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SALINITY–SODICITY RELATIONSHIPS OF THE KALIPATNAM DRAINAGE PILOT AREA, GODAVARI WESTERN DELTA, INDIA†

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ABSTRACT

The present study was conducted to characterize the nature of salinity, to understand the relationship between pH, EC, Ca, SAR and ESP and to develop leaching curves for the Kalipatnam drainage pilot area, India. Soils are saline sodic. A relation was developed between the ECe and EC_5 for routine soil analysis. A negative correlation was observed between pH and salinity. A regression equation was developed between SAR and ECe of the soils. Variations in soluble Ca^{2+} ion concentrations between soils were negatively related to soil pH and positively related to soil salinity. A negative relation was observed between organic carbon and ESP. Gapon's coefficient for these soils is 0.031 with a negative intercept of −0.499.

Water requirements for leaching of saline soils of the Kalipatnam drainage pilot area were estimated. An irrigation depth of 30 cm leached about 50% of salts only in clay and sandy loam soils. The plateau after 50% salt reduction can be attributed to a shallow water table (40 cm only). Empirical equations are not useful for these soil conditions for predicting desalinization pattern. Leaching curves developed based on Y and DW/DS, where $Y = \text{ECf} - \text{ECeq/ECi} - \text{ECeq}$ will give better estimates than other relations. Copyright © 2008 John Wiley & Sons, Ltd.

KEY WORDS: drainage pilot area; ECe-EC_5; pH-salinity; ESP-SAR; ESP-OC relationships; leaching curves; water requirement

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RÉSUMÉ

La présente étude a été conduite pour caractériser la nature de la salinité, pour comprendre les relations entre pH, EC, Ca, SAR et ESP et pour développer les courbes de lessivage concernant le secteur pilote de drainage, Kalipatnam, Inde. Les sols sont salin-sodiques. Une relation a été développée entre ECe et EC5 à partir des analyses de sol courantes. On a observé une corrélation négative entre le pH et la salinité. Une courbe de régression a été développée entre SAR et ECe. Les concentrations en ion Ca2+ soluble sont reliées négativement au pH et positivement à la salinité de sol. On a observé une relation négative entre le carbone organique et ESP. Le coefficient de Gapon pour ces sols est 0.031 avec une interception négative de −0.499.

Les besoins en eau pour le lessivage des sols salins du secteur pilote de drainage de Kalipatnam ont été estimés. Une quantité de l'eau de 30 cm a lessivé environ 50% de sels seulement dans les sols argilo-sableux organiques. Le plateau suivant la réduction de sel de 50% peut être attribué à la faible profondeur de la nappe (40 cm seulement). Pour ces types de sol les équations empiriques ne sont pas utiles pour prévoir les conditions de desalinisation. Les courbes de lessivage développées sont basées sur Y et DW/DS, où $Y = \text{ECf} - \text{ECeq/ECi} - \text{ECeq}$ donne de meilleures estimations que d'autres relations. Copyright © 2008 John Wiley & Sons, Ltd.

MOTS CLÉS: région pilote de drainage; CEE-EC5; relations pH-salinité; ESP-SAR; ESP-OC; courbes de lessivage; besoins en eau

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INTRODUCTION

The impact of continuous irrigation over the years has resulted in a rise of the groundwater table that in turn resulted in development of salinity and waterlogging in the commands of the Godavari Western Delta (GWD) leading to reduction in crop yields. To reclaim these soils, it is essential to know the nature of soil salinity (saline, sodic or saline sodic) and interrelations between these salinity attributes for regular drainage investigations in the drainage study area. The operational pilot area study serves as a viable solution for reclamation of salt-affected and waterlogged soils.

The operational research pilot area includes routine analysis of soil samples over longer period in the same area. For these studies it is essential to develop relations between various soil characteristics so that prediction can be used to discover the trend of parameters from the estimated parameters. In the present study attempts were made to determine the relationship of the soil reaction–salinity, ECe-EC_5, ESP-OC and ESP-SAR relations and to study the nature of their chemistry and interrelationship.

Leaching is the basic management tool for controlling salinity. The strategy is to keep the salts in solution and flush them below the root zone. The amount of water needed is referred to as the leaching requirement or leaching fraction.

The principle of desalinization is downward washing of salts at least from the upper soil layers by means of flooding and irrigation. The saline percolated water must be removed by means of a subsurface drainage system under conditions of high water table and insufficient natural drainage. The amount of irrigation water required to drain the salts depends on the initial salt content of the soil, desired level of soil salinity after leaching, soil depth to which reclamation is desired and soil characteristics. A useful rule of thumb is that a unit depth of water will remove 80% of the salts from a unit soil depth. Prediction models, though used to estimate the water requirement for one-time leaching, are useful only to a limited extent. However, for more reliable estimates, it is desirable to conduct salt leaching tests on a limited area and prepare leaching curves before installation of any subsurface drainage system. Leaching curves relate the ratio of actual salt content to initial salt content in the soil (ECo/ECi) to the depth of leaching water per unit depth of soil.

Hence, an attempt has been made to estimate the leaching requirement by different methods and to develop leaching curves for soils of the Kalipatnam drainage pilot area, to assess the nature of, and develop leaching curves for, salt-affected and waterlogged soils of the Kalipatnam operational drainage pilot area, Godavari Western Delta, India.

MATERIALS AND METHODS

Study area

Kalipatnam (16°23′ N and 81°32′ E), a typical representative salt-affected and water- logged canal command area, was selected as the operational pilot area (18 ha) to adopt suitable interventions for reducing the salinity problem and thereby improving crop yields.

The Kalipatnam pilot area is located in the West Godavari district of Andhra Pradesh (Figure 1). The elevation ranges from 0.3 to 0.6 m above MSL (mean sea level). The mean annual rainfall of the pilot area is 1200 mm while the evaporation is 1400 mm. Paddy–paddy–fallow is the major cropping system followed by aqua–paddy–fallow. The Kalipatnam pilot area is located adjoining the Upputeru (salt stream) that carries the excess water from Kolleru Lake to the Bay of Bengal. Seepage from Upputeru, the shallow groundwater table (Figure 2) and poor drainage are the main reasons for soil salinity.

In the Kalipatnam pilot area, soil salinity and waterlogging are the major problems in the *kharif* and *rabi* seasons. In the summer season because of high temperatures salts from lower depths are deposited on the surface soil, which hampers the establishment of transplanted rice seedlings in the following *kharif* season. During the *rabi* season, the crops are affected due to less availability of irrigation water resulting in low crop yields during the flowering to grain- filling stage.

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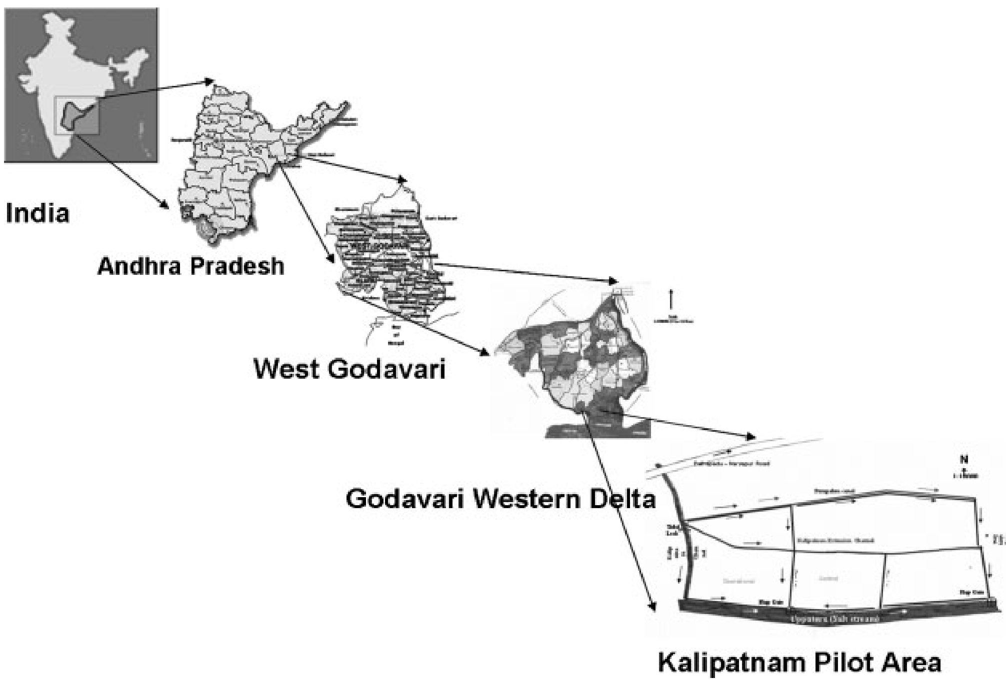

Figure 1. Location map of the pilot area, Kalipatnam drainage pilot area

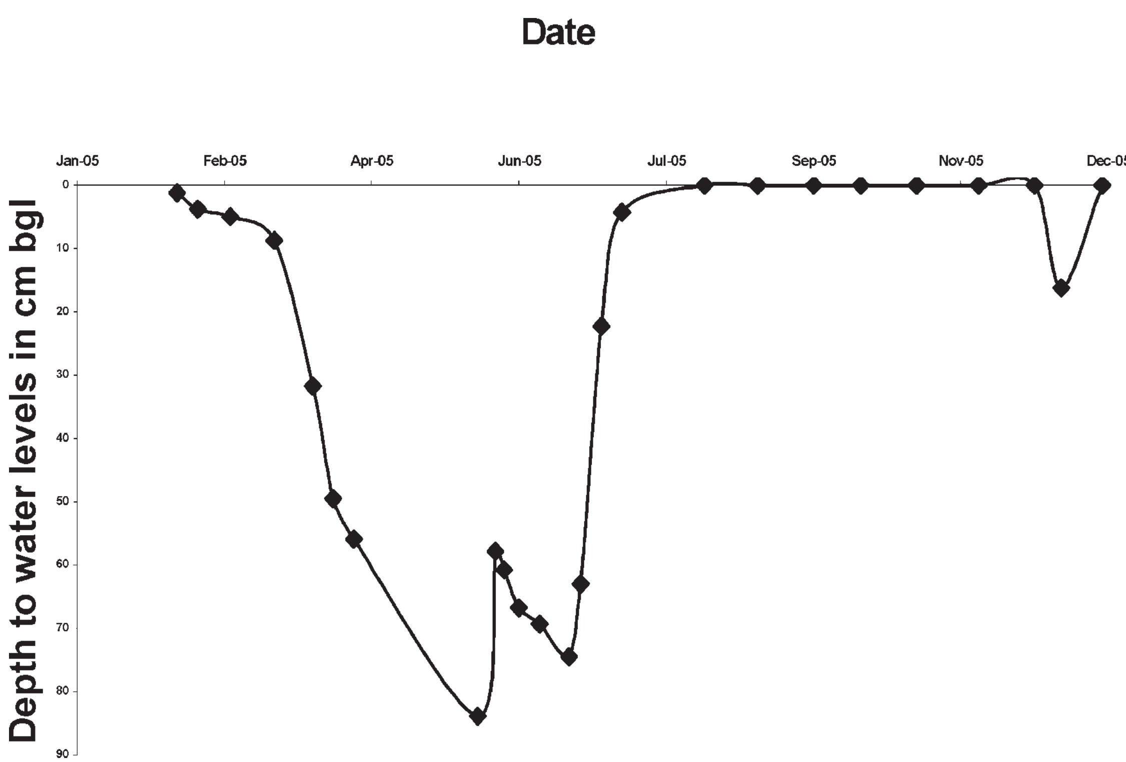

Figure 2. Depth to water levels in pilot area

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Soil sampling and preparations

Fifty-two surface soil samples (0–15 cm) were collected during summer 2004 from different locations. All samples were air dried at 25°C and passed through a 2 mm sieve and analysed for physicochemical and chemical properties (Table I).

Soil pH and EC_5 determination

Soil pH was determined for each sample in distilled water (pHwa) at a soil/solution ratio of 1: 5 (w/v) and shaken manually every 10 min for 30 min. Values of pH and EC (dS m^{-1}) were recorded using a glass electrode and conductivity bridge respectively after 1 min of stirring at room temperature (25 ± 2°C). The meter was recalibrated, if necessary, to ensure accuracy.

Determination of ECe, soluble cations and sodium adsorption ratio (SAR)

Soil salinity was assessed by measuring the electrical conductivities in saturated paste extracts (ECe). After adding distilled water and mixing, saturated soil pastes were left for 1 h to stand and then filtered under vacuum. Measurement of EC (dS m^{-1}) in the saturated extracts was performed by using a calibrated conductivity bridge.

Concentrations of Na^+ and K^+ in saturated paste extracts were measured by using a flame photometer. Ca^{2+} and Mg^{2+} in saturated paste extracts were measured by titration. The SAR for each soil sample was computed by using Miller's equation (1990):

$$\mathrm{SAR} = \mathrm{Na} + /[(\mathrm{Ca}^{++} + \mathrm{Mg}^{++})/2]^{1/2}$$

ESP values were computed by using exchangeable sodium and CEC values (Richards, 1954). Organic carbon was estimated in 0.2 mm sieved soil by Walkley and Black's (1934) rapid titration method.

Statistical analysis

Analysis of variance (ANOVA) was used to determine the significance of differences in pHwa and EC values between soils. The general linear model (GLM) procedure was used to test for least significant differences between means, and significance of regression equations.

Leaching curves development

Two locations were selected for the estimation of leaching requirements under field conditions. In the first location, soils are sandy clay loam in texture with an initial ECe of 14.1 dS m^{-1} and in the second location soil has a clay texture with ECe of 32.6 dS m^{-1}.

Table I. Physicochemical characteristics of soils of the Kalipatnam pilot area

S. No.	Parameter	Pilot area
		Range
1	pH	6.09–8.32
2	ECe (dS m^{-1})	5.90–44.80
3	Mg/Ca	0.14–4.05
4	SAR	17.18–89.18
5	ESP(%)–SAR	19.04–56.58
6	ESP(%)–CEC	38.7–70.3

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Essentially, the procedure involved the following:

- A 5×2 m main plot was chosen to carry out the experiment;
- Sub-plots of suitable size (30×30 cm) were chosen;
- A 15 cm bund around the main plot was formed to curtail seepage losses;
- In the sub-plots graded levels (i.e. 5, 10, 15, 20, 25 and 30 cm) of water was applied;
- 12 soil samples were collected from the sub- plots treated with 5, 10, 15, 20, 25 and 30 cm of water for each replication.

In the sub-plots, 5 cm depth of water was applied and leached and soil samples were collected with two replications from two locations at a depth of 0–15 cm. The process was continued for incremental additions of 5 cm for six trials. Samples were processed and analysed for EC (dS m^{-1}) in soil-saturated extract (Table II) and leaching curves were developed by plotting the percentage of salts remaining in the soil (ECo/ECi) and Ds/Dw and comparing the results with other estimates.

RESULTS AND DISCUSSION

Soil properties

Minimum and maximum values for each property measured are given in Table I for Kalipatnam pilot area soils. Soils were characterized by relatively high ECe, SAR values, ranging from 5.90 to 44.80 and 17.18 to 89.18 dS m^{-1}, respectively, suggesting that these soils are saline sodic. Spatial distribution of soil reaction (Figure 3) indicated that more than 80% of the area of soil is in the neutral range (6.5–7.5). Hence pH is not a problem for these soils at this juncture. Soil salinity distribution (Figure 4) indicated that these soils are highly saline. The sodium adsorption ratio (SAR) surfer map (Figure 5) indicated that the entire area is in the danger range (>15). Spatial distribution of exchangeable sodium (Figure 6) also followed a similar trend to that of SAR. Hence these soils are saline sodic, excess of the salts hampering the hydrolysis of sodium and hence lower pH.

Electrolyte dilution effect on salinity

Estimation of EC (dS m^{-1}) in soil-saturated extract is difficult, laborious and time consuming. For routine soil analysis EC_5 is commonly used. The FAO developed a relation between EC_5 and ECe as below (Equation 1) (FAO, 2005):

$$ECe = 8 \times EC_5 \tag{1}$$

A conversion factor for translating ECe to EC5 will depend upon the clay content of the soil and should be used with caution. Charman and Murphy (2000) quote a factor of $1/8.6 = 0.116$ for converting a clay loam ECe to EC5, $1/7.5 = 0.133$ for a light clay and $1/5.8 = 0.172$ for medium or heavy clays (Van de Graaff and Patterson, 2001).

Table II. Saturated soil extract salinity (dS m^{-1}) for incremental application of irrigation water

Depth of water applied (cm)	ECe (dS m^{-1})	
	Location 1	Location 2
0	14.1	32.6
5	11.65	26.6
10	10.7	23.9
15	10	22.6
20	9.35	20.4
25	9.25	19.6
30	9.1	16

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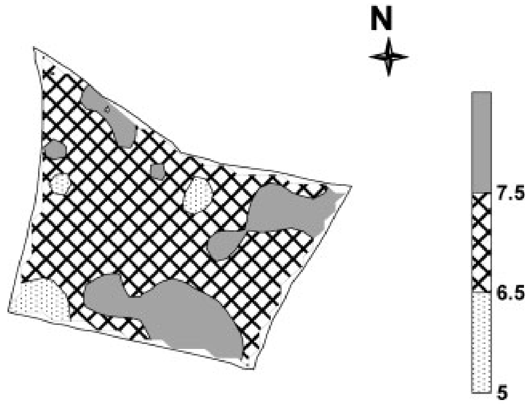

Figure 3. Soil reaction of pilot area, Kalipatnam

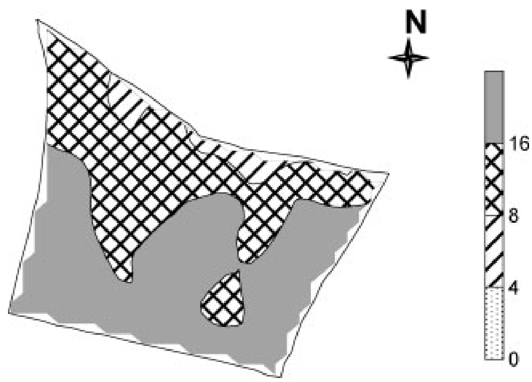

Figure 4. Soil ECe levels (dS/m) of pilot area, Kalipatnam

But for soils of the Kalipatnam pilot area with mean ECe of 15.6 dS m^{-1}, this FAO equation does not hold good, hence attempts have been made to relate EC_5 values with that of saturated soil salinity (ECe). A strong correlation was observed ($R^2 = 0.908^{**}$) between EC_5 and ECe. Hence, Equation (2) was developed between EC_5 and ECe for pilot area soils for easy conversion which gives a good prediction of ECe.

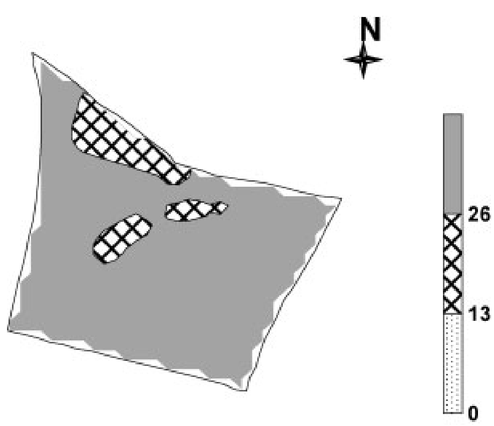

Figure 5. Soil SAR values of pilot area, Kalipatnam

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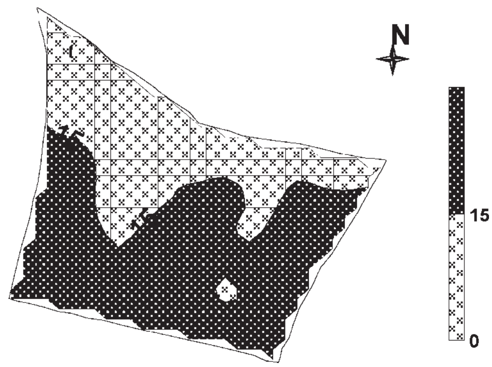

Figure 6. Soil ESP levels of pilot area, Kalipatnam

Relational equation between ECe and EC_5.

$$EC_e = 3.68EC_5 \quad (2)$$

where ECe is electrical conductivity of soil in the saturated extract and EC_5 is electrical conductivity of soil in 1:5 soil solution.

Soil salinity– pH relationship

In the present study a negative correlation was observed between the pH and saturated extract salinity of the soil (Figure 7). Soil salinity and sodicity can affect nutrient movement to plants, soil properties, and various soil chemical reactions including pH. In alkaline soils, pH usually increases with an increase in salinity due to the presence of sodium bicarbonate and carbonate (Gupta *et al*., 1989). However, Tan (1993) reported that increasing sodicity in soil does not necessarily yield a rise in pH. Many sodic soils are neutral in reaction, whereas some are even acidic in reaction. The strongly alkaline reaction (pH around 10) of most sodic soils is caused by alkalinization during which sodium carbonate and bicarbonate are formed. Under less alkaline conditions, i.e. where calcium carbonate dominates the soil mineralogy, soil pH has been shown to drop with an increase in salinity (Lai and Stewart, 1990). In the soils of Kalipatnam, high concentration of sodium chloride in the soil solution suppressed the displacement of exchangeable sodium by hydrogen and hence the lower pH was observed. Similar kinds of results were reported by Cresser *et al*. (1993). McGeorge (1935) showed that pHwa decreases with increasing concentrations of NaCl. He speculated that the pH of the soil increased as the salt concentration of the soil solution was reduced because of an increase in the hydrolysis of the sodium clay complex. Salinity increases the ionic

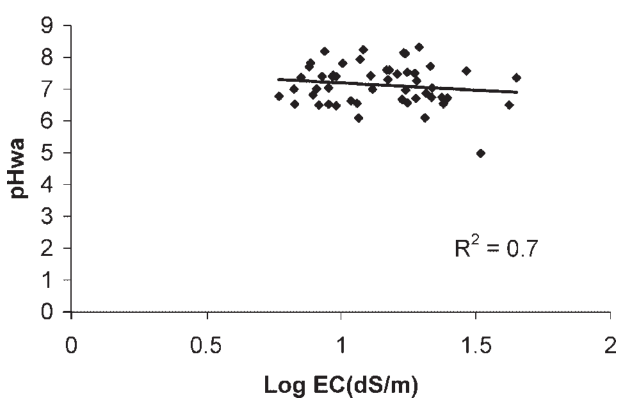

Figure 7. Relationship between soil reaction and salinity of Kalipatnam soils

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strength of the soil solution and consequently suppresses the activity coefficient of ions in solution. This would result in increasing the pH values, but increasing ionic strength mainly decreases the pH values because salinity decreases the junction potential.

The linear regression equation developed between pH and ECe is given in Equation (3):

$$\mathrm{pHwa} = 7.655 - 0.4574 \log \mathrm{ECe} \tag{3}$$

EC–SAR relation

The linear regression line fitted to SAR and EC (Figure 8) suggests that the cause of salinity in these soils was a high concentration of sodium ions. Similar results were also reported by Al-Busaidi and Cookson (2003) in calcareous soils of Oman.

The calculated regression equation between the SAR and ECe is given below (Equation 4):

$$\mathrm{SAR} = 1.06\ \mathrm{ECe} + 15.54 \tag{4}$$

ESP–SAR relationship

The linear regression was noted between ESP and SAR. Gapon's coefficient for these soils is 0.031 with a negative intercept of −0.4995. This high Gapon's coefficient indicates the possible tendency to alkalization. Once these soils are leached with a good quality of water, then sodium will come into the picture and pH will rise. These results are in agreement with the findings of Harron *et al*. (1983).

ESP-OC relationship

A negative relation was observed between soil organic carbon (OC) and exchangeable sodium percentage (ESP) of the soil (Figure 9). There is consensus in the sodicity literature that soils high in ESP may suppress organic matter production, resulting in low soil organic carbon contents from the reduced plant growth and biological activity (Nelson and Oades, 1998). These results serve as evidence that application of organic matter to these soils will reduce the sodification.

The regression equation developed is given below (Equation 5):

$$\mathrm{OC} = 1.89 - 0.042\ \mathrm{ESP} \tag{5}$$

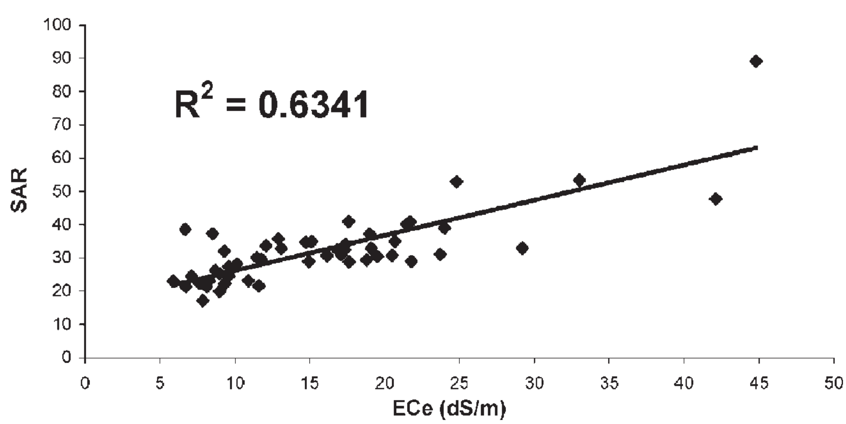

Figure 8. Relation between ECe and SAR of the soils of Kalipatnam pilot area

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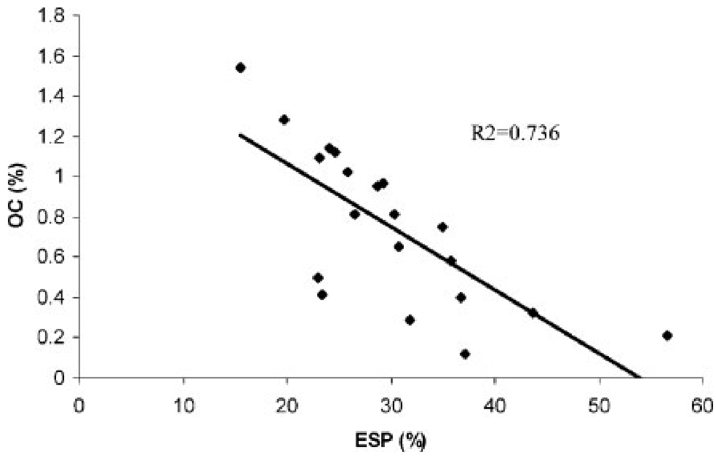

Figure 9. Relation between ESP (estimated) and OC (%) for the soils of the Kalipatnam pilot area

Leaching curves

The quantity of salts removed per unit quantity of water leached can be appreciably increased by leaching the soil at low moisture conditions, i.e. under unsaturated conditions. Moreover, use of leaching curves will enable us to arrange the various steps of accurate planning in relation to reclamation water requirements as well as the time needed for completion of reclamation procedures.

Soil saturated extract salinity levels (ECe, dS m^{-1}) for each incremental addition of water (5 cm, Dw) for top 15 cm soil depth (Ds = 15 cm) are reported in Table II. As expected, addition of water decreases the soil salinity levels in both locations. In location 1, soil is medium in soil texture (sandy clay loam) and lower in salinity (14.1 dS m^{-1}) than in location 2 (clay texture, ECe = 32.6 dS m^{-1}). Hence, with application of 30 cm of water, amount of salts leached should be more in location 1 than location 2.

Leaching curves (Figure 10) were developed by plotting the amount of salts retained to the amount of water applied as studied by Dieleman (1963). This graph will not give information about the depth of soil under study, which is the important parameter for development of leaching curves. Therefore, attempts were made to plot the relation between the fraction of salts retained and the depth of water per unit depth of soil (Dw/Ds) (Figure 11) as given by Reeve (1957). Though this graph gives more information for the leaching pattern, final salts leached in location 1 are still lower than in location 2.

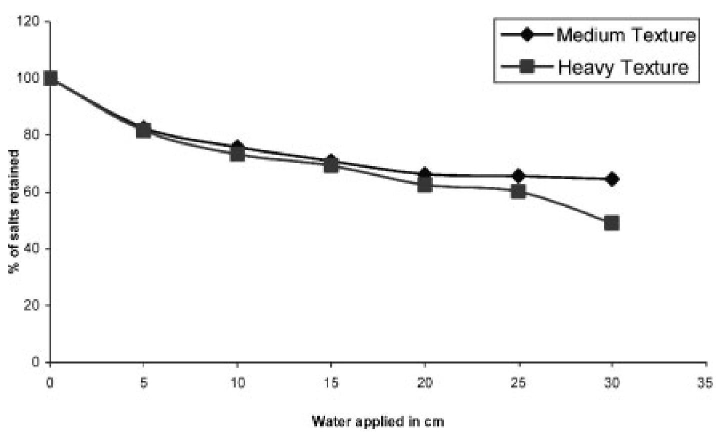

Figure 10. Graph between the percentage of salts retained and depth of water applied

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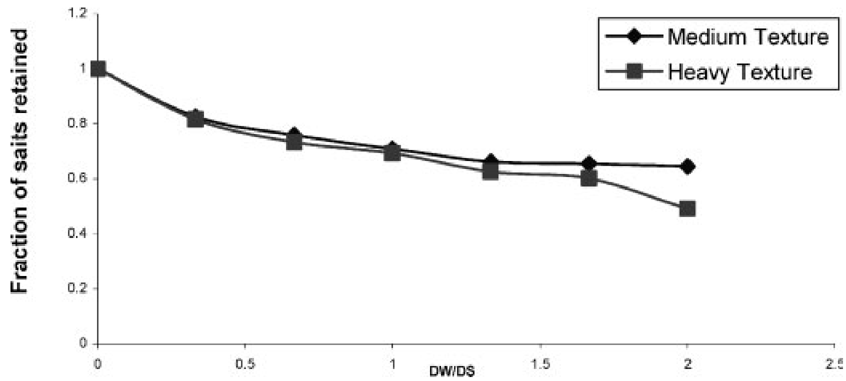

Figure 11. Graph between percentage of salts retained and depth of water applied for unit depth of soil (Dw/Ds)

Therefore, curves were plotted between Y and DW/DS, where (Leffelaar and Sharma, 1977)

$$Y = ECf - ECeq/ECi - ECeq$$

where ECf is the electrolytic conductivity after addition of water, ECi the initial soil salinity and ECeq the desired soil salinity level.

As these soils are under cultivation of rice crop, $4\,dS\,m^{-1}$ was selected as ECeq as per FAO (2005) guidelines. In these leaching curves (Figure 12), location 1 retained lower salts when compared to location 2. Thus these curves give a better estimate of the desalinization pattern of the soils and are independent of salinity of leaching or irrigation water, existing drainage and evaporation conditions.

This lower percentage of fraction of salts leached can be attributed to a higher water table (Figure 2) and evaporative demand higher than precipitation (Figure 13). Though the continuous flooding shows lower leaching efficiency than the sprinkler or intermittent ponding, ponding is inevitable. During the summer fallow period, capillary rise of saline groundwater (Table III) or sea water intrusion through the salt stream (Upputeru) will be there, and proper leaching with copious water for flushing of salts from the soil is recommended in the leaching programme.

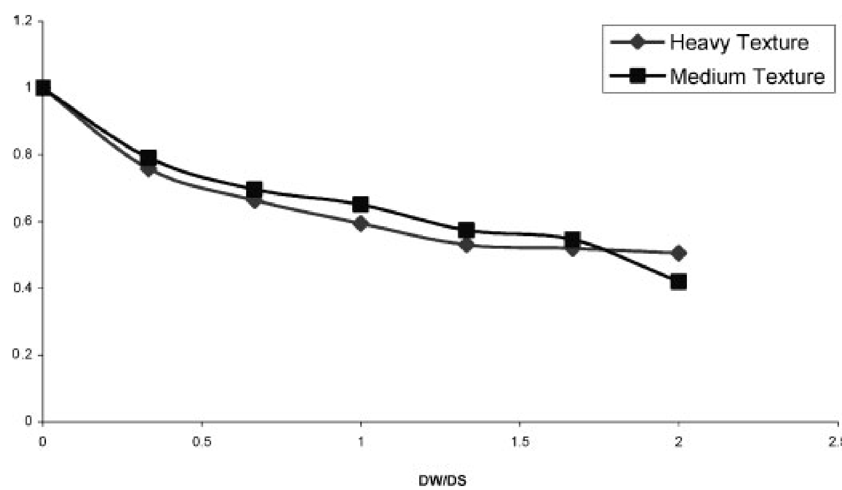

Figure 12. Graph between Y (ECf − ECeq/Eci − ECeq) and depth of water applied for unit depth of soil (Dw/Ds)

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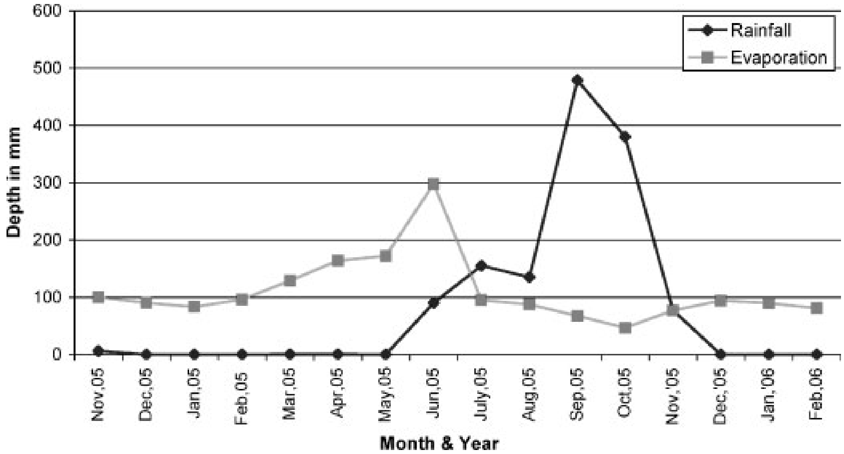

Figure 13. Monthly rainfall and evaporation (mm) of Kalipatnam drainage pilot area

Table III. Groundwater quality of the pilot area, Kalipatnam

S.No	Sample	EC ($dS\ m^{-1}$)	Ca ($me\ l^{-1}$)	Mg ($me\ l^{-1}$)	Ca + Mg ($me\ l^{-1}$)	Mg/Ca	Na ($meq\ l^{-1}$)	SAR	CO_3^{-2} ($meq\ l^{-1}$)	HCO_3^- ($meq\ l^{-1}$)	Cl ($meq\ l^{-1}$)
1	OW_1	27.1	15	110	125	7.33	32.60	4.12	0	10	340
2	OW_3	11.54	12	25	37	2.08	27.16	6.32	0	7	130
3	OW_5	28.2	10	85	95	8.50	27.16	3.94	2	14	370
4	OW_7	12.64	12	35	47	2.92	35.31	7.28	0	6	140
5	OW_9	5.12	4.5	13.5	18	3.00	9.05	3.02	0	5	60
6	OW_{11}	28.5	8.5	69.5	78	8.18	19.01	3.04	2	20	400
7	Upputeru	4.52	7.5	12.5	20	1.67	6.34	2.00	0	7	60

*OW = Observation well to monitor the water quality and water table depth.

From the leaching curves it is evident that in soils where poor groundwater is present at shallow depth (<60 cm) this restricts the complete removal of salts from the soil profile. Subsurface drainage system installation with a design discharge of 1 mm day^{-1} was recommended.

CONCLUSIONS

Kalipatnam drainage pilot area soils are saline sodic in nature. A linear relation was observed between soil EC_5 and ECe. The developed relation equations can be used for routine prediction of salinity in the saturated extract with EC_5 values. The linear regression equation between SAR and ECe indicates that sodium is the major cation contributing to salinity. Excess concentration of sodium chloride present in the soil solution might contribute to lower pH values. The high Gapon's coefficient (0.031) of these soils indicates the possible tendency of alkalization of the soil, once the salts are leached from the soil solution. The negative relation between organic carbon and ESP indicates possible low organic carbon content of saline sodic soils.

This lower percentage of fraction of salts leached can be attributed to the higher water table and evaporative demand higher than precipitation. Though the continous flooding shows lower leaching efficiency than the sprinkler or intermittent ponding, ponding is inevitable. During the summer fallow period, capillary rise of saline groundwater or sea water intrusion through the salt stream (Upputeru) will be inevitable, and proper leaching with copious water for flushing of salts from the soil is recommended in the leaching programme.

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