAS Conference (December 8-15, 1990), United Arab Emirates University Al Ain, UAE. Kluwer Academic Publishers, Dordrecht, the Netherlands, pp 389-397.

M.Sc/ Ph.D. Thesis: Ammer MHM (2004). Molecular Mapping of Salt Tolerance in Rice. Ph.D. Thesis, Indian Agricultural Research Institute, New Delhi, India.

Bulletin: Abrol IP, Dargan KS and Bhumbla DR (1973) *Reclaiming Alkali Soils*. Bulletin No. 2. Central Soil Salinity Research Institute, Karnal, 58p.

Short communication: While writing Short Communication one should focus on studies of limited scope, preliminary data, unique observations or research technique and apparatus. The length of short communication should not exceed 3 published pages. Short communication should comprise of short title, title, names with affiliations and text dealing with material and methods, results and discussion and references but there should not be any main head except of references. It should not have abstract and keywords.

Book review: These are generally invited, however, one may send critical Book Review along with one original book for consideration by editorial board.

Units to be followed

The international system of units (SI units) should be used throughout. Authors may consult Clark's Tables: Science Data Book by Orient Longman, New Delhi (1982) for guidance.

The terms like Nitrogen, Phosphorous, Potassium and Zinc may be denoted as N, P, K and Zn, respectively and dose expressed as kg ha^{-1} for field experiments. For pot studies, units like mg kg^{-1} should be followed.

Common units and symbols

time=t, metre=m, second=s, centimeter=cm, cubic centimeter=cm^3, cubic metre=m^3, degree Celsius=ÚC, day=d, gram=g, hectare= ha (10^{4}m^2), Hour=h, Kilometer=km, Kilogram=kg, litre=l, Megagram=Mg (tons to be given in Mg), Microgram=µg, Micron=µm, milimole=mmol, milliequivalent=meq, micromol=µmol, milligram=mg, milliliter=ml, minute=min, nanometer=nm, square centimeter=cm^2, square kilometer=km^2,electrical conductivity= (EC)=dS m^{-1} (deci Siemens m^{-1}), gas diffusion=g m^2 s^{-1}, water flow=m^3 m^{2}s^{-1}, ion uptake= mol kg-^{1} of dried plant material, leaf area=$m^2 kg^{-1}$, nutrient content in plants= mg g^{-1} (dry matter basis), root density or root length density= m m^{-3}, soil bulk density= g cm^{-3}, transpiration rate=mg m^2 s^{-1}, water content of soil=kg kg^{-1}, water tension=kPa, yield (grain or forage)= Mg ha^{-1}, organic carbon content of soil= percent (%), cation exchange capacity of soil= cmol (p+) kg^{-1}

Style Guidelines

All soils discussed in the manuscript should be identified according to the U.S Soil Taxonomic System at first mention. The Latin binomial or trinomial and authority must be must be shown for all plants, insects, pathogens, microorganisms and animals when first mentioned. Both the accepted common name and the chemical name of any chemicals mentioned (including pesticides) must be provided. SI units must be used throughout the manuscript. Corresponding metric or English units may be added in parentheses at the discretion of the author. For spelling, Webster's *New Collegiate Dictionary* should be used as reference. If a commonly available product is mentioned, the name and the location of manufacturer should be included in parentheses after first mention. Responsibility of the facts and opinions expressed in the articles rests entirely with the author(s) and not with the journal.

Form IV

1	Place of Publication	Karnal
2	Periodicity of its Publication	Twice in a year
3	Printer's Name	M/s Cambridge Printing Works
	Nationality	Indian
	Address	B-85, Phase - II Naraina Industrial Area New Delhi - 110 028
4	Publisher's Name	Dr PC Sharma
	Nationality	Indian
	Address	ICAR-Central Soil Salinity Research Institute Zarif Farm, Kachhwa Road Karnal – 132 001 (Haryana), India
5	Chief Editor's Name	Dr JC Dagar
	Nationality	Indian
	Address	ICAR-Central Soil Salinity Research Institute Zarif Farm, Kachhwa Road, Karnal – 132 001 (Haryana), India
6	Name and Address of Individuals, who own the Journal and Partners or share holders holding more than one percent of the total	General Secretary Indian Society of Soil Salinity and Water Quality Registered Office: ICAR-Central Soil Salinity Research Institute Zarif Farm, Kachhwa Road, Karnal – 132 001 (Haryana), India

I, Dr PC Sharma, hereby declare that the particulars given above are true to the best of my knowledge and belief.

Sd/-
PC SHARMA
General Secretary
Indian Society of Soil Salinity and Water Quality