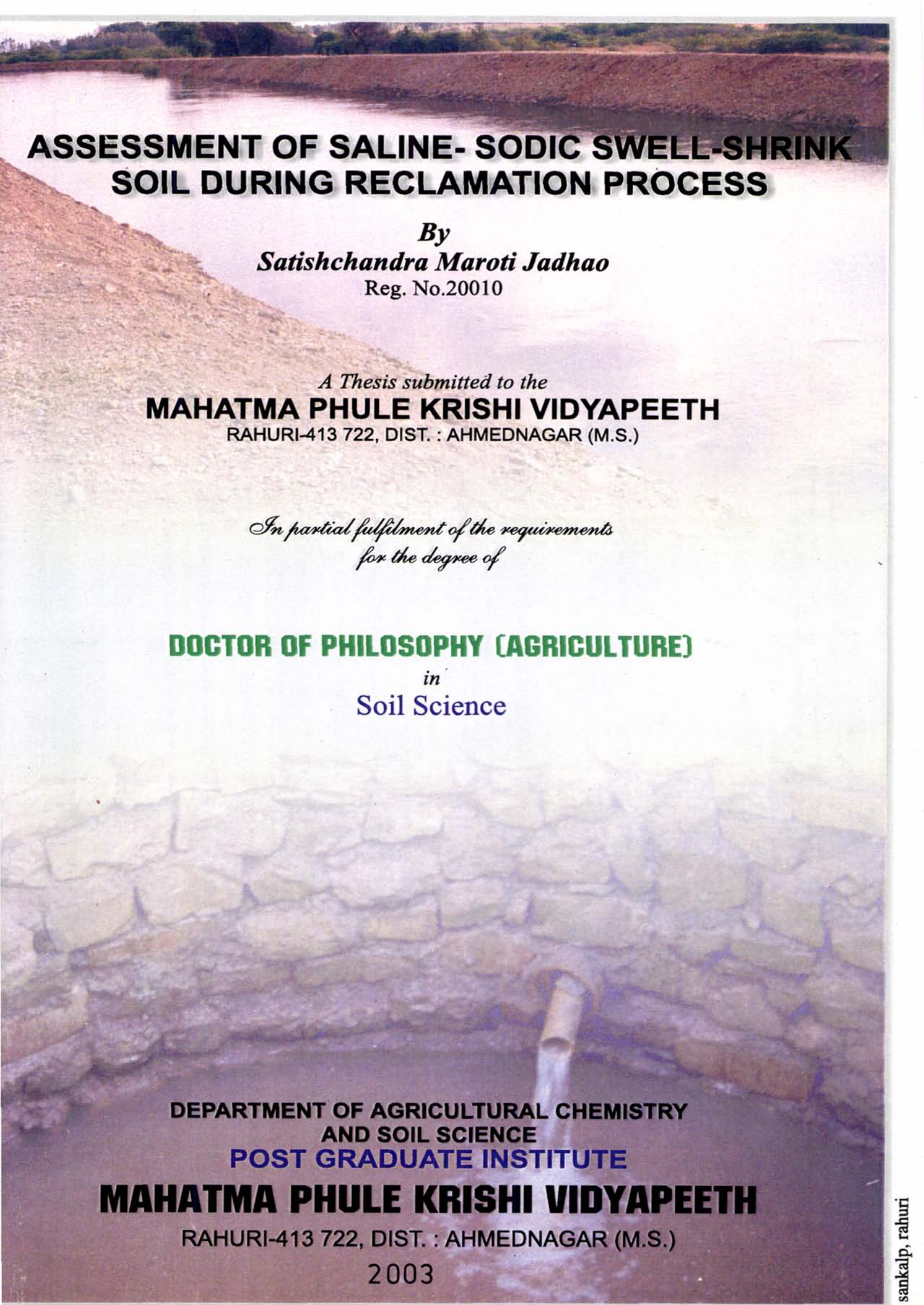




ASSESSMENT OF SALINE- SODIC SWELL-SHRINK SOIL DURING RECLAMATION PROCESS

By
Satishchandra Maroti Jadhao
Reg. No.20010

A Thesis submitted to the
MAHATMA PHULE KRISHI VIDYAPEETH
RAHURI-413 722, DIST. : AHMEDNAGAR (M.S.)

*In partial fulfilment of the requirements
for the degree of*

DOCTOR OF PHILOSOPHY (AGRICULTURE)

in
Soil Science

DEPARTMENT OF AGRICULTURAL CHEMISTRY
AND SOIL SCIENCE
POST GRADUATE INSTITUTE
MAHATMA PHULE KRISHI VIDYAPEETH
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2003

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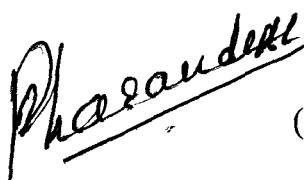
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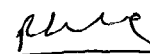
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MAHATMA PHULE KRISHI VIDYAPEETH,
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MAHARASHTRA, INDIA**

2003

CANDIDATE'S DECLARATION

*I hereby declare that this thesis or part
thereof has not been submitted
by me or other person to any
other University or Institute
for a Degree or
Diploma*

Place : MPKV, Rahuri


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Dated : 25/ 6 /2003.

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This is to certify that the thesis entitled, "**ASSESSMENT OF SALINE-SODIC SWELL-SHRINK SOIL DURING RECLAMATION PROCESS**", submitted to the Mahatma Phule Krishi Vidyapeeth, Rahuri for the award of the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE)** in **SOIL SCIENCE**, embodies the results of a *bona fide* research carried out by **Mr. SATISHCHANDRA MAROTI JADHAO**, under my guidance and supervision and that no part of the thesis has been submitted for any other Degree or Diploma.

The assistance and help received during the course of this investigation have been acknowledged.

Place : MPKV, Rahuri

Dated : 25 / 06 / 2003.


(A.S. Patil)

Research Guide

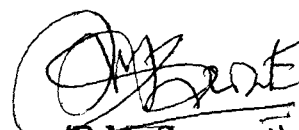
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Place : MPKV, Rahuri

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(S.M. Jadhao)

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ABBREVIATIONS

@	: At the rate of
C mol	: Centimole
C.V.	: Coefficient of variation
CD	: Critical difference
cm	: Centimetre
dSm ⁻¹	: Deci Siemen per meter
ECe	: Electrical conductivity of saturation paste extract
ESP	: Exchangeable sodium per cent
ESR	: Exchangeable sodium ratio
FeS ₂	: Iron pyrite
g	: gram
G.R.	: Gypsum requirement
h	: hours
ha	: hectare
K _G	: Gapon selectivity constant
kg	: kilogram
K _{KDO}	: Krishnamoorthy, Davis and Overstead selectivity constant
Kpa	: Kilo Pascal (s)
K _V	: Venselow selectivity constant
L	: Litre
M ha	: Million hectare
m	: meter
Mg	: Mega gram
mg	: milligram
pH _e	: pH saturation paste
PMC	: Press mud compost
ppm	: parts per million
θ	: Water content
SAR	: Sodium adsorption ratio
t	: ton
TEC	: Total Electrolyte concentration
viz.,	: namely
Yan	: anion exclusion

ABSTRACT

ASSESSMENT OF SALINE-SODIC SWELL-SHRINK SOIL DURING RECLAMATION PROCESS

By

JADHAO SATISHCHANDRA MAROTI

Mahatma Phule Krishi Vidyapeeth,

Rahuri - 413 722

2003

Research Guide : Dr. A.S. Patil

Department : Agril. Chemistry and Soil Science

In the present study on "Assessment of saline sodic swell-shrink soil during reclamation process" a field experiment was conducted over 8.1 ha area at Central Research Station B-block Mahatma Phule Krishi Vidyapeeth, Rahuri where sub-surface drainage system were installed. A column study and pot culture experiment was conducted at Department of Agricultural Chemistry and Soil Science with the objectives.

1. To assess saline-sodic soil with respect to time and space.
2. To assess the quality of drainage water periodically under reclamation process.
3. To study the leaching behaviour of saline sodic soil.
4. To study the predictive approaches for sodicity appraisal.
5. To study the influence of saline sodic soil with different amendments on growth and yield of wheat.

Abstract contd.....**Jadhao S.M.**

In the field experiment five representative soil pedons were selected and the depthwise (0-30, 30-60 and 60-90 cm) soil samples were collected for analysis and based on the data the saline sodic soil were classified as Vertic Halaquept and tentatively identified at soil series as Phule-3. The grid samples from 50 m x 50 m grid point were collected from 8.1 ha area at an interval of four months upto one year and analysed it for E_{Ce}, Na⁺, SAR, ESP and soil bulk density, from which variogram was computed and descriptive statistics indicated the large within site variability except bulk density.

In order to study the effect of subsurface drainage on soil properties, the soil samples from study area were collected with respect to drain spacing and depth at an interval of four months and analysed for various salinity parameters viz., pH_s, E_{Ce}, Ca²⁺, Mg²⁺, Na⁺, K⁺, Cl⁻, CO₃⁻, HCO₃⁻, SO₄²⁻ which showed that the 15 m drain spacing and 120 cm drain depth found better in improving the saline-sodic swell-shrink soil.

From each drainage chamber water samples were collected at an interval of one month for one year and analysed for assessment of quality. It showed that the removal of salts and ions was recorded maximum with decreasing drain spacing from 60 m to 15 m and increasing drain depths (60 to 90 cm). The removal was

Abstract contd.....

Jadhao S.M.

more from July 2001 to January 2002 and decreased thereafter indicating opening and closing of canal.

In a column study experiment layerwise soil samples were filled in a column as simulated in the field and saturated it. After saturation allowed it to leach by keeping 15 cm constant head with different amendments viz., FYM (93.74 g/column), FeS_2 (46.87 g/column), PMC (46.87 g/column), sulphur (3.73 g/column), FeS_2 + PMC (46.87 + 46.87 g/column) and sulphur + PMC (3.73 + 46.87 g/column) for 120 days and observed that the sulphur found better in removing salts from soil through leachate and improving the soil properties.

In order to study the predictive approaches for sodicity, synthetic water was prepared having TEC 5, 10, 20 and 50 meL^{-1} and SAR, 2.5, 5, 10, 15, 20 and $30 \text{ mmol}^{1/2} \text{L}^{-1/2}$. The soils were equilibrated with these combinations of water and recorded that, predictive approaches for sodicity, SAR of equilibrium solution decreased as compared to that of equilibrating solution and more so in waters of low salt concentration and high SAR. Increase in TEC and SAR eq resulted in increase in exchangeable sodium per cent in soils and it increased with depth. A linear relationship between SAR and SAReq solution was observed. K_g , K_v and K_{kdo} decreases with TEC of solution and

Abstract contd.....**Jadhao S.M.**

increased with depth on the basis of C.V. per cent K_g can give fair idea of sodicity than K_v and K_{kdo} .

In a pot culture experiment with wheat as a test crop, the 40 kg soil collected from study area was filled in a pot with FYM (178.50 g/pot), FeS_2 (89.28 g/pot), PMC (89.28 g/pot), sulphur (7.12 g/pot), FeS_2 + PMC (89.28 + 89.28 g/pot) and sulphur + PMC (7.12 + 89.28 g/pot) as an amendments and observed that the FYM found better for improving the grain, straw yield of wheat and available N, P, K, Zn and Cu under saline-sodic conditions followed by PMC, whereas available Fe was highest with FeS_2 . The uptake of N, P, K, Zn and Cu was highest with FYM and PMC. Whereas uptake of Fe was recorded highest with iron pyrites treated pots.

Pages 1 to 216

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Chapter Opener Page



INTRODUCTION

1. INTRODUCTION

(Soil salinity/sodicity is one of the most serious forms of land degradation affecting approximately 10 per cent of the total land surface of the globe). The problem occurs in varying intensities in more than 120 countries and is more prominently witnessed in the arid and semi-arid areas (Yadav, 1993).

Salt affected soils consists of saline, saline-sodic and sodic soils. Millions of hectares (955 M ha) of land throughout the world is affected by salinity and sodicity and this area is increasing year after year because of salt accumulation (Lal *et al.*, 1993). In India these soils occupy an area about 12 Mha (Sharma and Gupta, 1986). In Maharashtra about 0.54 M ha of swell-shrink soils are initially reported to be salt affected (Abhange *et al.*, 1986) which has been increased to 1.06 M ha (3.4 %) of the total geographical area (Gaikwad and Challa, 1996).

In semi-arid and arid regions, irrigation induced problems of water logging, secondary salinization and sodification go hand-in-hand. These problems posing a great threat to the sustainable productivity. Nearly 10-12 per cent of swell-shrink soils under command of Mula, Pravara, Godavari, ~~Godavari~~, Girna, Purna, Jayakwadi, Nira, Krishna, Mutha and several such major and minor irrigation projects have turned into saline and sodic (Varade *et al.*, 1985).

The introduction of canal irrigation and seepage resulted in rise of water table to the crucial 1 to 1.5 m depth in large areas.

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Every rise of water table is accompanied by an increase in the mineralization and dissolution of salts from the upper salt rich horizons which are ultimately drawn upto the surface by evaporation. Under perennial irrigation, some soils developed salt problems according to the nature and concentration of various salts particularly the chlorides, sulphates and bicarbonates of sodium (Zende and Hapse, 1985).

In the different irrigation commands of Maharashtra state, it is reported that 48 to 68 per cent area have water table within three meter (Zende, 1968) and about 37 thousand hectares are salt affected which is concentrated in the command areas, where high water demanding sugarcane cultivation is being practiced. Introduction of canal irrigation in this area proved beneficial for few decades, it has showed problems of drainability and soil degradation. The ground water table in this area has been rising steadily and thereby bringing the dissolved salts to the surface especially in areas with low topography. These soils having high swell-shrink potential and poor drainability (Sehgal, 1995).

The major causes of formation of salt affected vertisols under command areas are excessive and unscientific irrigation water management, aridity of the climate, unlined canals on elevated lands, canal and leakage contributing to rise of ground water, poor permeability of swell-shrink soil profile and chocking of natural drains (Abhange, 1986).

The study area comes under Mula (right) canal command area consist of typical deep vertisols having swell-shrink properties.

Because of high clay content, these soils pose serious problem of drainage. Hence in order to study periodical changes in soil characteristics and quality of drainage water the present investigation was taken up to reclaim the saline-sodic swell-shrink soil with sub-surface drainage and a column study were conducted in laboratory to study the leaching behaviour of these soil with different amendments. An equilibration study was undertaken for testing the predictive approaches for sodicity appraisal and a pot culture experiment was also conducted with different amendments, wheat as a test crop.

Hence with this view the present research work was undertaken with the following objectives.

1. To assess saline-sodic soil with respect to time and space.
2. To assess the quality of drainage water periodically under reclamation process.
3. To study the leaching behaviour of saline sodic soil.
4. To study the predictive approaches for sodicity appraisal.
5. To study the influence of saline sodic soil with different amendments on growth and yield of wheat.

Chapter Opener Page



**REVIEW OF
LITERATURE**

2. REVIEW OF LITERATURE

The most widely used criteria for assessment of saline-sodic swell-shrink soil during reclamation process was the one evolved by United State Salinity Laboratory (Richard, 1958), where in on the basis of pH_e , EC_e and ESP the soils are classified as saline, saline-sodic and sodic. In India these soils are mainly confined to the arid and semiarid regions. In Maharashtra with the introduction of canal irrigation and seepage resulted the development of salt affected soils. The pertinent literature on these soils were reviewed and presented under the appropriate sub-heads.

- 2.1 Occurrence and distribution
- 2.2 Factors responsible for the formation
- 2.3 Characterization of salt affected soils
- 2.4 Properties of salt affected soils
- 2.5 Spatial variability
- 2.6 Effect of subsurface drainage on soil properties
- 2.7 Effect of subsurface drainage on quality of drainage water
- 2.8 Leaching behaviour of soils under column
- 2.9 Predictive approaches for sodicity
- 2.10 Reclamation measures and its effect on growth and yield of wheat

2.1 Occurrence and distribution

Salt affected soils consist of saline, saline-sodic and sodic soils. Millions hectares (about 955 M ha) of land throughout the

world are affected by salinity and sodicity and these are increasing year after year because of salt accumulation (Lal *et al.* 1993). In India these soils occupy an area of about 12 M ha (Sharma and Gupta, 1986), out of which 4 M ha are spread over Indo-Gangetic alluvial plain (Uttar Pradesh, Bihar, Delhi, Punjab, Haryana) and rest in part of Madhya Pradesh, Gujrat, Rajasthan, Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu (Gupta and Gupta, 1987).

In Maharashtra State 0.54 M ha of black soils were initially reported to be salt affected (Abhange *et al.*, 1986) which had been increased to 1.06 M ha, which extended to 3.4 per cent of the total geographical area (Gaikwad and Challa, 1996). In the Purna command area of Maharashtra, the per cent of saline, saline-sodic and sodic soils were 22.9, 14.5 and 33.3, respectively (More *et al.*, 1987). Varade *et al.* (1985) reported that approximately 10 per cent of the irrigable vertisols area in each irrigation project of Maharashtra state is adversely affected due to salt and water logging problems.

Somawanshi and Patil (1986) reported that the introduction of Mula canal irrigation in 1972 had turned normal soils of Central Research Farm, M.P.K.V., Rahuri to highly saline to the extent of 75 per cent. These land went out of cultivation within a period of 4 years in the absence of artificial drainage.

Yadav *et al.* (1993) reported that the soil salinity/ sodicity is one of the most serious forms of land degradation affecting approximately 10 per cent of the total land surface of the globe. The problem occurred in varying intensities in more than 120 countries and was more prominently witnessed in the arid and semiarid areas.

Challa *et al.* (1995) reported that the chemical deterioration is the deterioration of land through development of salinity and alkalinity in Maharashtra which are mainly restricted to the command areas under major and minor irrigation projects and in the alluvial plains of Krishna, Mula, Nira, Pravara, Purna and Godavari rivers where water is used indiscriminately for irrigation during cultivation of crop throughout the year either through canal or through lift irrigation.

2.2 Factors responsible for the formation

Agarwal *et al.* (1982) pointed out the combination of factors like geological, climatic and hydrologic in nature which were responsible for formation of alkali soils. They observed that alkali soils occupy concave soil scape position led to the belief that alternating wet and dry cycles seem to be contributing causes. During the wet period the runoff from the surrounding areas collects in the low lying areas which upon evaporation get concentrated. At higher concentration CaCO_3 precipitate resulting in gradual increase in the proportion of sodium in the soil solution and consequently in the exchange complex.

Abhange *et al.* (1986) described the major causes of formation of salt affected vertisol under Purna canal command which were 1) excess and unscientific irrigation 2) topographic situation 3) aridity of the climate 4) unlined canal above the ground, canal seepage and leakage contributing to rise of ground water 5) poor permeability of vertisol 6) use of saline ground water for irrigation and 7) Blocking of natural drains.

More *et al.* (1988) envisaged that the fast deterioration of land were due to salinity and waterlogging, cultivation of rice at higher elevation close to main canal caused rise in water table in low lying areas, thereby resulting in secondary salinization of soil. Such twin problems of waterlogging and rise in water table lead to secondary salinization and sodimization within a few years of starting a canal irrigation. Some causes were also reported by Tiwari *et al.* (1983) in central alluvial region of Uttar Pradesh.

✓Hebbara *et al.* (1992) reported that command area of Gagarati in Dharwad, monocropping of rice was a common practice irrespective of topography of land. In addition the soil being a heavy texture had problem of poor drainage and heavy irrigation may led to salinization.

✓Nimkar *et al.* (1992) studied the salinity problems in swell-shrink soil (vertisols) of Purna Valley in Amaravati district. They reported that the non irrigated soils had mild alkalinity (pH 8.5 to 8.9), very low exchangeable sodium percentage (ESP) and ECe in the sub soil horizon. Despite uniform clay content and non-sodic nature of the soils the saturated hydraulic conductivity decreased sharply with depth (5.5 to 0.3 mm hr⁻¹) and thus, led one to know how the drainage of the soils could be severely impaired due to incomplete leaching of salts. The well and river water of the area were not safe for irrigation. Continuous use of such waters would hasten the sodification process that may adversely affect the soil.

✓Balpande *et al.* (1996) concluded that the semi-arid climate is the prime factor responsible for starting the pedogenetic

process which result in the depletion of Ca^{++} ions from soil solution in the form of CaCO_3 and also in the simultaneous increase of both SAR and ESP with pedon depths in vertisols of the Purna Valley.

Reddy *et al.* (1998) reported that salinity in soils of Andhra Pradesh was because of capillary rise from sub soil containing salts due to semi-arid and arid conditions, indiscriminate use of canal water and poor quality of water for irrigation. Primary salinity was due to weathering of parent materials rich in salts.

✓ Bharambe *et al.* (2001) reported that the considerable area of fertile land under the irrigated commands had gone out of production due to the waterlogging and salt related problems. Jaiyakwadi and Purna irrigation of Maharashtra consist of typical deep vertisols. Because of high clay content and dominance of montmorillonite, these pose serious problem of drainage and the water table is rising very rapidly with indiscriminate use of water for sugarcane and other perennial crops (Bharambe *et al.*, 1992).

2.3 Characterization of salt affected soils

2.3.1 Saline soils

✓ Kearny and Schofield (1936), classified salt affected soils into five categories on the basis of percentage of soluble salts content : i) excessive salinity ($> 1.5\%$) ii) strong salinity (0.8 to 1.5 %) iii) medium salinity (0.4 to 0.8 %) iv) weak salinity (0.1 to 0.4 %) v) negligible salinity ($< 0.1\%$). Saline soils defined as the soils which contain sufficient neutral soluble salts in the root zone, which adversely affect the crop growth by osmotic and toxic effects of specific ions viz., Cl^- , B and Li (Singh *et al.*, 1995). According to

Richard (1968), saline soils are those which have E_{ce} more than 4 dSm^{-1} . Chloride and sulphate salts of sodium, calcium and magnesium are the most predominant ions in highly saline soil. Small amount of bicarbonate may occur but soluble carbonate are almost invariably absent, pH of saturation paste of saline soil is < 8.5 and $ESP < 15$ (Gupta *et al.*, 1995). ✓

The saline soils were grouped into different classes on the basis of E_{ce} : very slight 0-2, slight 2-4, moderate 4-8, strong 8-15, very strong 15-25, severe 25-50 and very severe $> 50 \text{ dSm}^{-1}$ (Sehgal *et al.*, 1987).

2.3.2 Saline-sodic soils

Agarwal and Yadav (1954) reported that the main source of soluble salts in saline-alkali soils of the Indo-Gangetic alluvial in Uttar Pradesh seems to be the weathering of minerals and subsequent transport of dissolved salts and accumulation in ground water. These soils exhibits morphological properties similar to those of saline soils but a sub soil layers are compact and indurated hard clay or kankar pan of few inches to few feet in thickness in the sub-soil, which may obstruct drainage. At places there may not be kankar pan but lime nodules of varying sizes may be present. In the presence of high concentration of soluble salts the harmful effect of exchangeable sodium remain suppressed but if the salt are leached, the properties of these soils become similar to those of non-saline alkali soils (Agarwal *et al.*, 1982).

Richard (1968) defined saline-alkali soils having E_{ce} more than 4 dSm^{-1} , ESP more than 15, pHe generally less than 8.5

after leaching of soluble salts, chloride and sulphates of sodium, magnesium and calcium were generally the main salts present, but bicarbonate and sometimes carbonate occurred in sizable quantity. Initial pH and EC measurement often indicated the saline nature. Infiltration and percolation rates, stability of soil aggregation and good physical conditions remain reminiscent of saline soils. But on salt leaching especially with water having a low degree of mineralization clay particles begins to deflocculate as the salt concentration decreases. These seals micropores and decrease hydraulic conductivity and infiltration rate (Tuncay and Okur, 1992).

Terminology Committee of the Soil Science Society of America (1974) proposed classification of saline-sodic soils as $E_{ce} > 2$ dSm^{-1} and $SAR > 15$. Varade^{et al.} (1985) recorded maximum values of pH (9.3), E_{ce} ($106 dSm^{-1}$) and ESP (90) in salt affected vertisols in canal command areas of various irrigation projects of Karnataka and Gujarat. Whereas, in Maharashtra state, these soils had E_{ce} in the range from 2 to $16 dSm^{-1}$ and ESP 15 to 40. Sagare *et al.* (1991) characterized the saline sodic soils of Purna Valley tract of Vidharbha region, which had soil pH_e in the range of 8.3 to 8.8, E_{ce} 2.25 to $3.90 dSm^{-1}$ and ESP 16 to 60.96.

2.3.3 Sodic soils

Richard (1968) characterized sodic soils as $ESP > 15$ and dominated with carbonate and bicarbonate salts of sodium and lack of neutral salts. E_{ce} of soil were $< 4 dSm^{-1}$, $pH_e > 8.5$. The dark colour of sodic soil was due to dispersion of clay and dissolution and coating

of organic matter. Generally the surface of these soils were dry and hard at field condition.

Bhargava *et al.* (1976) characterized sodic soils having sodium more than half of the soluble cations and anions were Cl^- , SO_4^{2-} and some time NO_3^- , small amount of HCO_3^- but absence of soluble CO_3^{2-} . Further they reported that in saline-sodic soils, the chief soluble salt was Na_2CO_3 which boosted soil pH caused nearly all soluble and exchangeable Ca^{2+} and Mg^{2+} got precipitated. Because of high pH and low calcium caused toxic effect of soluble carbonate such soil did not support any crop growth. Similar, observations in respect of characterization of sodic soil were also reported by Abrol and Bhumla (1978).

More *et al.* (1987) characterized sodic soils having pH in the range of 8.5 to 10.26, ECe 0.84 to 3.64 dSm^{-1} and ESP 16 to 395 Sehgal *et al.* (1987) classified alkalinity hazard classes on the basis of ESP as slight to negligible < 15 moderate 15 to 30, strong 30 to 50 and severe > 50 which were slightly modified by Patil (1986) as slight ESP 5-10, moderate 10-15, strong 15-30 and very strong 30-50. Sagare *et al.* (1991) characterized sodic soils of Purna Valley which had soil pH in the range of 8.4 to 8.9 ECe 0.91 to 1.2 dSm^{-1} , ESP 15.25 to 51.23. Padole and Deshmukh (1998), characterized sodic soils of Purna Valley as pHs in the range of 7.98 to 9.20, ECe 1.00 to 5.54 dSm^{-1} and ESP 7.91 to 29.14.

2.4 Properties of salt affected soils

Swell-Shrink soils are in general, alkaline in nature (pH 7.5 to 8.3) calcareous (1 to 20 % CaCO_3), low in organic carbon which

decrease with depth, CEC is generally high (35 to 60 cmol (P⁺) kg⁻¹) saturated with base, especially Ca²⁺ constituted to 60 to 80 per cent while Mg²⁺ constituted to the tune of 10 to 30 per cent on exchange complex. These soils are deficient in available N but have high available potassium content (Sehgal and Lal, 1988).

Sharma *et al.* (1968) described two typical salt affected soil profile, irrigated one with canal water and other with well waters in Rajasthan. The well irrigated profile showed a lower EC which ranged from 3.0 to 8.5 dSm⁻¹ at different layer as compared with the variation of 25 to 65 dSm⁻¹ in canal irrigated profile. The ESP varied from 15 to 25 in well irrigated profile as against 11 to 14 in canal irrigated soil.

Rakhunde (1980) characterised salt affected soils of seven adjoining village of Walwa taluka of Sangali district. He observed that the soil had pH ranged from 7.10 to 7.85 (saline soil), 6.8 to 10.25 (saline – alkali soil) 7.7 to 9.0 (alkali soil). ECe (dSm⁻¹) ranged from 5.20 to 56, 4 to 75 (saline – alkali) 0.44 to 3.95 (alkali), whereas ESP varied from 2 to 14.6 (saline), 15 to 79.5 (Saline-alkali) and 15 to 43 (alkali).

Mediratta *et al.* (1985) conducted a chemical analysis of salt affected soils of Harsi command area of Madhya Pradesh and reported that the pH range of Vertic Halaquept was from 7.8 to 8.9, EC 1.3 to 13.9 dSm⁻¹ and ESP 11 to 24. All these values gradually decreased in lower horizon indicating a initiation of process of salinization from the upper layers. The soluble anions were in order of Cl⁻ > SO₄²⁻ > HCO₃⁻ > CO₃²⁻, all were decreased with depth.

More *et al.* (1987) collected soil samples from Purna command and analysed saline, saline-sodic, sodic and normal soils. They recorded soil pH from 8 to 10.74. The ECe of soil varied from 0.84 to 39.20 dSm⁻¹ and chloride and sulphate were dominant anions in saturation paste extract in saline soil. The HCO₃⁻ content in sodic soil was relatively high while CO₃²⁻ content in all the soils was comparatively low. Exchangeable Na⁺ was relatively high in sodic (11.27 me 100 g⁻¹) and saline-sodic soils (9.26 me 100 g⁻¹), CEC of soil ranged from 33.6 to 4.8 me 100 g⁻¹ soil. The average ESP of saline sodic and sodic soils were 23.97 and 27.28 per cent, respectively.

Dubey and Sharma (1990) analysed saline-sodic soils of flood plain area of Gujrat state and reported that the pHs values from 7.7 to 8.9 and that of 1 : 2 soil : water suspension from 8.2 to 9.2. The ECe values in general decreased with increase in depth. The salinization of upper layer was due to aridity and resulted in accumulation and concentration of salt through capillary rise of saline water. The dominant anions were Cl⁻, SO₄²⁻ in these soils and classified these soils as fine smectite hyper thermic family.

Sagare *et al.* (1991) characterized the soils of Purna Valley of Vidarbha and found that the soils of Gandhigram, Dhaga and Macchindrakhed were saline-sodic with pHs, ECe and ESP range between 8.4 to 8.9, 0.90 to 1.20 dSm⁻¹ and 15.25 to 51.13 respectively. Values of ECe and ESP increased with increase in soil depth.

Verma *et al.* (1995) characterized salt affected soils of Awagarh and Jalesar of Etah district of Uttar Pradesh. They reported

slightly high value of Na^+ (22 meL^{-1}) and Cl^- (16 meL^{-1}) and SO_4^{2-} (13.0 meL^{-1}) in saline-alkali soil cause moderate alkalinity and moderate salinity hazards. An excess quantity of Na^+ (184 meL^{-1}) in the presence of HCO_3^- (211 meL^{-1}), SO_4^{2-} (167 meL^{-1}) and Cl^- (144 meL^{-1}) in alkali soils resulted in to very strong salinity and severe alkalinity hazard.

Surekha *et al.* (1997) studied the alkaline Konkala Vertisol soils of Andhra Pradesh and reported that the soils were fine in texture dominant in smectite, alkaline in reaction (8.2 to 9.2) contained more exchangeable sodium [1.7 to $8.0 \text{ cmol (P}^+) \text{ kg}^{-1}$] with COLE value of 0.21.

Yeresheemi *et al.* (1997) characterized the salt affected vertisols of upper Krishna commad and reported that the soils were neutral to strongly alkaline in reaction (pH 7.5 to 9.1) with ECe values of 1.0 to 6.4 dSm^{-1} . The calcium and magnesium were the major contributing exchangeable cations followed the order $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+}$ and salinity was chloride sulphate type. He also reported that the bulk density (1.38 to 1.60 Mg m^{-3}) tended to increase with depth.

Durgude (1999) conducted a survey of Central Research Farm, M.P.K.V., Rahuri for morphology, characterization, classification and mapping of salt affected soils and reported that the COLE values of saline sodic soils are in the range from 0.14 to 0.28 and it increased with depth. He also reported that the soils of B-block are fine smectic hyperthermic family and Vertic Halaquept and tentative soil series Phule-3.

2.5 Spatial variability

Vieira *et al.* (1981) measured spatial variability of 1,280 field infiltration rates on Yolo loam using geostatistical concept. The measurements were made at the nodes of an irregular grid consisting of 160 rows and eight columns. Sample spacing within column was 1 m. A variogram for the 1280 measurements was used to draw a contour map of the area. The large number of measured values made it possible to calculate the minimum number of samples necessary to reproduce the infiltration rate measurements with a fairly large approximation. As a result it could be concluded that a minimum of 128 samples were enough to obtain nearly the same information as with 1,280 samples.

Trangmar *et al.* (1987) reported that crop yields on cleared forest land of the humid tropics are often highly variable due to spatial heterogeneity of soil properties. Analysis of spatial dependence using semivariograms indicated that the variation of soil properties and crop components was generally isotropic. Directional variograms of most properties were poorly structured. Only those of organic and total N indicated any anisotropy with maximum variation occurring along a SE-NW axis. Anisotropy ratios for these two properties were not large (1.6 and 1.8) and probably indicate a weak directional component in the land clearing methods or subsequent soil management.

Miller *et al.* (1988) collected surface soil samples on 400 m x 250 m grid to determine the relationship between wheat yield and soil properties influenced by erosion and reported that

semivariograms and cross-semivariograms showed a strong spatial dependence between soil properties and wheat yield. Total above ground biomass increased from the knolls to the swales, while harvest index increased in the reverse direction. Particle size distribution varied by landscape position as a result of both mechanical and water erosion. Harvest index was shown to be positively correlated with per cent clay $< 2 \mu\text{m}$ but not correlated with per cent sand. Surface soil thickness was not found to be spatially correlated with crop growth.

Mulla (1988) collected soil samples to a depth of 12 cm at spacings of 20 m and these were analysed for sand, clay and water content. The spatial variability in each property was described using spherical semivariogram. Kriging was used to estimate spatial patterns in clay and sand content along each transect at 5 m spacings. Spherical cross semivariograms of surface temperature and water content were used along with cokriging techniques to estimate water content at 5 m spacings. The geostatistical estimates of spatial patterns in water content, clay content and sand content were used for texture based estimates of matric suction and hydraulic conductivity at 5 m spacings along both transects. A comparison of texture based and laboratory-based estimates of matric suction showed that although the two estimates gave similar spatial pattern and means they had significantly different standard deviations.

West *et al.* (1989) studied the rectangular 0.44 ha pastures in South Central Iowa and included three soils, a fine montmorillonitic, mesic *Typic Argiaquoll*, a fine loamy mixed mesic *Typic Argiudoll* and a fine montmorillonite, mesic *Aquic Argiudoll*. The

soil was sampled 0 to 75 and 75 to 150 mm on a grid pattern starting from water source and analyzed for extractable P and exchangeable K total N and organic carbon. Chemical values between grid points were interpolated by krigging and contour plots were constructed for each variable. Extractable P and exchangeable K exhibited large accumulation near the water source with P and K measurement exceeding 100 and 1000 mg kg⁻¹, respectively. The summary of geostatistics showed that although most of the semivariograms could be approximated with a linear model. Some nutrients had either a linear or quadratic drift associated with than or were geometrically anisotropic. Thus, no range or sill data are given. Nugget variances were generally higher for measurements at the 0 to 75 mm depth compared with the 75 to 150 mm depth indicating greater small scale spatial variability at the top of soil.

Grewal *et al.* (2001) measured the spatial dependence of available phosphorus (P) content of Haryana soils was measured using geostatistical technique. Four hundred and seventy soil samples at a node of 10 km x 10 km were collected all over the state. The semivariogram of P was bounded because the semivariance attained a constant value at a separation distance of about 61.5 km and well expressed by an exponential model. Thus, any two values were found to be mutually dependent within this separation distance and after that the values were spatially uncorrelated.

Nayak *et al.* (2002) collected the soil samples from 1.75 x 1.75 km of a square grid of Sardar Sarovar Canal command. The descriptive statistics of the data indicated considerable variability of

the soil salinity within site. The isotropic semi variograms of surface and sub-surface and sub-surface salinity were best fitted to spherical model which indicated that the data are having spatial structure.

2.6 Effect of subsurface drainage on soil properties

Singh (1981) conducted an experiment with four sub soil drainage systems *viz.*, sub soiling, mole drains, plastic pipes and asbestos cement pipe in a total area of 40 hectares and reported that after 2 years of installation desalinization occurred in the treatments where plastic pipe drains were installed with sub-soiling with decrease in EC 0.62 to 0.21 dSm⁻¹, pH 8.5 to 7.5, SAR 7.63 to 2.28 and SSP 86.35 to 56.22 upto 20 cm soil depth.

Hundal and Sharma (1984) evaluated the rate of subsurface drainage in reclamation of saline soil and control of secondary salinization in highly saline soil with shallow ground water table at Sampla in Rohtak district, Prior to installation of subsurface drainage the E_{Ce} in 0-15 cm depth ranged from 30 to 80 dSm⁻¹. Installation of the drains at 1.75 m depth and drain spacing of 25, 50 and 75 m resulted in appreciable reduction of salts in the surface 0 to 30 cm depth over the first monsoon season. Soil salinity in the non-drained area remained at a higher level than in the drained plot.

Suryavanshi *et al.* (1986) conducted an experiment with subsurface drainage system covering an area of 2.5 ha and evaluated with respect to water table fluctuations, hydraulic properties of soil and E_{Ce} and pH of soil. The drain spacing and depth were 60 m and 1.6 m, respectively. Subsurface drainage found effective in lowering

the water table to the depth of 75 cm for most of the time. Water table fluctuations were 45 cm to 110 cm below soil surface. Basic infiltration rate and hydraulic conductivity improved from 3 mm hr⁻¹ and 0.32 m day⁻¹ to 5 mm hr⁻¹ and 0.432 m day⁻¹, respectively. It was observed that the EC_e and pH of soil was decreased from 4.8 to 3.2 dSm⁻¹ and 8.6 to 8.0, respectively.

Buckland *et al.* (1986) studied the leaching trails for two years on two irrigated saline-sodic soils with subsurface drains installed at depths of 0.76, 1.22 and 1.68 m. At one site, after two years of leaching average salinity levels in the 0 to 20 m soil depth were reduced to 91, 88 and 74 % of original levels with drain depth of 0.76, 1.22 and 1.68 m, respectively. At the other site, where less water was applied respective salinity levels were 114, 86 and 99 per cent of original levels. Resalinization and resodification of the surface 0.2 m of soil occurred at both sites in the second year, which was a drought year and were most pronounced with drain depth of 0.76 m. Relative reduction in salinity and efficiency of leaching were the lowest for the 0.76 m depth drains at both sites.

Sadik *et al.* (1988) reported the changes in soil salinity, sodicity water table and CaCO₃ with time (3 years) soil depth (60 cm) and location in relation to main drain or main irrigation canal were monitored after installation of a subsoil drainage system in a clay soil. The soil initially had an EC_e upto 15 mmhos cm⁻¹, ESP of upto 24 and pH of upto 8.8, but was improved to a non-saline, non-sodic soil with EC < 3 mmhos cm⁻¹, ESP < 13 and pH of 7.6 to 8.3. Soil CaCO₃ (3-8 %) aided reclamation. The shallow 37-55 cm water table fall to 75-101

cm by the 3rd year with an average of 88 cm depth. Salt, ESP, and pH generally decreased with depth.

Ranade *et al.* (1992) conducted a study at Barwaha experimental farm on a sodic Vertisol. The characteristics of soil CaCO_3 6 %, ECe 3.4 to 4.3 dSm^{-1} average ESP 50, pH 9.3 and clay 51 per cent, silt 43 per cent, sand 6 per cent. Seven lateral drains were dug by keeping distance 9 m, 12 m and 15 m and observed that the ESP values of soil decreased from 44.0 to 26.5, 46 to 37.5, 50 to 46.0, 54 to 50 and 55 to 51 to the depth of 0-15, 15-30, 30-45, 45-60 and 60-90 cm, respectively.

Sharma *et al.* (1992) conducted a field experiment to evaluate the effects of three sub-surface drain spacings (25, 50 and 75 m) on soil salinity and reported that prior to installation of sub-surface drains resulted in appreciable decrease in average soil salinity after three monsoon leaching and cropping. The decrease in salinity was more in 25 m and 50 m spacing as compared with 75 drain spacings. Average ECe values were less than 4 dSm^{-1} upto the depth of 60 cm in 25 m drain spacing remain 76.8 dSm^{-1} in 75 m drain spacing.

Devdattam (1994) reported that with the installation of subsurface drainage the electrical conductivity of saturation extract was reduced from 9.3 to 1.44 dSm^{-1} under 10 and 15 m drain spacing and from 11.0 to 2.25 dSm^{-1} under 25 and 35 m spacing with passage of time, however the variation in soil pH was not appreciable over the period.

Rao *et al.* (1994) studied the requirements of subsurface drainage for problem areas by establishing experimental field a drain depth of 1.4 m and 65 m spacing and reported that with installation of subsurface pipe drains the electrical conductivity of saturation extract decreased from 38 to 7.5, 31 to 7.0, 23 to 8, 22.5 to 8.5 and 22.5 to 14.0 dSm^{-1} to the depth of 0-15, 15-30, 30-60, 60-90 and 90-120 cm, respectively.

Sharma and Singh (1998) conducted a field experiment for 8 years with installation of subsurface drainage and reported that the E_{Ce} reduced from 58.90 to 4.43 dSm^{-1} , SAR reduced from 10.80 to 4.38 and reduction of chloride recorded from 635 to 40.00 m mol^{-1} to the depth of 0-15 cm.

Bharambe (2001) conducted an experiment by laying subsurface drains on Research Farm at Parbhani on Vertisol by laying subsurface drains 25 m, 50 m and 75 m spacing and reported that the bulk density of soil was 1.29 g cm^{-3} in control and 1.26, 1.25 and 1.25 g cm^{-3} with 25, 50 and 75 m, respectively. The pH in central ^Q was 9.22 and 8.26, 8.28, 8.24 with 25, 50 and 75 m, respectively and ESP was recorded 13.3 in control and 10.2, 9.8, 9.9 in 25, 50 and 75 m spacing, respectively.

2.7 Effect of subsurface drainage on quality of drainage water

Pandey and Sahi (1980) conducted an experiment in Gandak command area in Bihar and reported that sulphates and carbonates were highest in June decreased during rainy and winter seasons and increased again during summer, while bicarbonates

followed a reverse trend. Chloride concentrations remained more or less constant during rainy and winter seasons and increased considerably during summer.

Bharambe *et al.* (1992) recorded periodical observations on fluctuations of ground water table and quality of waters were made in Jayakwadi command area during 1985 to 1990. The ground water table rose during rainy season (June–August) in the Jayakwadi command area. The average water table depth decreased from 2.60 to 1.78 m during rainy season remained almost constant during winter season and subsequently increased during summer season. Periodical analysis of water samples during 1989–1990 showed that sodium adsorption ratio of ground water decreased during rainy and winter seasons and increased considerably during summer season. pH decreased during June to August and thereafter followed an increasing trend, soluble salt concentration (EC) remained more or less unchanged.

Sharma *et al.* (1992) conducted an experiment to evaluate the effect of sub-surface drainage on salinity control on Vertisols (dominantly Kota series) and reported that the salinity concentration of drain effluent from the test plot averaged 2.05 dSm^{-1} from test laterals during 1991 monsoon season. During 1992 season effluent EC declined to an average of 0.8 dSm^{-1} .

William and Johnston (1993) carried out an analysis of the first four years of data of drainage system in age 0 and 12 years, resulted in a good correlation between the drainage effluent EC, selected ions in the effluent and the age of drainage systems. The first

four years of data showed that the salinity and selected ions found in the drainage effluent decreased logarithmically from the time and the drain system were installed.

Mark and Grismer (1993) reported in the steady-state analysis, the effects of drain depths of 2.5 m, 3 m and 4 m and spacings of 20 m, 40 m, 60 m and 80 m on drain water quality and indicated that as drain spacing and depth increased, the salinity of water collected by the drainage system also increased. Increasing the depth of the drainage system deteriorated water quality more than did increasing drain spacings by a factor 4 (from 20 m to 80 m) reduced water quality by practically the same amount as increasing the drain depth from 2.5 m at 20 m spacing.

Rao *et al.* (1994) reported that the quality of drainage effluent was very poor and there was slight improvement over the years. The salinity of drainage effluent ranged from 30 to 20 dSm⁻¹ during the first year of reclamation and improved to about 7 dSm⁻¹ in about 9 years. There was also a strong influence of seepage of ground water from the surrounding area on the quality of drainage effluent. The chemical composition of the drainage water was the same as that of the ground water having predominantly chlorides of calcium and magnesium followed by sodium.

Sharma *et al.* (1994) reported that the quality of drainage discharge depends on the nature and amount of salts present in the soil profile and the salinity of underground water. The quality of drainage water of Sampla drainage system was very poor but there was a slight improvement over the years. The electrical conductivity

decreased from 26.5 to 12.5 dSm⁻¹ from 1986-87 to 1991-92, the Ca²⁺ + Mg²⁺ content decreased from 173 to 103 meL⁻¹, sodium 156 to 188 meL⁻¹, HCO₃⁻ 1.8 to 1.8 and Cl 315 to 162 meL⁻¹ over the years 1986-87 to 1991-92.

Singh *et al.* (1994) reported that after the installation of subsurface drainage system and its subsequent operation, a gradual change in the drain water salinity was observed. The drainage water salinity was measured after each year before and after the monsoon. The drain water salinity was maximum with a value of 7.2 dSm⁻¹ in June and after subsequent operation during monsoon season and the same decreased to a value of 3.0 dSm⁻¹.

Kundu and Singh (2001) conducted an experiment for assessment of impacts of farming on water quality. Water samples were collected from irrigation sources and corresponding drainage points and analyzed for viz., pH, EC, CO₃²⁻, HCO₃⁻, Cl⁻, Ca²⁺, Mg²⁺, K⁺, Na⁺, SAR and RSC and reported that pH was considerably higher in drainage than in irrigation water whereas EC, HCO₃⁻ and Cl⁻ were higher in drainage water than irrigation water.

2.8 Leaching behaviour of soil under column

2.8.1 Effect of leaching on leachate quality

2.8.1.1 Effect of water

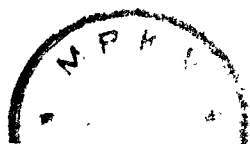
Satyanarayan (1954) studied gypsiferous saline soils and observed that chloride ion content was more than the sodium ion showing that some chloride ions were in combination with other cations especially magnesium and potassium in the first leachate. Chloride and sodium were removed earlier and sulphate ions

predominates in the latter leachates. Magnesium and potassium ions continued to come out in solution when the sodium and chloride ions were absent. In the latter leachates calcium and sulphate ions remained steady and divalent cations calcium and magnesium were in excess of monovalent ions.

Banerjee (1957) reviewed the various studies on the percolation of water through soils. He showed that all the cations can be in the largest amount in the first leachate. The amount fell very sharply in the successive leachates but continued to come even in the 18th leachate. All the replaceable sodium was removed in the 3 or 4 leachates.

Mohite and Shingte (1984) conducted a laboratory experiment to study the changes in effluent composition during reclamation of saline-sodic soil by high salt water dilution method. They found that the electrical conductivity of the first leachate was the highest and it continuously decreased in the subsequent effluent waters of the successive dilutions in all the treatments. Further, they also observed that sodium content in the first effluent water under each treatments was the highest, which decreased gradually until the equilibrium point was attained.

Selassie *et al.* (1992) conducted a column study involving the reclamation of saline and saline-sodic soils. The amount of water moving through the soils was measured as the pore volume of drainage. During saline soil reclamation, under saturated soil moisture flow, electrical conductivity of the effluent was defined by a multiple slope, apparent first order kinetic equation. For saline-sodic soil



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reclamation under saturated soil moisture flow both the decrease in the effluent EC and the sodium adsorption ratio were described by multiple slope, apparent first order kinetic equation. Reclamation under an unsaturated moisture regime used 36-40 per cent less water than saturated moisture flow.

2.8.1.2 Effect of organic amendments

Murthy (1960) conducted laboratory leaching trials on saline-alkali soil by treating it with FYM, paddy straw and green leaves, then three successive leaching were carried out, he found that the presence of more chloride ions than sodium ions in first leachate. It indicated that some chloride ion was in combination with other cations, sodium was found mostly in the first and second leachate.

Periaswamy (1967) found that leaching with water alone was as efficient as green manuring plus leaching in removing sodium from soil.

2.8.1.3 Effect of chemical amendments

Singh *et al.* (1980a) conducted the laboratory experiment on alkali soils to study the effect of the application of gypsum and pyrites on the leachate composition and they reported that in the leachates collected from amended soils, Na^+ , K^+ , Ca^{2+} , CO_3^{2-} , HCO_3^- and SO_4^{2-} were increased with the levels of applied gypsum and pyrites.

Verma and Abrol (1981) found that the application of gypsum and pyrites amendments on the surface of sodic soil removed the greater amount of soluble and exchangeable sodium from the soil than the leaching of soils without any amendments. Sodium removal

indicated an improvement in the effectiveness of pyrites, which appeared to be about one half as effective as gypsum.

Sampaio and Ruiz (1996) amended saline-sodic soils in PVC columns with gypsum and subjected to six successive leaching with solutions of CaCl_2 and MgCl_2 at 50 per cent the pore volume. Electrical conductivity of the leachates decreased with successive leachings and calcium and magnesium were absorbed on the exchange complex. During the final leaching the pronounced decreased in soluble salts concentration promoted gypsum dissolution.

2.8.2 Effect of leaching on soil

2.8.2.1 Effect of water

Shriramamurthy (1961) conducted an experiment with saline-alkali soil and reported that leaching of soil without addition of any amendments decreased total soluble salts content but increased the pH, soluble sodium and magnesium.

Gallez *et al.* (1981) conducted a laboratory trials of irrigation have been performed on several undisturbed soil columns in order to show that reclamation of these soils can be easily carried out. At low flow rates and with good drainage irrigation with local water allows rapid desalinization of the profile desodification, though slower can be partially or sometimes completely effected due to natural gypsum content of those soils.

Verma and Gupta (1989) reported the effect of continuous and intermittent application of water of varying depth in the leaching behaviour of salts. Before the commencement of leaching the maximum salt concentration was in the surface 10 cm of the soil. The

salt peak was gradually displaced downward and more salts leached with increasing quantity of water passed through the soil column. An application of 60 cm water resulted in appreciable desalinization of the soil profile. The salinity level decreased markedly and observed $E_{ce} < 2 \text{ dSm}^{-1}$ in top layer with initial E_{ce} of $> 8.2 \text{ dSm}^{-1}$. There was about 80 per cent reduction in initial salt concentration upto depth of 0-10, 0-20, 0-40 cm with application of 15, 30 and 60 cm water, respectively.

2.8.2.2 Effect of organic amendment

Manzoor *et al.* (1988) reported that the application of organic matter in PVC columns reduced Electrical conductivity of soil, pH and exchangeable sodium percentage.

Singh (1997) studied the leaching behaviour and salt dynamics under different modes of water application in presence of FYM in *Vertic Ustochrept* through a column study having surface (0-0.15 m) soil properties E_{ce} - 110 dSm^{-1} , with a water soluble Ca, Mg, Na, K, $\text{CO}_3 + \text{HCO}_3$, SO_4 and Cl content of 20.6, 105.9, 972.0, 1.4, 3.8, 49.0 and $1047.0 \text{ m mol L}^{-1}$, respectively. The initial pH was 8.0 and ESP 15.3. The soil was leached and observed that among the cations sodium was leached significantly in higher quantity as compared to calcium and magnesium. The residual salt content after leaching was recorded, as E_{ce} was reduced from 110 to 1.6 dSm^{-1} and water soluble Ca, Mg, Na, K, $\text{CO}_3 + \text{HCO}_3$, SO_4 and Cl contents 9.1, 3.9, 0.8, 0.1, 2.6, 8.9, 0.8 m mol^{-1} , respectively showing decreasing trend over initial value, pH 8.0.

2.8.2.3 Effect of chemical amendments

Venkatkrishnan (1979) conducted an experiment on oxidation of pyrites in a sodic soil and found that mixing of pyrites in soil column was inferior to just placing it on surface of the column. Mixing the surface pyrites with the rest of soil after 12 and 18 days of surface application performed comparably and resulted better and more uniform improvement of the soil than when pyrites was retained on the surface unmixed. More amounts of leachate was collected from columns where the pyrites was incorporated in soil.

Shehata *et al.* (1983) studied the effect of gypsum (as a source of calcium) application and successive leaching on the concentration of different ions and on their redistribution in soil column experiment and recorded that sodium was the main soluble and exchangeable cation to be leached, a first leaching resulted in the removal of more than 60 per cent of total soluble salts, 70 per cent of chloride and 38 per cent of SO_4 ions ESP of the soil was decreased from 63.6 to 30 and pH from 9.4 to < 8.5.

Moazed and Sepaskha (1987) carried out a column experiment with the best granule size and application rates of sulfur for reclaiming a saline-sodic soil (ESP > 15, EC 74 mmhos cm^{-1} and pH < 9.6) and reported that soil conditions were improved and pH lowered to 8.3 in the upper 10 cm after application of 4 t ha^{-1} sulfur granules smaller than 1 mm in size and 0.45 m water per unit depth of soil. Granules of 1-2 mm size may give similar results but those larger than 2 mm were not as effective as the application of 4 t ha^{-1} .

Granules smaller than 2 mm improved the efficiency of salt leaching and reduced ESP.

Minhas and Sharma (1989) studied the displacement of salts after infiltration and redistribution of water in vertical homogenous columns of a saline-sodic soil (pH 8.6, EC_e 29.2 dSm^{-1} , SAR 13, sandy loam texture) and after amending it with calcium chloride, the soils leached with 15 cm of low electrolyte water under transient and steady state infiltration conditions, compared with the amended soil the original saline-sodic soil due to its vulnerability to clay dispersion exhibited higher retention of moisture in the upper portions of soil columns following redistribution period and showed shallower salt displacement and narrower spread of salts around the salt peak. Salts were found to be displaced deeper with transient infiltration than with steady state rates when infiltration and redistribution timing were the same under two conditions. The study indicates that salt leaching efficiency of saline-sodic soils could be considerably enhanced if its structural deterioration during leaching could be checked by the application of calcium amendments.

Zahow and Amrhein (1992) reported that the application of synthetic polymers in column, the addition of gypsum increased the hydraulic conductivity from 0.0 to 0.063 $mm\ h^{-1}$ in the soil with an ESP of 32 when polymers were used in conjunction with gypsum the hydraulic conductivity increased to 0.28 $mm\ h^{-1}$.

Sharif *et al.* (1998) conducted column study with two types of water in the absence or presence of gypsum (as a Ca source) as a amendment were used to reclaim saline-sodic soil (EC_e 29.25

dSm⁻¹ and ESP 30 %) reported that the soil salinity was reduced markedly where the ECe values decreased from 29.25 to 10.1, 7.14, 2.5 and 2.7 dSm⁻¹ for treatments of leaching technique using canal water, drainage water, gypsum + canal water, gypsum + drainage water, respectively.

2.9 Predictive approaches for sodicity

Vanselow (1932) proposed equations for exchange reaction in soil.

$$K_v = \frac{(M^+)^2}{(M^{++})} \frac{a^{2+}}{(a^+)^2}$$

Where M⁺ and M⁺⁺ are mole fraction of mono and divalent cations and a⁺ and a⁺⁺ are the activity in mole L⁻¹ of mono and divalent cations, respectively.

Gapon (1933) gave the equation for calculating its selectivity coefficient.

$$K_v = \frac{N^+}{N^{++}} \frac{(a^{2+})^{1/2}}{(a^+)}$$

Where N⁺ and N⁺⁺ are the equivalent fractions of monovalent and divalent cations, respectively and a⁺ and a⁺⁺ are the activity in mole L⁻¹ of monovalent and divalent cations, respectively.

Krishnamoorthy *et al.* (1948) modified the equation as.

$$K_{kdo} = \frac{(M^+)^2}{M^{++} (UM^{++} + M^+)} \frac{a^{2+}}{(a^+)^2}$$

Where M⁺ and M⁺⁺ are mole fractions of mono and divalent cations, respectively. U is equal to 2 (Y - D)/Y with Y as number of

exchange sites influencing a given site. Generally for calculation of K_{KDO} values of Y is taken as 4.

Levy and Mar (1964) recorded a considerable difference in the average value of Gapon coefficient for two soils indicating significant effect of soil properties on Na-Ca specificities.

Spostio (1977) found the selectivity coefficient for Na-Ca exchange of soils will not be mean different numerically whether it is calculated by Vanselow or Gapon's approach, provided the exchangeable sodium level does not exceed 20 per cent and total soluble cation concentration is same.

Ghaji and Bladed (1975) conducted an experiment to study the calcium-sodium exchange equilibrium on some typical calcareous soils varying in CaCO_3 (3.4 to 64.7 %) CEC (17.7 to 49.3 me 100 g^{-1}) and organic matter (0.7 to 5.0 %) from Morocco with typical montmorillonite clay. A wide variation in the KG value (0.0044 to $0.012 \text{ m mol L}^{-1})^{-1/2}$ for different soil indicated that the soil factors like CEC, organic matter, CaCO_3 and type of clay minerals had a significant effect on the specificity of Na for these exchange.

Oster and Spostio (1980) tested the thermodynamic theory of cation exchange and developed an ESR-SAR relationship which was consistent even at SAR upto $40 \text{ m mol}^{1/2} \text{ L}^{-1/2}$. They used a corrected thermodynamic equation for the KG.

$$\text{KG} = (\text{SAR}/2\text{E} \times \text{NA}) (1 - \text{Ex. Na}/2)^{1/2}$$

Frenkel and Alerovitch (1983) reported that the ESP-SAR relationship of 623 soil samples from arid and semi-arid zones in Israel, dependent on soil salinity and cation exchange capacity. The

KG values decreased as salinity increased and at a constant salinity level, decreased as the soil saturation percentage increased.

Harron *et al.* (1983) recorded the SAR-ESR relationship in saline and sodic soils of Canada. Correlation between ESR-SAR was significant for the A and B horizons. The slope of regression line indicated that Na was adsorbed three times more strongly relative to Ca in the B horizon than in the A horizon. Such difference was attributed to the differences in soil properties particularly clay and organic matter content.

Jurinak *et al.* (1984) studied the effect of salinity (electrolyte conc. 10 to 500 meL^{-1}) and SAR (5 to 80 $\text{m mol L}^{-1/2}$) on Gapon selectivity and observed that KG values in the range of 0.079 to 0.0097 (m mol L^{-1}) $^{-1/2}$ for these soils and noted a declining value of KG (0.014 to 0.0055 m mol L^{-1}) $^{-1/2}$ with increase of electrolyte concentration.

Curtin *et al.* (1995) examined ESR-SAR relationship in the irrigated / brown chernozemic soils of South-Western Saskatchewan in Canada and reported a good relationship where SAR was $> 30 \text{ m mol}^{1/2} \text{ L}^{-1/2}$ at an SAR < 30 the KG was $0.013 \text{ m mol}^{-1/2} \text{ L}^{1/2}$.

Girdhar (1996) reported that Gapon selectivity coefficient (KG) was determined after equilibrating the soil with waters of different RSC at varying SAR and EC. The chloride, sulphate, carbonate and bicarbonate salts of sodium, calcium and magnesium were used in this study. The KG value increased with an increase in SAR on the soil solution at a given EC and RSC and its value further increased with an increase in salinity at the same SAR and RSC. This

FYM alone increased the grain yield of maize by about 6.7 q ha^{-1} over control in sandy soil.

Somani and Saxena (1981) reported that, FYM, poultry manure, dhaincha and rice husk were applied as source of organic materials alone or in conjunction with gypsum or sulphur on saline sodic soil. All the amendments increased the wheat yield.

Patil and Kale (1983) reported that when pressmud cake was added @ 18.5 and 12.5 t ha^{-1} to the medium black alkali soil and cv. CO-740 variety of sugarcane was planted the highest cane yield was on the plots receiving the pressmud cake @ 12.5 t/ha .

Mahajan *et al.* (1986) conducted a pot culture experiment on saline-sodic black calcareous soil by amending with FYM, gypsum, Iran pyrite at the rate of 75 per cent gypsum requirement and growing wheat crop after leaching the soil. They found that the yield of wheat straw and grain increased significantly with the application of FYM, gypsum and pyrites and their combination over simple leached soil. The grain yield was maximum under the treatment of FYM (20 t ha^{-1}) + gypsum (75 % gypsum requirement) and followed by the treatments of FYM (20 t ha^{-1}) + pyrites (75 % gypsum requirement).

Wahid *et al.* (1998) conducted a laboratory study to determine the effect of adding FYM, Egyptian clover hay and wheat straw at 1 and 3 per cent of soil weight. Wheat grown in these soils indicated significant differences for various growth and yield variables, especially the root growth, number and areas of green leaves and grain yield. It was concluded that FYM ameliorated salt

affected soils promoted growth of wheat better than clover hay and wheat straw.

2.10.2 Effect of chemical amendments

Pathak *et al.* (1978b) studied the effect of pyrites in combination with zinc in saline sodic soils at Kanpur on rice crop. They found that the application of pyrites increased the yield of rice significantly. The average grain yield of the first crop of rice increased from 15.51 q ha⁻¹ to the extent of 34.41 and 40.05 q ha⁻¹ at 40 and 80 per cent gypsum requirement levels of pyrites application, respectively. However grain yield due to pyrite application at 80 per cent gypsum requirement level was significantly higher as compared to 40 per cent level. As compared to control, pyrites application at 40 and 80 per cent level gave 122 to 158 per cent additional yield.

Singh and Singh (1978) carried out field trails in alkali soils at Varanasi and Mirzapur Districts to study the effects of levels of iron pyrites (0, 7.25, 14.50 and 21.75 t/ha) on grain and dry matter of wheat varieties namely S-308, RR-21 and Kalyansona. They found that with the increasing levels of pyrites, grain and dry matter yields increased from 9.16 to 31.45 q ha⁻¹ and from 17.97 to 58.0 q ha⁻¹, respectively in case of S-308 variety. Similar trend were observed in other two varieties of wheat.

Singh *et al.* (1980a) studied the comparative effect of gypsum and pyrites on yield of wheat and rice in sodic soil. They observed that different levels of amendments increased the wheat yield. The highest yield of wheat was found with gypsum applied at

40 per cent gypsum requirement. While in case of pyrites, the highest yield was obtained with 200 per cent gypsum requirement level.

Alam *et al.* (1986) reported that the grain yield of wheat was increased with increasing doses of pyrites over control i.e. 20.5 g pot⁻¹ in control to 28.6 g pot⁻¹ with 4.5 Mg ha⁻¹ pyrite.

Narwal *et al.* (1991) studied the response of different sources of sulphur applied through single superphosphate, gypsum, pressmud and pyrites was studied on mustard on an Entisol and reported that the grain/stalk yield increased significantly with increasing levels of sulphur.

2.10.3 Effect of organic amendments on availability of nutrients

Singh and Prakash (1968) noted that the availability of nutrients in soil was higher with organic fertilizers. Further, they stated that organic matter undergoing slow oxidation, produced organic acids which increased the availability of phosphate.

Prasad (1976) in laboratory incubation studies observed that the application of filter pressmud (equivalent to 40 and 80 t ha⁻¹ on dry weight basis) increased the availability of P, K, Ca, Mg and Zn.

Mann *et al.* (1978) reported that the application of FYM to the saline soil increased the availability of iron and manganese in the soil. These two elements are known to form stable complexes with organic ligands decreasing their susceptibility to adsorption fixation or precipitation in soils. Application of FYM might be resulted in the formation of such metalo-organic complexes of higher extractability. The increase in the availability of native micronutrients cations (Fe

and Mn) appears to have resulted from the transformation of their solid phase form to soluble metal complexes.

Patil *et al.* (1978) conducted experiment at Central Sugarcane Research Station, Padegaon, on medium black alkali soil by the application of 12.5, 18.5 and 25.0 t ha⁻¹ pressmud cake to sugarcane crop var. CO-740 and reported that with the increase in levels of pressmud cake there was increase in organic carbon content and available nitrogen, phosphorus and potassium.

Leather (1983) reported successful reclamation and improvement of nutrient availability of highly alkali soil by application of FYM @ 20-25 t ha⁻¹ in first year and half of its quantity during second year. Application of organic manure alone helps both in the proper nutrition of the crop plant and in maintaining the fertility of soil.

Patil and Kale (1983) studied the residual effect of pressmud cake on chemical properties of medium black alkali soil and uptake of nutrients by sugarcane CO-740 at Central Research Station, Padegaon and reported that fertility status was observed at higher levels with the increase in organic carbon, total N and available P₂O₅ content.

Swarup (1986) reported that the application of FYM increased the availability of applied Zn over control. Since Zn is known to form stable complexes of different stability with organic ligands which decrease their susceptibility to adsorption, fixation or precipitation reaction in soil application of such a metallo-organic complexes of higher extractability.

2.10.4 Effect of chemical amendments on availability of nutrients

Babaria and Patel (1980) conducted incubation study of medium black clayey calcareous soil with the application of iron ($\text{FeSO}_4 \cdot 2\text{H}_2\text{O}$) FYM and elemental sulphur at various soil moisture regimes showed that FYM @ 10 t ha^{-1} S @ 80 ppm and Fe @ 10 ppm significantly increased the available iron. The effect of these treatments was more pronounced as incubation period increased upto 42 days.

Hattar (1983) carried out an incubation studies and found that application of sulphur and H_2SO_4 in calcareous soil increased the availability of P and reduced the amount of active CaCO_3 . Sulphuric acid had more pronounced effect on levels of micronutrients as compared to that of elemental sulphur.

Alam *et al.* (1986) conducted an experiment in pots to study the effect of low grade pyrites on calcareous saline-sodic soils under rice-wheat rotation. There was an appreciable decrease in pH, EC, ESP, CO_3 , HCO_3 , RSC and increase in Ca^{2+} , Mg^{2+} and SO_4^{2-} in the saturation extract and available phosphorus due to application of pyrites.

Naik (1988) found that with the application of pyrites availability of active iron and other plant nutrients increased. The application of pyrites @ 2.0 t ha^{-1} on moist alkaline soil surface during summer is found to be more advantages.

2.10.5 Effect of organic amendments on uptake of nutrients

Hofner *et al.* (1979) conducted a pot culture experiment to study the influence of compost and different Fe compound on the uptake of Fe, Zn and Mn from calcareous soil by using sunflower and maize crops. They found that the compost treatment without Fe resulting in a lower Fe content in sunflower and maize this effect was partly or completely counteracted by the addition of Fe compound.

Dahiya and Singh (1980) conducted a pot culture experiment to study the effect of FYM and CaCO_3 on the uptake of nutrients and reported that the application of FYM resulted in a significant increase in concentration and uptake of phosphorus. Phosphorus uptake increased by 23.60, 54.28, 91.01 and 134.61 per cent over control with 0.5, 1.0, 2.0 and 4.0 per cent FYM, respectively. Iron concentration and uptake increased upto 2 per cent FYM and then decreased thereafter.

Patil and Kale (1983a) studied the effect of PMC on chemical properties of medium black alkali soil and uptake of nutrients in sugarcane (adsali) CO-740 at Central Sugarcane Research Station, Padegon. They found that the uptake of N and P_2O_5 increased the incorporation of PMC 25 t ha^{-1} over inorganic fertilizer treatments.

Singh and Tomer (1991) reported that the application of K and FYM on saline soil increased significantly the yield and uptake of K by wheat under greenhouse condition. The content of N, Ca and Mg decreased with applied K and increased with FYM.

Kumar and Mishra (1991) reported that with the application of PMC increased total NPK uptake of rice plants with increasing doses of PMC upto 10 t ha^{-1} .

Swarup (1991) conducted a pot experiment to study the effect of gypsum, green manure FYM and zinc fertilization on rice in water logged saline soil and reported that the application of FYM and green manure increased the concentration of Zn, Fe and Mn because of decrease in pH and ESP of soil.

2.10.6 Effect of chemical amendments

Mohite *et al.* (1985) conducted a pot culture experiment using black calcareous clay soil with combination of three levels of P (30, 45 and $60 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$) and iron pyrites (0, 300 and 600 kg ha^{-1}) and they found that uptake of N, P and Fe by wheat (straw and grain) significantly increased with the increasing levels of pyrites and phosphorus except that the uptake of Fe by wheat straw decreased with the increasing levels of phosphorus.

Sharma and Yadav (1987) conducted a green house experiment to study the uptake of Fe, Mn and P by rice on sodic soil amended with iron pyrites and FYM. They found that the uptake of iron, manganese and phosphorus by rice increased significantly with the increasing doses of pyrites but the effect of FYM application was not statistically significant. However the interaction effect of FYM and pyrites was significant only for Fe uptake by rice straw.

Mahajan *et al.* (1989) conducted a pot culture experiment on saline-sodic calcareous soil (EC $9.4 \text{ mmhos cm}^{-1}$, pH 8.4, ESP 23.30 and CaCO_3 14.95 %) soil treating with FYM (0-20 t ha^{-1}),

gypsum (0, 75 % of gypsum requirement) iron pyrites (75 % of gypsum requirement) and their combinations and leaching with good quality water. They observed that the uptake of N, P and Fe by wheat straw and grain significantly increased with the application of FYM, gypsum, iron pyrites and their combinations over simple leached soil.

Gangadhara *et al.* (1990) conducted a field experiment on *Typic Chromustert* to investigate the effect of sulphur on uptake of nutrients during *kharif* 1987 at Dharwad and reported that sulphur application @ 5 and 10 kg ha⁻¹ increased concentration of SO₄-S, B, Fe, Mn and Cu in plant parts.

Ghosh *et al.* (1999) conducted an experiment on a sulphur deficient sandy loam soil at the Sugarcane Research Institute, Lucknow farm to assess the effect of sulphur application on uptake of nutrients, nitrogen use efficiency and yield of cane and sugar. It was showed that the uptake of N, P and S increased with application of S while Fe, Mn and Zn contents were decreased in earlier stages of growth. However, after 120 days of plant growth levels of Fe, Cu and Zn increased.



Chapter Opener Page



MATERIAL AND METHODS

3. MATERIALS AND METHODS

The field experiments were carried out over an area of 8.1 ha at Block-B Central Research Farm, M.P.K.V., Rahuri, during 2001-2002 which comes under Mula canal command area consist of typical deep vertisols having swell-shrink properties and due to seepage from canal it pose serious problem of soil salinity/sodicity and the laboratory experiment were conducted in Post Graduate Laboratory at Department of Agricultural Chemistry and Soil Science, M.P.K.V., Rahuri for "Assessment of saline sodic swell-shrink soil during reclamation process."

3.1 Materials

3.1.1 Location of experimental area

The Central Research Farm, M.P.K.V., Rahuri is located between 19° 19' to 19° 24' N latitude and 74° 36' E longitude. Its elevation is 500 m above mean sea level. The farm is situated on the unlined Mula right bank canal passes West to East through the study area.

3.1.2 Physiography

The soils of study area are slight to severely salt affected, nearly levelled to very gentle slopping midlands of lowlying area of lower and upper piedmont plains (basin shape topography). The slope gradient of study area ranges between 1 and 3 per cent. Due to land levelling the natural drains found to be devastated.

Table 1. Details of meteorological data during the experimental period (June 2001- July 2002)

Meteorological week	Temperature (°C)		Humidity (%)		Sunshine (hours)	Wind velocity (km hr ⁻¹)	Rainfall (mm)	Rainy days
	Maximum	Minimum	Morning	Evening				
June 2001								
23	34.7	22.8	76	49	7.2	1.7	18.2	2
24	25.5	22.7	81	65	1.9	6.8	47.9	3
25	31.2	23.4	73	48	6.7	8.6	4.2	1
26	32.1	22.6	71	48	6.7	6.9	0.6	-
July								
27	26.5	22.5	78	58	4.0	5.9	2.6	1
28	31.1	22.9	77	60	1.7	9.1	-	-
29	29.3	21.8	78	62	1.3	5.4	-	-
30	31.5	22.5	77	51	3.3	4.3	-	-
August								
31	31.1	22.0	81	52	2.7	2.1	4.6	1
32	27.6	21.9	89	80	0.9	1.1	96.0	4
33	29.1	22.0	84	65	2.1	4.1	9.6	1
34	29.8	21.3	86	62	4.2	2.2	9.2	2
35	30.6	21.4	81	51	5.2	2.7	-	-
Sept.								
36	31.6	20.5	86	49	5.5	0.8	9.8	1
37	31.7	20.8	86	46	7.1	0.8	-	-
38	30.8	21.3	87	61	5.6	0.2	115.6	3
39	32.1	22.0	87	49	7.3	1.1	29.0	3
Oct.								
40	30.9	21.9	91	63	3.1	1.3	42.0	3
41	29.4	21.0	94	62	5.7	0.9	148.2	4
42	31.1	18.9	80	41	7.8	1.3	4.6	1
43	31.6	13.6	77	24	9.6	0.8	-	-
Nov.								
44	32.2	14.0	73	25	9.9	0.5	-	-
45	31.1	13.9	72	30	9.8	0.6	-	-
46	30.4	13.6	76	33	9.3	0.6	-	-

Table 1 contd.....

Meteorological week	Temperature (°C)		Humidity (%)		Sunshine (hours)	Wind velocity (km hr ⁻¹)	Rainfall (mm)	Rainy days
	Maximum	Minimum	Morning	Evening				
47	30.2	12.2	77	27	9.6	0.3	-	-
48	28.3	11.2	78	28	9.3	0.6	-	-
Dec.								
49	30.3	12.4	73	27	9.3	0.2	-	-
50	31.0	11.0	79	28	9.2	0.4	-	-
51	28.2	11.5	79	31	9.0	1.1	-	-
52	29.3	12.4	82	33	9.4	0.2	-	-
Jan. 2002								
1	26.7	8.5	78	38	8.5	1.1	-	-
2	26.9	8.7	86	36	8.3	0.8	-	-
3	28.5	8.6	80	35	9.4	0.6	-	-
4	24.0	7.9	74	42	9.9	1.3	-	-
Feb.								
5	25.0	10.4	76	42	8.0	1.0	-	-
6	29.1	12.2	77	35	9.0	0.5	4.6	1
7	30.0	15.2	77	35	9.0	0.5	-	-
8	32.0	13.6	71	30	9.6	0.4	-	-
March								
9	31.1	13.6	64	31	9.9	0.5	-	-
10	33.6	13.9	53	20	9.7	0.5	-	-
11	32.4	-	55	24	7.2	1.5	-	-
12	36.0	15.9	51	17	9.3	0.9	-	-
13	36.5	15.6	54	16	9.7	0.9	-	-
April								
14	36.9	-	67	27	9.5	1.7	15.4	2
15	36.6	-	52	18	10.3	0.6	0.8	-
16	38.4	23.6	47	19	7.9	0.9	-	-
17	38.6	-	49	19	10.0	1.2	-	-

Table 1 contd.....

Meteorological week	Temperature (°C)		Humidity (%)		Sunshine (hours)	Wind velocity (km hr ⁻¹)	Rainfall (mm)	Rainy days
	Maximum	Minimum	Morning	Evening				
May								
18	39.0	24.1	51	19	9.9	1.4	-	-
19	39.1	24.0	71	30	9.9	3.5	-	-
20	37.9	24.7	69	33	10.4	6.3	-	-
21	38.0	22.7	67	30	10.0	3.8	7.8	1
22	37.0	-	68	34	8.5	2.2		
June								
23	37.2	23.3	69	31	7.2	2.7	0.4	-
24	34.4	23.0	68	50	2.7	3.2	90.4	2
25	34.4	23.0	68	50	2.7	3.2	90.4	2
26	27.5	22.3	83	60	0.9	7.3	76.8	3
July								
27	32.0	27.2	73	49	4.3	8.1	-	-
28	32.7	22.0	74	46	7.6	5.1	0.6	-
29	30.1	18.9	81	58	3.6	4.2	13.0	1
30	30.4	22.0	82	57	4.4	5.5	0.6	-

Table 2. Basic properties of soil

Sr. No.	Parameters	Value
1.	Particle size analysis	
i.	Sand (%)	21.59
ii.	Silt (%)	23.19
iii.	Clay (%)	55.22
2.	Soil texture	Clay
3.	Bulk density Mg m^{-3}	1.40
4.	Hydraulic conductivity (m day^{-1})	0.15
5.	Infiltration rate (m S^{-1})	5.2×10^{-6}
6.	Moisture retention	
i.	1/3 bar	42.4
ii.	15 bar	14.12
7.	COLE	0.19
8.	pH (1 : 2.5)	8.4
9.	EC (1 : 2.5)	4.8
10.	Organic carbon (%)	0.56
11.	CaCO_3 (%)	16.00
12.	Available nutrients (kg ha^{-1})	
i.	Nitrogen	150.12
ii.	Phosphorus	10.59
iii.	Potassium	410.12
13.	DTPA extractable micronutrient (mg kg^{-1})	
i.	Fe	11.00
ii.	Mn	14.00
iii.	Zn	0.80
iv.	Cu	4.00
14.	Composition of saturation paste extract of soil	
i.	pHe	8.00
ii.	ECE	7.96
iii.	Ca^{2+} (meL^{-1})	10.1
iv.	Mg^{2+} (meL^{-1})	8.20
v.	Na^+ (meL^{-1})	48.50
vi.	K^+ (meL^{-1})	0.13
vii.	Cl^- (meL^{-1})	23.2
viii.	CO_3^{2-} (meL^{-1})	Traces
ix.	HCO_3^- (meL^{-1})	8.8
x.	SO_4^{2-}	26.00
xi.	NO_3^-	Traces
15.	CEC ($\text{cmol (p}^+) \text{ kg}^{-1}$)	58.6
16.	ESP	24.39
17.	SAR	16.05

3.1.3 Geology

Soils are derived from the igneous rocks viz., Basalt (Deccan trap) which is basic in nature containing mainly feldspars (Plagioclase), augite and small amount of titaniferrous minerals. In the vesicular rocks the amygdaloidal cavities are filled with mineral like zeolite and quartz. The free lime reserve is fairly high (6.9 to 20.8 %) and at places excessive quantities of lime nodules are precipitated in the weathered basaltic material in the profile.

3.1.4 Climate

The area falls in semi-arid sub-tropical zone with annual rainfall from 307 to 619 mm the average being 520 mm. The distribution of rain is quite erratic as can be seen from the fact that the number of rainy days ranges between 15 to 45 days in different years. Most of the rainfall is received from South-West monsoon. This tract is in rain shadow area lying on the eastern side of the western ranges and agroclimatically falls in scarcity zone having low rainfall and dry climate (Table 1).

3.1.5 Laying of subsurface drainage system

The subsurface drains were laid out over 8.1 ha area with different spacing i.e. 15, 30, 45 and 60 m and depth 60, 90, 120 cm.

3.1.5.1 Lateral drain

Material	:	PVC, corrugated perforated pipe
Perforation size	:	20 x 15 mm
Perforation No.	:	120 per m length
Diameter	:	80 mm OD
Slope given	:	0.2 per cent

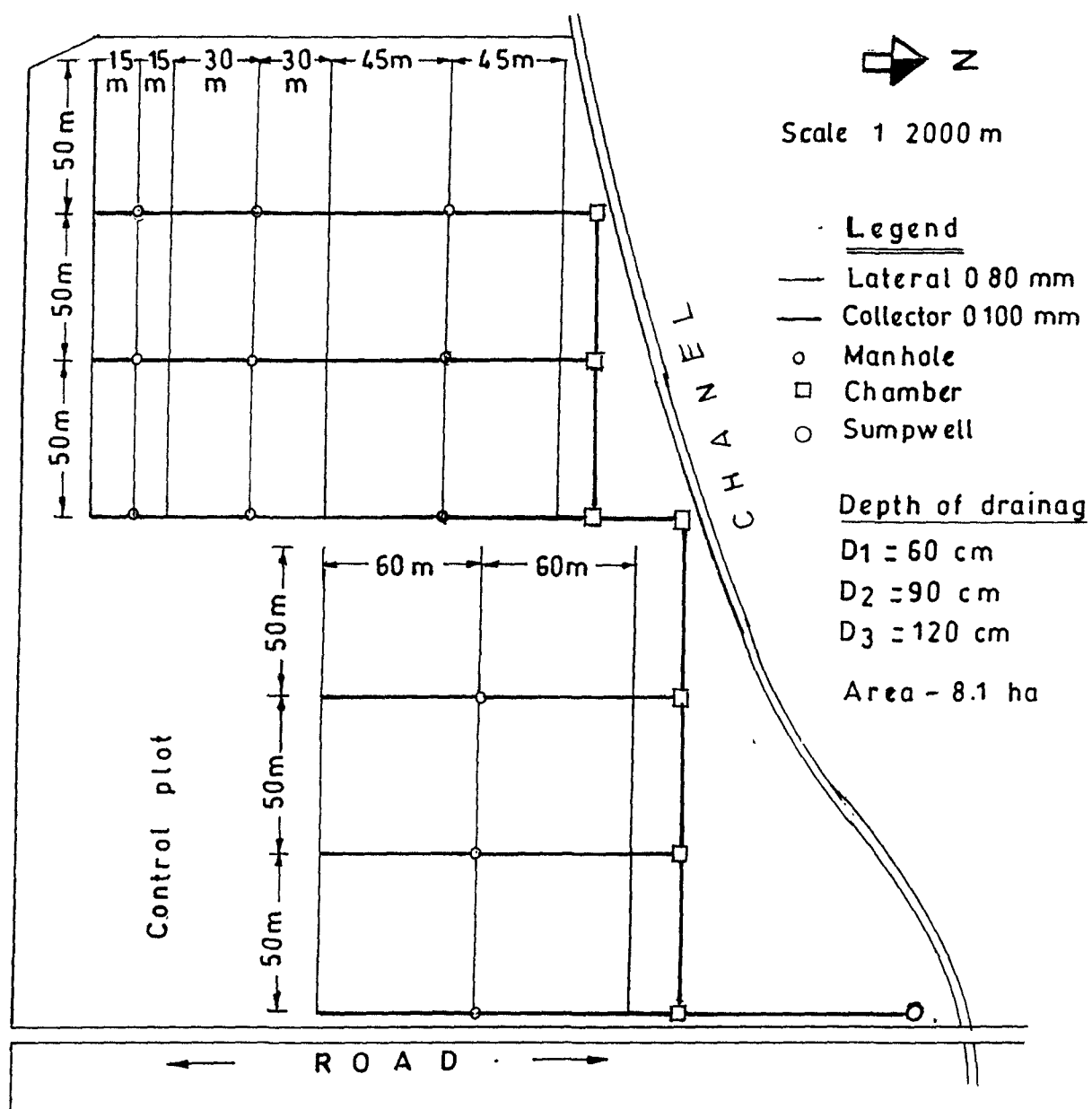


Fig.1 Map showing the experiment layout for study area.

3.1.5.2 Collector/Main drain

Material : PVC, corrugated non-perforated pipe
 Diameter : 100 mm OD
 Slope given : 0.1 per cent

3.1.5.3 Manholes

Depth of manholes : according to the depth of drain

1. 100 cm for 60 cm depth
2. 130 cm for 90 cm depth
3. 160 cm for 120 cm depth

Diameter of manhole : 1 m (inside)

3.1.6 Columns

PVC columns having diameter 15 cm were used for studying leaching behaviour of soil.

3.1.7 Pots

Plastic pots having size 34 x 34 x 47 cm were used for wheat sowing.

3.1.8 Collection of soil samples

3.1.8.1 Profile samples

Five representative soil profiles were dug on the study area of an about 1 m x 1m size and samples were collected at three depths viz., 0-30, 30-60, 60-90 cm.

3.1.8.2 Surface soil

The study area was laid out on grid basis by 50 m x 50 m and from each grid point one samples were collected from 0-30 cm depth at an interval of four months.

3.1.9 Collection of water samples

In order to assess the effect of sub-surface drainage leachate from the drains were collected periodically at an interval of one month for one year for salinity assessment.

3.1.10 Collection of plant samples

For studying the uptake of nutrient by wheat crop plant samples were collected after harvest of wheat crop from pot culture experiment and analysed it for N, P, K, Fe, Mn, Zn and Cu content

3.2 Experimental details

3.2.1 Field study

- i. Area of field : 8.1 ha
- ii. Spacing of grid : 50 x 50 m
- iii. No. of grid samples : 30
- iv. No. of drain chambers : 12

Treatment details

- D₁ : Control
- D₂ : Subsurface drainage spacing 15 m and depth of 60 cm
- D₃ : Subsurface drainage spacing of 15 m and depth of 90 cm
- D₄ : Subsurface drainage spacing of 15 m and depth of 120 cm
- D₅ : Subsurface drainage spacing of 30 m and depth of 60 cm
- D₆ : Subsurface drainage spacing of 30 m and depth of 90 cm
- D₇ : Subsurface drainage spacing of 30 m and depth of 120 cm
- D₈ : Subsurface drainage spacing of 45 m and depth of 60 cm
- D₉ : Subsurface drainage spacing of 45 m and depth of 90 cm
- D₁₀ : Subsurface drainage spacing of 45 m and depth of 120 cm

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- D_{11} : Subsurface drainage spacing of 60 m and depth of 60 cm
 D_{12} : Subsurface drainage spacing of 60 m and depth of 90 cm
 D_{13} : Subsurface drainage spacing of 60 m and depth of 120 cm

3.2.2 Column study

- No. of columns : 14
 No. of replication : 2
 No. of treatments : 7

Treatment details

- C_1 : Control
 C_2 : FYM @ 10 Mg ha⁻¹
 C_3 : Iron pyrite @ 5 Mg ha⁻¹
 C_4 : Press mud compost @ 5 Mg ha⁻¹
 C_5 : Sulphur @ 400 kg ha⁻¹
 C_6 : Iron pyrite @ 5 Mg ha⁻¹ + Press mud compost @ 5 Mg ha⁻¹
 C_7 : Sulphur 400 kg ha⁻¹ + Press mud compost @ 5 Mg ha⁻¹

3.2.3 Pot culture

A pot culture experiment was undertaken with 40 kg soil collected from study area, were filled in pot and different amendments were mixed with it prior to sowing and after saturation of soil wheat seeds were sown, the details of the experiment are as below.

- Crop : Wheat
 Variety : HD. 2189
 Seed rate : 100 kg ha⁻¹

Table 3. Chemical composition of PMC and FYM

Sr. No.	Ingredients	PMC	FYM
I.	Macronutrients per cent on oven dry basis (ODB)		
1.	Total nitrogen	1.54	0.79
2.	Total phosphorus	1.01	0.56
3.	Total potassium	0.57	0.63
4.	Total sulphur	0.58	0.21
5.	Organic carbon	19.05	15.42
6.	Total calcium	0.92	0.56
7.	Total magnesium	0.13	0.07
8.	C/N ratio	12.27	19.52
II.	Micronutrients (mg kg⁻¹)		
1.	Iron	7950	3765
2.	Manganese	290	224
3.	Zinc	78	46
4.	Copper	45	34

Table 4. Itemwise expenditure in study area for installation of sub-surface drainage system

Sr. No.	Item	Expenditure (8.1 ha)	Expenditure (1 ha)
1.	Land <u>clearing</u> with JCB	22,825.00	2817.90
2.	PVC corrugated pipe of 80 mm and 100 mm	1,09,332.00	13497.80
3.	Freight charges from kota to Rahuri	20,000.00	2469.60
4.	Sand, cement and rubble for construction of manholes, sump well	86,180.00	10639.50
5.	Fitting material	11,474.00	1416.50
6.	Fabrication of MS sheet guides for laying of pipe and filling of sand around pipe	9,509.00	1174.00
7.	Trenching with JCB	1,94,425.00	24003.00
8.	Charges on job work	49,000.00	6049.40
9.	Digging charges for manholes	3,600.00	444.50
10.	Miscellaneous charges i.e. blasting and removing slurry etc.	5,600.00	691.50
	Total	5,11,945.00	63203.00

Fertilizer dose : 120:60:60 kg NPK ha⁻¹
 Replication : 3
 Treatments : 7
 Design : Completely Randomised Design

Treatment details

T₁ : Control
 T₂ : FYM @ 10 Mg ha⁻¹
 T₃ : Iron pyrite @ 5 Mg ha⁻¹
 T₄ : Press mud compost @ 5 Mg ha⁻¹
 T₅ : Sulphur @ 400 kg ha⁻¹
 T₆ : Iron pyrite @ 5 Mg ha⁻¹ + Press mud compost @ 5 Mg ha⁻¹
 T₇ : Sulphur 400 kg ha⁻¹ + Press mud compost @ 5 Mg ha⁻¹

3.3 Methods

3.3.1 Filling of columns

In the column at the bottom 10 cm sand were filled and over it soil were filled as simulated in the field, 0-30, 30-60 and 60-90 cm and 15 cm constant head ^{with water} were maintained. Two tensiometer were fitted at 30 cm and 60 cm depth and the capillary joined in mercury cup and the mercury rise was measured in order to calculate the flux of water. The end cap was fitted at the bottom of pipe with central hole for collection of leachate (Plate 3D).

3.3.2 Preparation of different qualities of synthetic water

Twenty four different qualities of synthetic water were prepared with six levels of sodium adsorption ratio (SAR) viz., 2.5, 5, 10, 15, 20 and 30 m mol^{1/2} L^{-1/2} and four levels of total electrolyte

concentration (TEC) viz., 5, 10, 20 and 50 meL⁻¹. The Ca : Mg ratio was kept at 1 : 1 in all waters. Pure AR grade chloride salts of calcium magnesium and sodium were used to prepare different quality waters. Ionic composition of different quality water is given in Table 3. Each quality of waters was prepared as below.

As per definition

$$SAR = \frac{Na^+}{\sqrt{Ca^{2+} + Mg^{2+}}}$$

Now, if SAR = A and TEC = Na⁺ +

$$Ca^{2+} + Mg^{2+} = B \text{ or } Ca^{2+} + Mg^{2+} = B - Na^+$$

The SAR can be rewritten as

$$A = Na^+ / [(B - Na^{2+})/2]^{1/2}$$

$$\text{or } (B - Na^+)/2 = (Na^+)/A^2$$

This can be rearranged in a quadratic equation as

$$2 (Na^+)^2 + A^2 Na^+ - A^2 B = 0$$

and here

$$Na^+ = [-A^2 \pm (A^4 + 8A^2B)^{1/2}]/4$$

$$\text{or } Na^+ = [(8B + A^2)^{1/2} - A] A/4 \text{ meL}^{-1}$$

If suppose Na⁺, MeL⁻¹ = X then

$$Ca^{2+} + Mg^{2+} \text{ meL}^{-1} = B - X$$

but Ca : Mg = 1 : 1 therefore

$$Ca^{2+} \text{ meL}^{-1} = (B - X)$$

$$\text{and } Mg^{2+} \text{ meL}^{-1} = B - (Na^+ + Ca^{2+})$$

3.3.3 Procedure for soil equilibration

In a 50 ml centrifuge tubes 4 grammes of < 0.4 mm sieved soil was taken and 30 ml given equilibrating water was added. The suspension was then shaken for 15 minutes and centrifuged. This procedure was repeated three times, after which only the final equilibrium solution was analysed for Na^+ , Ca^{2+} , Mg^{2+} and Cl^- . After decanting off the solution, the tubes plus samples were weighed. The weight of the solution was determined by difference and the solution volume by dividing the density of the solution. The density of the solution was calculated by taking weight of known volume of solution and reported as g cm^{-3} . From these data the final solution SAR and ionic concentration values were calculated for each water quality.

The samples were then extracted three times with 30 ml solution of 1 N NH_4OAC having pH 8.6 and volume was made upto 100 ml and extracts were analysed for the total Na^+ and Cl^- ions.

3.3.4 Calculation of cation exchange equilibrium

These equilibration studies were performed according to the method outlined by Jurinak *et al.* (1984). After preparing the equilibrated soil samples, the method used to calculate the exchangeable sodium (NaX) and exchangeable calcium and magnesium $[(\text{Ca} + \text{Mg})^{1/2} \text{X}]$ was based on the ions excess concept applied to charged interface which takes into account the negative adsorption of anions at the interface. The Na X was calculated as

$$\text{Na X} = T \text{ Na} - \theta \text{ Co Na}$$

Where, $T \text{ Na}$, $\text{me } 100 \text{ g}^{-1}$ is the total Na^+ ions content obtained by extracting the sample with a N NH_4OAC solution having pH 8.6 and

QCoNa, me 100 g⁻¹ is the soluble Na⁺ ions content, where Q is the water content cm³ 100 g⁻¹ and CoNa is the equilibrium concentration me cm⁻³ of Na ions.

The term $(Ca + Mg)^{1/2} X$ was calculated as

$$(Ca + Mg)^{1/2} X = CEC - NaX - Yan$$

Where, CEC is the cation exchange capacity me 100 g⁻¹ and Yan is the anion exclusion term that accounts for the anions being repelled from the region adjacent to negatively charged clay surface. The term Yan is defined as a positive number and is calculated using the chloride ion as.

$$Y Cl = \theta CoCl - TCl$$

Where, θ is the water content (cm³ 100 g⁻¹) CoCl is the equilibrium chloride concentration (me 100 g⁻¹) and TCl is the total chloride content obtained by extracting the samples with 1 N NH₄OAC solution with pH 8.6. The exchangeable sodium ratio (ESR) in the system was computed as

$$\begin{aligned} ESR &= NaX / (Ca + Mg)^{1/2} X \\ &= NaX / CEC - NaX - Yan \end{aligned}$$

and ESP was calculated as

$$ESP = ESR / 1 + ESR$$

Properties of equilibrium and equilibrating solution are presented in Appendix 13.

3.3.5 Calculations of activity of soluble ions in the equilibrium solution

The activity coefficient of mono and divalent ions of the equilibrium solutions of these soils was calculated by extended Debye

and Huckel equation as given by Bolt (1976) for the solution strength less than 0.1 mole L^{-1} as,

$$-\text{Log } f_i = \frac{Az^2 I}{1 + aB I}$$

and for ionic strength more than 0.1 mole L^{-1} as

$$-\text{Log } f_i = \frac{Az^2 I}{1 + aB I} - 0.3 I$$

Where,

f_i is the activity coefficient of the ion, z is the valency of an ion, A , a constant $(0.5081 \text{ mole L}^{-1})^{-0.5}$, B is temperature constant $(0.33 A^{0.1} \text{ mole}^{-0.5} \text{ L}^{0.5})$ a , is the ionic size parameter ($\text{\AA}^0$) and I is the ionic strength of the solution (mole L^{-1}). the value of aB is taken as 2.2967 and 1.312 for divalent and monovalent ions, respectively.

The ionic strength (I) of the solution was calculated by

$$I = \frac{1}{2} \sum C_i Z_i^2$$

Where,

C_i = Concentration of ion in mole L^{-1} and

Z_i = Valency of the ions

The activity of an ion was calculated by multiplying activity coefficient with its molar concentration i.e. $a = f_i \cdot C_i$ and were used to calculate the selectivity coefficient as described below.

Selectivity coefficients

The values of different selectivity coefficients were calculated by using the following equations.

$$K_G = \frac{N^+}{N^{++}} \cdot \frac{(a^{++})^{0.5}}{a^+} \quad \text{Gapon (1933)}$$

$$K_V = \frac{(M^+)^2}{(M^{++})} \cdot \frac{a^{++}}{(a^+)^2} \quad \text{Vanselow (1932)}$$

$$K_{KDO} = \frac{(M^+)^2}{M^{++} (1.5 M^{++} + M^+)} \cdot \frac{a^{++}}{(a^+)^2} \quad \text{Krishnamoorthy et al. (1948)}$$

Where,

N^+ and N^{++} are the equivalent fractions

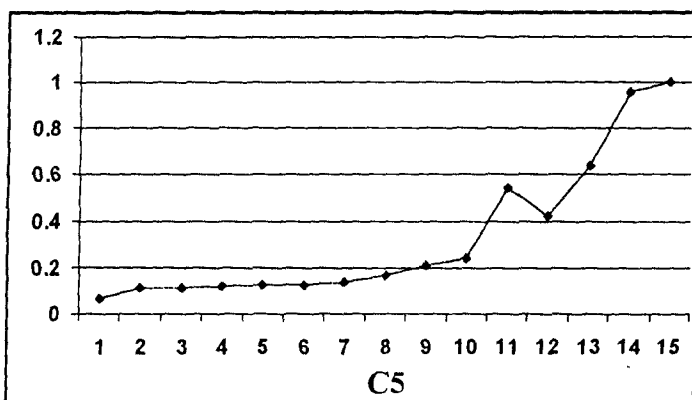
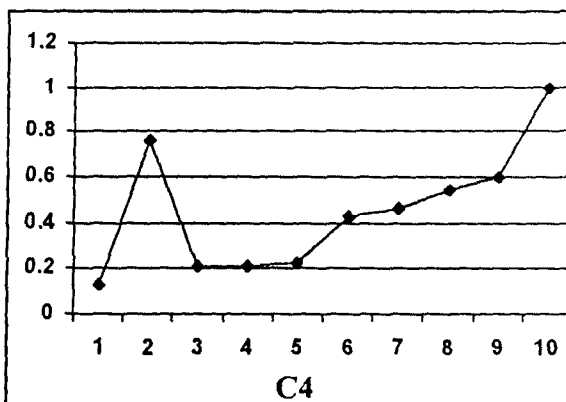
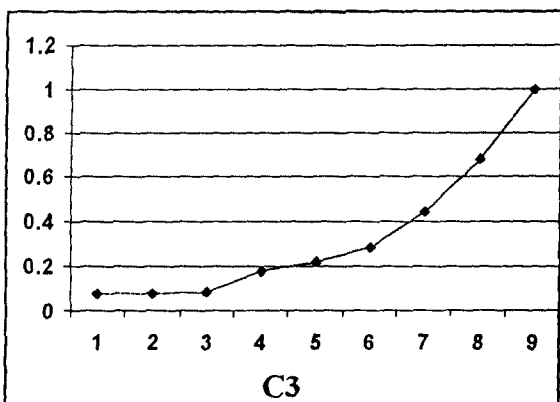
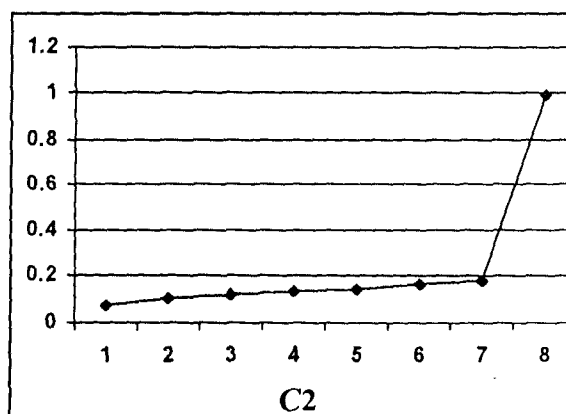
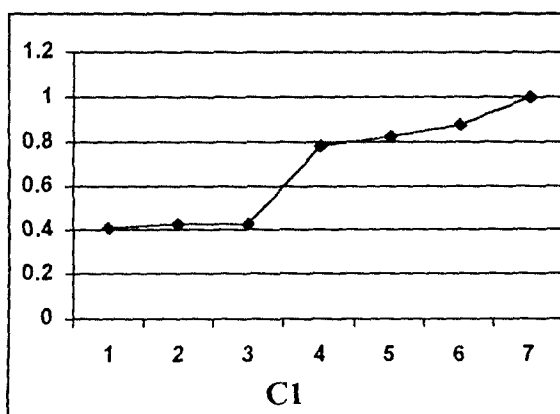
[] and M^+ and M^{++} are mole fractions of monovalent and divalent cations, respectively in the exchange complex a^+ and a^{++} are the activity in mole L^{-1} of mono and divalent cations, respectively in the equilibrium solution.

3.3.6 Break through curve

The effluent was collected from the columns with a fraction collector and analysed for chloride. The reduced concentrations of chloride were plotted against the effluent volume. Reduced concentration was expressed as C/Co where, C = concentration of chloride in a particular fraction and Co = Total Cl^- concentration in percolating solution. These curves were called Break through curves (BTC) of chloride (Fig.2).

3.3.7 Methodology adopted

The methods used for different soil parameters are given in Table 4.



X Axis - Pore Volume
Y Axis - Reduced Concentration
of Chloride

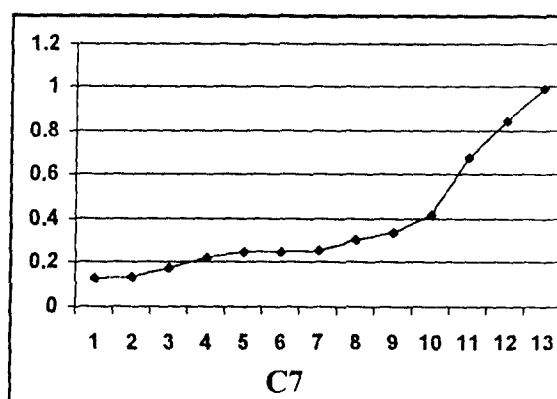
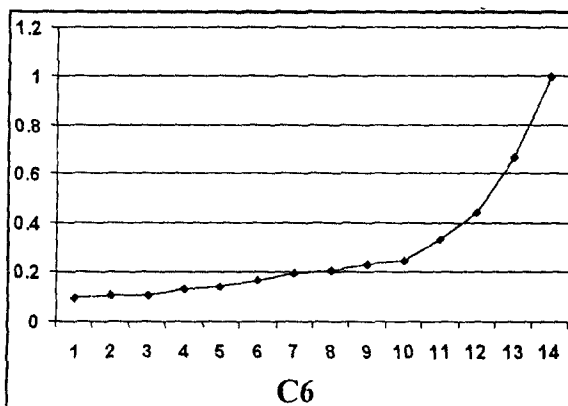


Fig. 2 Break Through Curve for Chloride

3.4 Statistical analysis

The data obtained in respect of soil characteristics analysed for spatial variability in variowin software (IASRI, New Delhi) and for available nutrients and uptake of nutrients by wheat crop statistically processed as per the procedure given by Panse and Sukhatme (1967).

Table 5. Chemical composition of different quality of waters

SAR m	TEC 5 meL ⁻¹				TEC 10 meL ⁻¹				TEC 20 meL ⁻¹				TEC 50 meL ⁻¹			
mol ^{1/2} L ^{-1/2}	Na ⁺	Ca ²⁺	Mg ²⁺	Cl ⁻	Na ⁺	Ca ²⁺	Mg ²⁺	Cl ⁻	Na ⁺	Ca ²⁺	Mg ²⁺	Cl ⁻	Na ⁺	Ca ²⁺	Mg ²⁺	Cl ⁻
2.5	2.68	1.16	1.16	5.0	4.24	2.88	2.88	10	6.49	6.75	6.75	20	11.03	19.48	19.48	50
5	3.82	0.59	0.59	5.0	6.22	1.72	1.72	10	10.75	4.62	4.62	20	19.51	15.24	15.24	50
10	4.58	0.21	0.21	5.0	8.54	0.73	0.73	10	15.31	2.34	2.34	20	30.90	9.54	9.54	50
15	4.79	0.10	0.10	5.0	9.24	0.375	0.375	10	17.33	1.33	1.33	20	37.5	6.25	6.25	50
20	4.88	0.06	0.06	5.0	9.54	0.225	0.225	10	18.32	0.84	0.84	20	41.42	4.28	4.28	50
30	4.94	0.025	0.025	5.0	9.78	0.10	0.10	10	19.18	0.41	0.41	20	45.41	2.29	2.29	50

Table 6. Methods used for analysis

Sr. No.	Property	Method adopted	Reference
	Soil analysis		
A.	Physical properties		
1.	Soil texture	International pipette	Piper (1966)
2.	Bulk density	Clod	Blake and Hartage (1986)
3.	Hydraulic conductivity	Constant head	Klute and Dirksen (1986)
4.	Infiltration rate	Double ring infiltrometer	Black <i>et al.</i> (1968)
5.	Moisture retention	Pressure plate	Richard (1948)
6.	COLE	Soil paste rod	Schafer and Singer (1976)
B.	Chemical properties		
1.	pH (1 : 2.5)	Potentiometry	Jackson (1973)
2.	EC (1 : 2.5) dSm ⁻¹	Conductivity bridge	Jackson (1973)
3.	Organic carbon (%)	Wet digestion method	Walkley and Black (1934) Nelson and Sommers (1982)
4.	CaCO ₃ (%)	Rapid titration	Piper (1966)
5.	Avail. Nitrogen	Alkaline permanganate	Subbiah and Asija (1956)
6.	Avail. Phosphorus	Na HCO ₃ (0.5 M) pH 8.5 (ascorbic acid)	Watanabe and Olsen (1965)
7.	Avail. Potassium	Neutral normal NH ₄ OAc extract pH 7.0	Knudsen <i>et al.</i> (1982)
8.	Avail. Zn, Fe, Mn, Cu	DTPA extractable	Lindsay and Norvell (1978)
9.	CEC (C mol (P ⁺) kg ⁻¹)	Saturating solution NH ₄ OAc and extracting solution Mg (NO ₃)	Palemio and Rhoados (1977)

Table 6 contd...

Sr. No.	Property	Method adopted	Reference
C.	Saturation paste extract	Extract through vacuum	Richard (1968)
1.	pHe	Glass electrode potentiometric	Richard (1968)
2.	ECe	Conductometric	Richard (1968)
3.	CO_3^{--} , HCO_3^- and Cl^-	Titrimetric	Richard (1968)
4.	SO_4^{--}	Turbidimetry	Chopra and Kanwar (1980)
5.	Ca^{++} and Mg^{++}	Versanate titration	Richard (1968)
6.	Na^+ and K^+	Flame photometer	Ricahrd (1968)
D.	Plant analysis		
1.	Nitrogen	Microkjeldhal	Jackson (1956)
2.	Phosphorus	Vandophosphomoly bdate yellow colour method	Piper (1966)
3.	Potassium	Flame photometer	Jackson (1973)
4.	Fe, Mn, Zn and Cu	Atomic absorption spectrophotometric (Perkinelmer 2380)	Lindsay and Norvell (1978)
E.	Water analysis		
1.	pH	Glass electrode potentiometric	Richard (1968)
2.	EC	Conductometric	Richard (1968)
3.	CO_3^{--} , HCO_3^- and Cl^-	Titrimetric	Richard (1968)
4.	SO_4^-	Turbidimetry	Chopra and Kanwar (1980)
5.	Ca^{++} and Mg^{++}	Versanate titration	Richard (1968)
6.	Na^+ and K^+	Flame photometer	Richard (1968)
7.	NO_3^-	Steam distillation with Devardas alloy + MgO	Black (1965)

Table 4 contd...

Sr. No.	Property	Method adopted	Reference
F.	Derived parameters		
1.	Gapon constant	$K_g = \frac{N^+ (a^{++})^{0.5}}{N^{++} a^+}$	Gapon (1933)
2.	Vanselow constant	$K_v = \frac{(M^{++})^2 (a^+)^2}{(M^+)^2 a^{++}}$	Vanselow (1932)
3.	K_{KDO}	$K_{KDO} = \frac{(M^{++})^2 (a^+)^2}{M^{++}(1.5 M^{++} + M^+) (a^+)^2} a^{++}$	Krishnamoorthy <i>et al.</i> 1948)
4.	SAR	$SAR = \frac{Na^+}{\sqrt{Ca^{2+} + Mg^{2+}/2}}$	Richard (1968)
5.	ESR	$\frac{Ex. Na}{CEC-EX Na-Yan}$	Jurinak <i>et al.</i> (1984)
6.	ESP	$\frac{100 (-0.0126 + 0.01475 SAR)}{1 + (-0.0126 + 0.01475 SAR)}$	Richards (1958)

Chapter Opener Page



RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

The field experiment was conducted for assessment of saline-sodic swell-shrink soil during reclamation process at College of Agricultural Engineering, Central Research Farm, Block-B, Mahatma Phule Krishi Vidyapeeth, Rahuri and the laboratory studies were conducted at Micronutrient Research Laboratory, Department of Agricultural Chemistry and Soil Science, Mahatma Phule Krishi Vidyapeeth, Rahuri and the results obtained are presented and discussed under different heads.

4.1 Assessment of saline sodic soil

4.4.1 Properties of saline-sodic soils

4.4.1.1 Morphometric properties

The solum thickness of all the saline sodic pedons ranged from 50 to 120 cm. The colour was 10 YR 3/3 to 5/3. The texture was clay and structure was moderate medium sub angular blocky to prismatic, dry hard, moist friable, wet sticky and plastic consistency 0.5 to 4 cm wide cracks in dry season and thin salt encrustation observed on the surface (Appendix-I). Similar results were reported by Dubey and Sharma (1990).

The texture of sub-surface horizon was clay, weak, structureless medium subangular blocky, peds showing shiny pressure faces weak slickensides (intersecting to non intersecting) dry hard to very hard, moist friable to very firm, ground water table at 0.8 to 1.2 m in all the pedons except pedon-1. Where it was 3 m aquic moisture

regime in all the pedons. Due to presence of shallow water table and poor drainage, these soils are subjected to occasional flooding in rainy season.

4.4.1.2 Taxonomic classification

Pedon 1, 2, 3, 4 and 5 showed typical saline. Sodic soil characteristics with aquic moisture regime as ground water fluctuated from 0.8 to 1.2 m from surface, ESP was > 15 , clay content was > 35 per cent, predominance with smectitic, 3 to 4 cm wide cracks extended upto 50 cm and hence it was classified as fine smectitic, hyperthermic family of Vertic Halaquept and tentative soil series was named Phule-3, which was proposed by Durgude (1999). Medirata et al. (1985) also classified the salt-affected soils of Harsi command area of Madhya Pradesh as Vertic Halaquept.

4.4.1.3 Physical properties

4.4.1.3.1 Bulk density

The bulk density of saline sodic pedon , ranged from 1.30 to 1.76 Mg^{-3} , which were generally increased with depth. This increase in bulk density might be due to the compactness in the sub-surface horizon, similar results were reported by Surekha et al. (1997).

4.4.1.3.2 Coefficient of linear extensibility (COLE)

The data pertaining the COLE value of saline sodic pedons are presented in Table 7 and it was revealed from the data that the COLE value of all the saline-sodic soil pedons are ranged from 0.18 to 0.29. It showed increasing trend with depth. This may be due to

Table 7. Chemical and physical properties of soil pedons

Depth	pHe	ECe dSm ⁻¹	me L ⁻¹						SAR	ESP	B.D. Mg m ⁻³	COLE	
			Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻					SO ₄ ²⁻
Pedon-1													
0-30 cm	8.34	8.69	15.50	10.00	49.78	0.11	51.00	8.00	19.99	13.94	16.21	1.47	0.18
30-60 cm	8.31	6.77	10.00	9.00	51.47	0.10	46.00	8.5	18.94	16.71	18.95	1.61	0.26
60-90 cm	8.84	4.48	5.0	3.5	54.73	0.10	24.0	9.2	15.8	26.56	27.49	1.76	0.29
Pedon-2													
0-30 cm	8.50	5.98	9.3	8.2	37.78	0.08	33.0	7.5	30.04	12.85	15.03	1.45	0.17
30-60 cm	8.63	4.87	7.0	5.0	39.9	0.09	24.0	7.5	20.31	16.35	18.61	1.55	0.24
60-90 cm	8.70	3.76	5.0	3.2	40.04	0.08	18.0	8.0	10.47	19.82	21.67	1.71	0.25
Pedon-3													
0-30 cm	8.54	8.67	17.0	12.5	50.0	0.09	43.0	7.0	31.0	13.62	15.22	1.43	0.18
30-60 cm	8.69	6.27	11.0	6.5	57.73	0.07	32.0	7.5	26.13	19.56	21.64	1.57	0.23
60-90 cm	8.85	5.84	8.5	4.5	61.13	0.07	25.0	7.5	18.87	24.09	25.50	1.62	0.26
Pedon-4													
0-30 cm	8.54	5.25	13.0	11.5	48.16	0.12	30.2	6.5	21.0	13.76	15.99	1.35	0.19
30-60 cm	8.58	4.51	9.5	8.0	48.51	0.11	22.2	6.5	17.64	16.42	18.68	1.54	0.25
60-90 cm	8.64	2.98	7.5	6.8	49.28	0.08	12.2	6.5	9.84	18.46	20.62	1.65	0.28
Pedon-5													
0-30 cm	8.37	6.75	12.0	10.5	50.37	0.08	37.6	5.0	22.0	15.02	20.46	1.26	0.19
30-60 cm	8.44	5.66	8.5	6.0	50.86	0.08	26.2	7.0	18.36	18.9	21.02	1.30	0.25
60-90 cm	8.64	4.69	4.0	3.0	52.17	0.07	15.0	8.0	13.15	27.89	28.52	1.47	0.28



A) Soil surface of saline -sodic soil with surface salt accumulation



B) Soil surface of swell-shrink saline sodic soil with wide cracks



Pedon-1 Showing typical characteristics of Saline-sodic swell-shrink soil (Vertic Halaquept)



D) Pedon-2 Showing well developed pressure faces and aquic moisture regime in Saline-sodic swell-shrink soil (Vertic Halaquept)

increase in sodicity with depth. Similarly results were obtained by Durgude (1999).

4.4.1.4 Chemical properties of saline sodic soil

4.4.1.4.1 pHe

From the Table 7 it is observed that the pHe values in all the five representative soil profiles of saline sodic soil ranged from 8.27 to 8.85 at all depths. Similar pHe value range was also reported by Sagare et al. (1991) in saline sodic soil of Purna command of areas of Maharashtra. Surface horizon showed low pHe values ranged from 8.27 to 8.54 which might be due to high soluble neutral salt concentration. The pHe values increased with depth, it might be due to the high sodimized clay content in sub surface soil horizon i.e. at 60-90 cm.

4.4.1.4.2 ECe

The electrical conductivity of saturation paste extract of saline-sodic soil horizons ranged from 5.25 to 8.69 dSm⁻¹ in upper 0-30 cm layer. The values in all the pedon decreased with depth indicating the initiation of sodimization process in the lower horizon (Balpande et al., 1996).

4.4.1.4.3 Cationic concentration

The cations viz., Ca²⁺, Mg²⁺, Na⁺ and K⁺ in all the five pedons are presented in Table 7. The Ca²⁺ content was in the range from 9.3 to 17.0 meL⁻¹, 7.0 to 11.0 meL⁻¹ and 4 to 8.5 meL⁻¹ at 30, 60 and 90 cm depths, respectively. Mg²⁺ was 8.2 to 12.5, 6.0 to 9.0 and 3 to 6.8 meL⁻¹ at 0-30, 30-60 and 60-90 cm depths, respectively where as the concentration of sodium at 0-30, 30-60 and 60-90 cm

depth was 37.78 to 50.37, 39.9 to 51.47 and 40.04 to 52.17 meL^{-1} , respectively. Similarly, the concentration of potassium was 0.08 to 0.12, 0.08 to 0.11 and 0.07 to 0.10 meL^{-1} at 0-30, 30-60 and 60-90 cm depths, respectively. The cationic concentration showed following decreasing trends $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$. The high sodium content might be due to formation of these soils from basalt, which contained sufficient amount of alkali feldspar to give alkali and alkaline earth bases. These results are supported with the findings of Dubey and Sharma (1990).

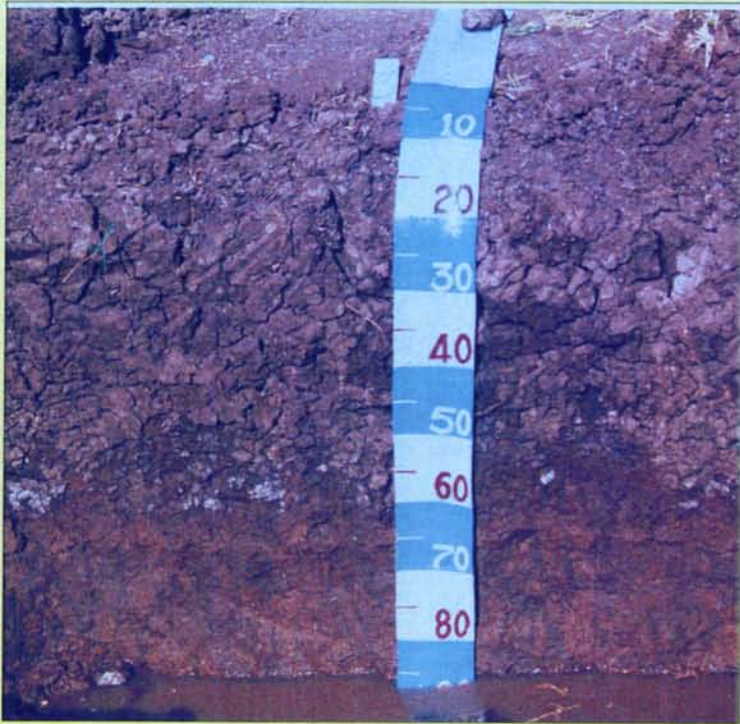
4.4.1.4.4 Anionic concentration

The Cl^- , HCO_3^- , and SO_4^{2-} in all three saline sodic pedon ranged from 12.2 to 51.0, 6.5 to 9.2 and 9.84 to 31.0 meL^{-1} respectively. The data regarding the anionic concentration showed following decreasing order $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^-$.

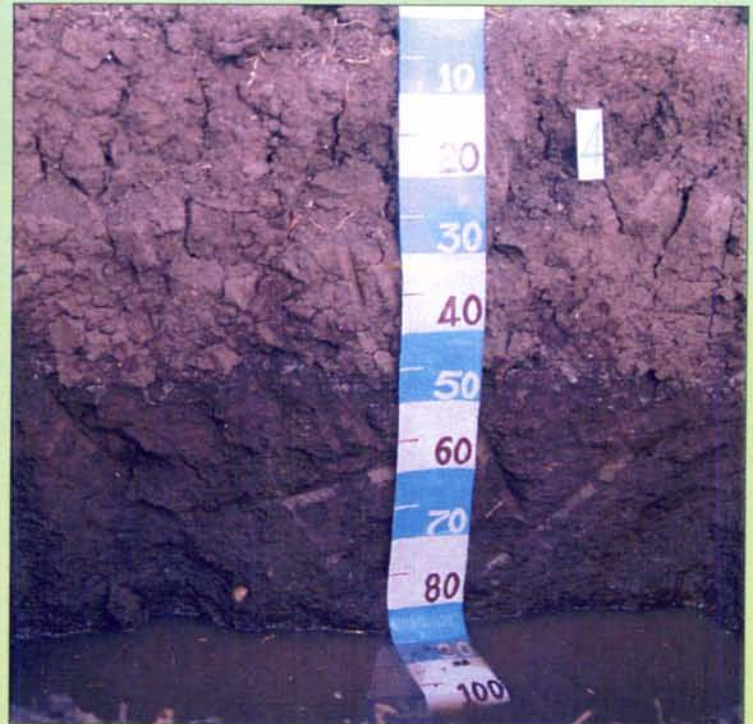
In saline sodic pedons, the dominant anionic concentration was of Cl^- . It was followed by SO_4^{2-} and HCO_3^- . The chloride and sulphate content decreased with depth. However HCO_3^- increased with depth. Similar results were reported by Durgude (1999).

4.4.1.4.5 Sodium adsorption ratio (SAR)

The data pertaining to the sodium adsorption ratio are presented in Table 7. The SAR values in all the five saline sodic pedons ranged from 13.62 to 27.89 $\text{mmol}^{1/2}\text{L}^{-1/2}$. The SAR values increased with depth. It indicated that sodification started in deeper layer and it is continuing upward. Sagare et al. (1991) recorded the similar trend.



A) Pedon-3 Showing aquic moisture regime in Saline-sodic swell-shrink soil (Vertic Halaquept)



B) Pedon 4, Showing aquic moisture regime in Saline-sodic swell-shrink (Vertic Halaquept)



C) Pedon 5 -Showing aquic moisture regime and slickensides in Saline-sodic swell-shrink soil (Vertic Halaquept)



D) Excavation of trench for laying drainage pipe

4.4.1.4.6 Exchangeable sodium per cent (ESP)

The data regarding exchangeable sodium per cent at different depths presented in Table 7. The ESP value of all the pedons of saline sodic soil ranged from 15.03 to 28.52. The ESP values increased with depth in all five pedons. The increase in ESP values with depth might be due to high sodimized clay content strong electrolyte condition and low electrolyte concentration Mohite (1978) and Rakhunde (1980) have also reported similar results in saline-sodic soils of Sangali district of Maharashtra.

4.1.2 Spatial variability in soil properties during reclamation process

To assess the saline sodic swell shrink soil during the reclamation process, the soil samples were collected from 50 m x 50 m grid spacing and analysed it for E_{Ce}, Na, SAR, ESP and soil bulk density and semi-variogram were prepared and presented.

4.1.2.1 Electrical conductivity of the saturation paste extract of soil

Descriptive statistics of the data viz., mean, standard deviation (S.D.), maximum, minimum and coefficient of variation (%) are given in Table 8.

It should be noted that in all cases the E_{Ce} decreases with time i.e. at an interval of four months upto one year. The coefficient of variation ranged from 57.18, 60.57, 62.37 and 64.02 in the month of June 2001, October 2001, February 2002 and June 2002 respectively which indicated considerable high within site variability

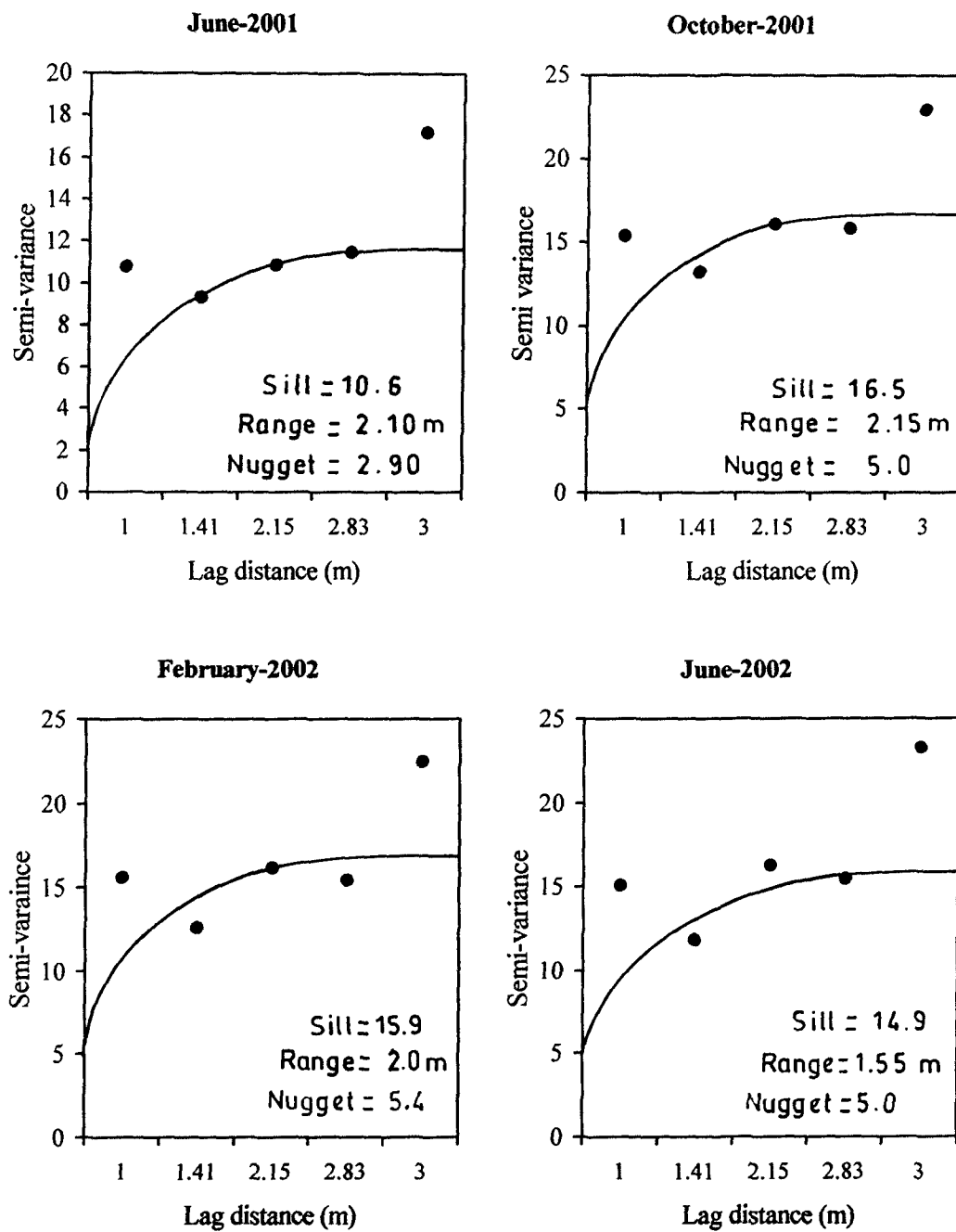


Fig. 3. Semi-variograms for ECE

of the soil salinity. This may accounted for its proximately to canal on one side and proximately to sub canal (University canal) on other sides.

The semi-variogram for soil salinity changes at an interval of four months are shown in Fig 2. There was increase in semi-variance from June 2001 to June 2002. It indicated the increase in variation in E_{Ce}. This might be due to the improvement of soil salinity with the installation of sub-surface drainage. The intercept i.e. nugget variance which is the estimate of γ at $h = 0$. The range and sill are depicted on Fig. 3.

The range of surface soil salinity was 2.1, 2.15, 2 and 1.55 m in the month of June 01, Oct 01, Feb. 02 and June 02, respectively. The wide variation in the soil E_{Ce} reflects that the land was very badly degraded and undulated. The presence of ground water at upper depth have much influence on soil salinity. Similar results were reported by Nayak et al. (2002).

4.1.2.2 Sodium content in saturation paste extract of soil

The data pertaining to the spatial statistics of sodium content in saturation paste extract of soil are presented in Table 9.

The table revealed that in all the four sampling intervals, the sodium content decreased over initial value. The descriptive statistics indicated that the coefficient of variation increased as sodium content in saturation paste extract of soil decreased. The coefficient of variation was 53.73, 58.89, 60.65 and 66.48 per cent in the month of June 2001, October 2001, February 2002 and June 2002, respectively. The coefficient of variation indicated that there

Table 8. Descriptive statistics of the ECe (dSm^{-1}) of the soil

Time	Number of samples	Minimum	Maximum	Mean	SD	CV (%)
June-2001	30	2.09	23.00	7.94	4.54	57.18
October 2001	30	1.91	22.84	7.81	4.73	60.57
February 2002	30	1.60	22.60	7.56	4.72	62.37
June 2002	30	1.02	22.10	7.41	4.75	64.02

Table 9. Descriptive statistics of the sodium (meL^{-1}) of the saturation paste extract of soil

Time	Number of samples	Minimum	Maximum	Mean	SD	CV (%)
June-2001	30	10.00	134.80	48.51	26.06	53.73
October 2001	30	7.82	130.00	41.28	24.31	58.89
February 2002	30	8.47	126.00	46.40	28.14	60.65
June 2002	30	8.21	130.00	42.58	28.31	66.48

Table 10. Descriptive statistics of the SAR of the saturation paste extract of soil

Time	Number of samples	Minimum	Maximum	Mean	SD	CV (%)
June-2001	30	5.00	22.73	13.97	4.00	28.68
October 2001	30	5.01	24.01	12.20	4.65	38.12
February 2002	30	5.70	30.141	13.17	5.37	40.77
June 2002	30	4.79	22.38	12.48	7.00	56.14

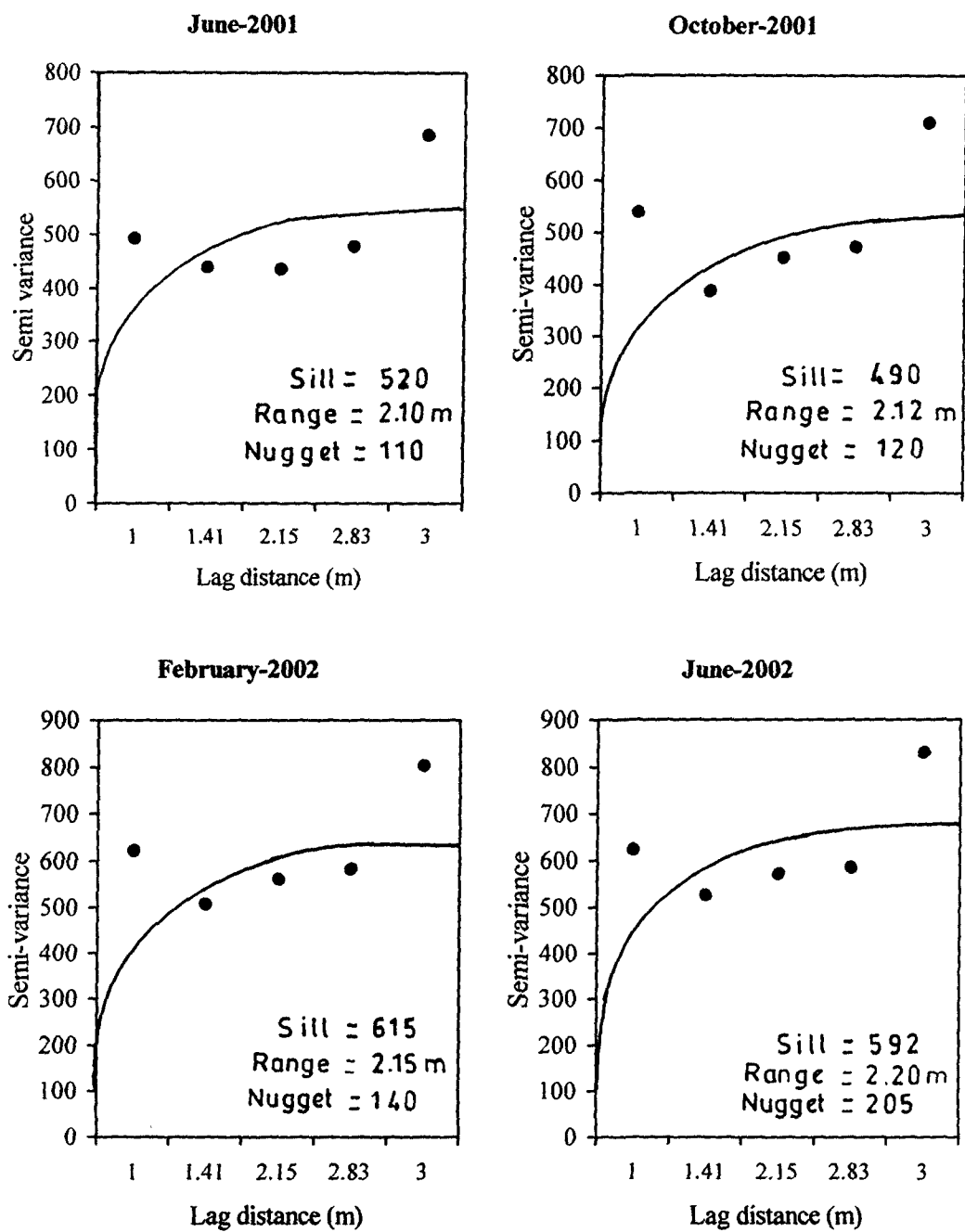


Fig. 4. Semi-variograms for sodium content in saturation paste extract of soil

was large variation in sodium content of saturation paste extract from grid point to grid point i.e. 50 m x 50 m.

From the Fig 4 it was observed that the semi-variogram showed increasing trend from June 2001 to June 2002 and it increased as lag distance. This reflects that the sodium content influence by the reclamation measures i.e. installation of subsurface drainage at different depth and spacing. The major difference between semi-variograms at different time was in the amount of variation occurring over small distance (nugget) i.e. 110, 120, 140 and 205 in June 2001, October 2001, February 2002 and June 2002, respectively (Fig. 4).

4.1.2.3 Sodium adsorption ratio of saturation paste extract of soil

The data regarding the descriptive statistics viz., mean, standard deviation (SD), maximum, minimum and coefficient of variation (%) with respective SAR are given in Table 10.

In all the sampling time the mean SAR decreased with time i.e. at an interval of four months. The coefficient of variation ranged from 28.68 per cent for June 2001, 38.12 per cent for October 2001, 40.77 per cent for February 2002 and 56.14 per cent for June 2002. The coefficient variation indicated considerable high within site variability of the sodium adsorption ratio of soil.

The semi-variogram for sodium adsorption ratio are presented in Fig 5. From these figures it is observed that the semi-variogram showed considerable changes in its structure from June 2001 to June 2002. The semi-variogram showed an increasing trend

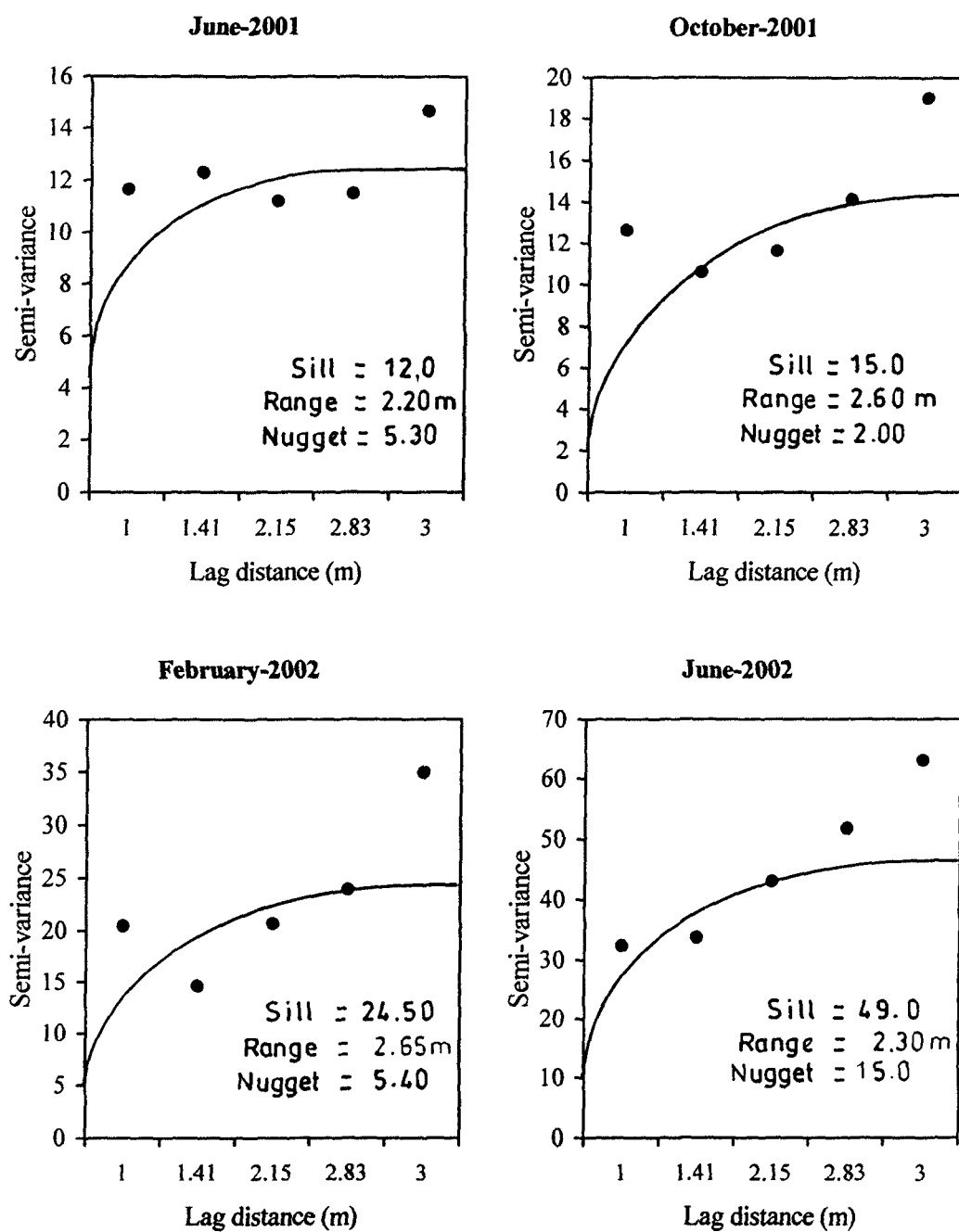


Fig. 5. Semi-variograms for sodium adsorption ratio of saturation paste extract of soil

at an interval of four months upto one year. The changes in semi-variogram indicated the increase in variation of SAR. This variation might be due to the reclamation measures which reclaim the soil but intensity of reclamation was different for different treatments.

The range of surface soil was 2.20, 2.60, 2.65 and 2.35 m in June 01, Oct. 01, Feb. 02 and Oct. 02, respectively. The nugget and sill values are depicted in Fig. 5 and from this figure it is revealed that the sill values increased with time i.e. 12, 15, 24.5 and 49 in June 01, Oct. 01, Feb. 02, respectively in one year. This indicates that the amount of variation occurring over small distances.

On the whole it was observed that there was large variation in sodium adsorption ratio of soil.

4.1.2.4 Exchangeable sodium per cent in soil

Descriptive statistics of the data i.e. mean, standard deviation (S.D.), maximum, minimum and coefficient of variation (%) for ESP are given in Table 11.

The mean ESP decreased from 16.05 to 13.55 per cent within one year. According to a classification scheme for identifying the extent of variability for soil properties based on their coefficient of variation values in which CV values 0-15, 16-35 and > 36 indicate little, moderate and high variability respectively. The coefficient of variation ranged 26.59, 30.57, 35.43 and 45.58 per cent in the month of June 2001, October 2001, February 2002 and June 2002 respectively indicating considerable high within site variability of the soil ESP. This may be accounted for its proximity to main Mula canal on one side and proximity to university sub-canal on other sides.

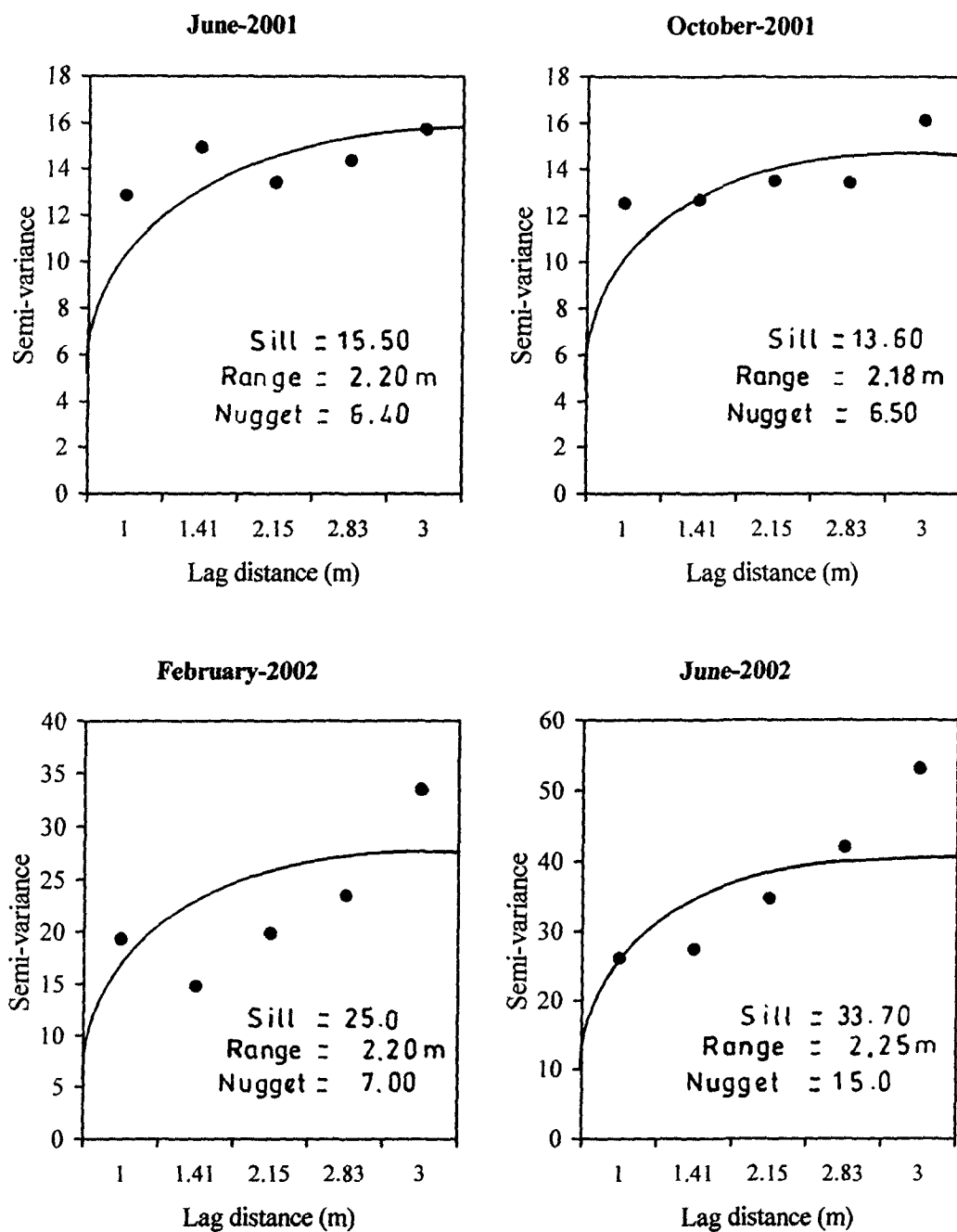


Fig. 6. Semi-variograms for exchangeable sodium percent in soil

The semi-variogram for the surface (0-30 cm) soil ESP are shown in Fig 6. There was a considerable difference in the direction of semi-variogram with respect to time i.e. June 2001, October 2001, February 2002 and June 2002. The semi-variogram indicated that the semi-variance increased with time which might be due to the variation developed in soil ESP by installation of sub-surface drainage.

The key parameters of the semi-variogram are presented on Fig. 6. The intercept i.e. nugget variance which is the estimate of γ at $h = 0$, provides an indication of short distance variation. The range of semi-variance is the distance (h) at which the γ attains maximum value (sill). At and beyond this distance, the sample becomes spatially independent and uncorrelated with each other. The range of the semi-variogram which indicates the size of the zone of influence i.e. the size of area in which the samples are statistically associated with a sample from the centre of area.

The zone of influence (range) for the soil ESP was 2.20, 2.18, 2.20 and 2.25 m in the month of June 2001, October 2001, February 2002 and June 2002. The wide variation in the zone of influence on soil ESP reflects that there was much influence of ground water on the soil properties. The sill values also increased from 15.60 to 39.7 from June-2001 to June-2002 and on the other hand the nugget values increased from 6.4 to 15.6 from June 2001 to June 2002, which indicates the major difference between all four semi-variograms of four months interval.

4.1.2.5 Soil bulk density

The data pertaining to the descriptive statistics of the viz., mean, standard deviation (SD), maximum, minimum and coefficient of variation (%) with respect the bulk density are presented in Table 12.

The presented data showed that at all the sampling time the mean of bulk density decreased i.e. 1.47, 1.42, 1.36 and 1.33 in the month of June 2001, October 2001, February 2002 and June 2002, respectively. The coefficient of variation ranged from 9.14, 8.20, 9.81 and 9.86 per cent in June 2001, October 2001, February 2002 and June 2002, respectively, this variation in coefficient of variation indicated smaller within site variability of the soil bulk density.

The semi-variogram for soil bulk density are presented in Fig 7. The semi-variance showed that there was considerable variation in semi-variogram with respect to time i.e. from June 2001 to June 2002. This variation indicated the impact of reclamation measures on soil bulk density.

The range of soil bulk density was 2.12, 2.15, 2.20 and 2.18 m and the sill values was 0.02, 0.013, 0.018 and 0.02 in the month of June 2001, October 2001, February 2002 and June 2002, respectively and similarly the nugget variance was 0.05, 0.012, 0.006 and 0.008 in the month of June 2001, October 2001, February 2002 and June 2002, respectively.

On the whole it is observed that the soil bulk density decreased with time having smaller within site variability.

Table 11. Descriptive statistics of the ESP in the soil

Time	Number of samples	Minimum	Maximum	Mean	SD	CV (%)
June-2001	30	5.76	24.39	16.05	4.27	26.59
October 2001	30	6.03	25.46	14.44	4.41	30.57
February 2002	30	7.60	30.16	15.06	5.34	35.43
June 2002	30	6.27	22.87	14.16	6.45	45.58

Table 12. Descriptive statistics of the bulk density of soil

Time	Number of samples	Minimum	Maximum	Mean	SD	CV (%)
June-2001	30	1.16	1.69	1.47	0.13	9.14
October 2001	30	1.21	1.61	1.42	0.12	8.20
February 2002	30	1.17	1.58	1.36	0.13	9.81
June 2002	30	1.17	1.62	1.34	0.13	9.86

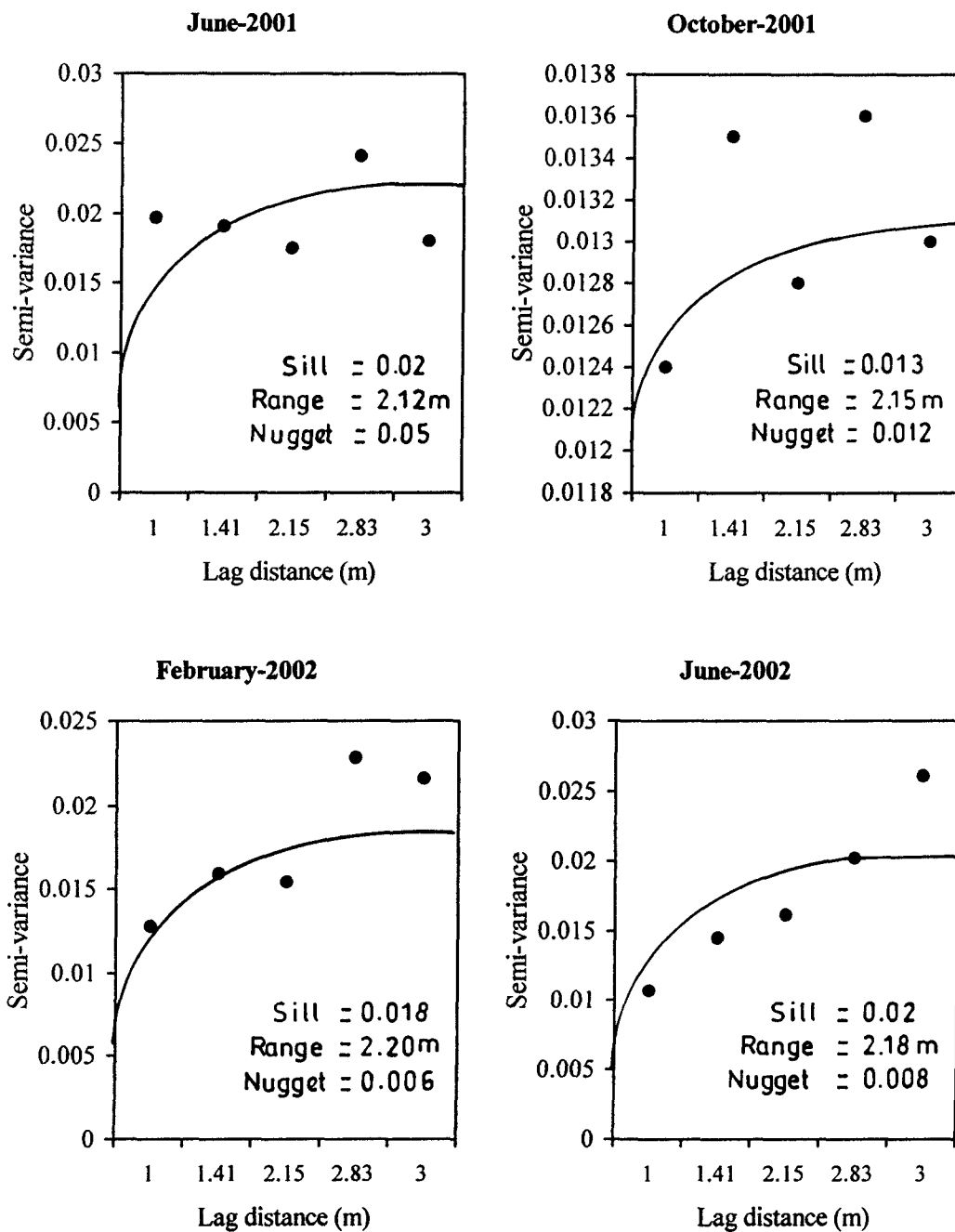


Fig. 7. Semi-variograms for soil bulk density

4.1.3 Effect of sub-surface drainage on soil properties

A field experiment was conducted in order to study the effect of sub-surface drainage on soil properties periodically with four different drain spacing i.e. 15, 30, 45 and 60 with 60, 90 and 120 cm depth and results obtained from these are discussed under the respective heads.

4.1.3.1 pH of the saturation paste extract of soil

Data presented in Table 13 showed that the pH($\leq$) of the soil decreased with decreasing sub-surface drain spacing and 15 m and 30 m drain spacing were found optimum. The maximum reduction was recorded with 15 m drain spacing and at 60 cm depth i.e. 5.05 per cent, followed by 90 cm depth i.e. 3.86 per cent over initial value. The pH of the saturation paste extract of soil increased in the control treatment. The least difference in pH($\leq$) might be due to the high buffering capacity of these swell-shrink soils. Similar results were reported by (Aher et al., 1994).

4.1.3.2 Electrical conductivity of saturation paste extract of soil

The data presented in Table 14 and Fig. 8 reveals that the electrical conductivity decreased considerably under different treatment of drain spacing with respect to time i.e. at an interval of four months upto one year. Maximum reduction in electrical conductivity was observed in the treatment having drain spacing 15 m. The reduction was 10, 24 and 28 per cent with 60, 90 and 120 cm drain depths respectively after one year. Minimum reduction was observed with 60 cm drain spacing. There was 29.8 per cent increase in electrical conductivity without installation of sub-surface drainage.

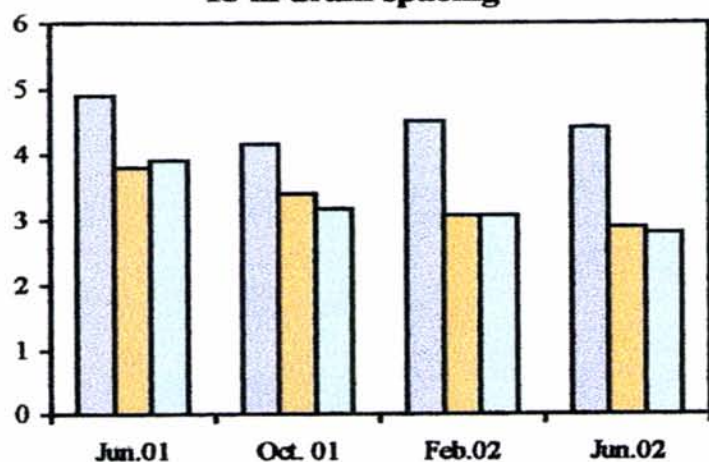
Table 13. Effect of subsurface drainage on pH of the saturation paste
of soil

Depth of drainage	June 2001 (Initial)	October 2001	February 2002	June 2002
Control	8.13	8.36	8.18	8.24
	15 m drain spacing			
60 cm	8.11	8.42	7.67	7.70
90 cm	8.28	8.40	7.52	7.96
120 cm	8.20	8.40	7.52	7.96
	30 m drain spacing			
60 cm	8.55	8.22	8.32	8.38
90 cm	8.44	8.28	8.36	8.30
120 cm	8.41	8.48	8.29	8.35
	45 m drain spacing			
60 cm	8.10	8.20	8.02	8.60
90 cm	8.34	8.26	8.36	8.28
120 cm	8.41	8.16	8.32	8.36
	60 m drain spacing			
60 cm	8.37	8.06	8.40	8.28
90 cm	8.40	8.27	8.42	8.36
120 cm	8.51	8.25	8.30	8.40

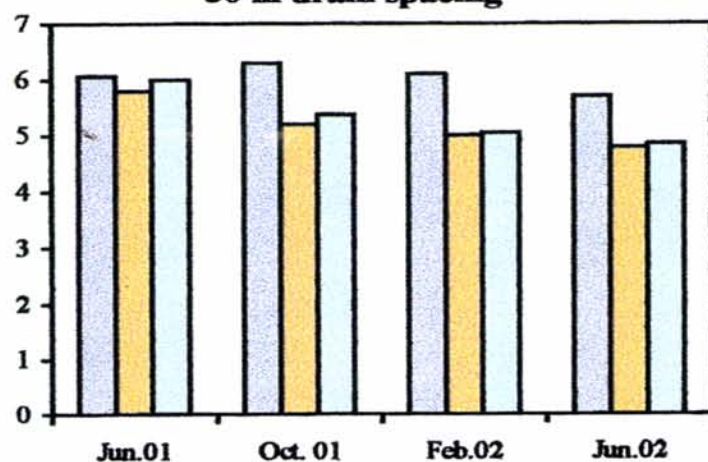
Table 14. Effect of subsurface drainage on ECe (dSm⁻¹)

Depth of drainage	June 2001 (Initial)	October 2001	February 2002	June 2002
Control	4.20	6.90	6.80	7.20
15 m drain spacing				
60 cm	4.90	4.16	4.50	4.40
90 cm	3.79	3.40	3.07	2.88
120 cm	3.90	3.16	3.07	2.80
30 m drain spacing				
60 cm	6.06	6.30	6.10	5.70
90 cm	5.80	5.20	5.00	4.80
120 cm	5.99	5.38	5.05	4.85
45 m drain spacing				
60 cm	7.91	7.79	7.70	7.56
90 cm	5.00	4.87	4.45	4.17
120 cm	9.30	8.85	8.65	8.30
60 m drain spacing				
60 cm	8.19	7.69	8.10	7.98
90 cm	9.60	9.20	9.03	8.88
120 cm	8.83	8.39	8.07	7.90

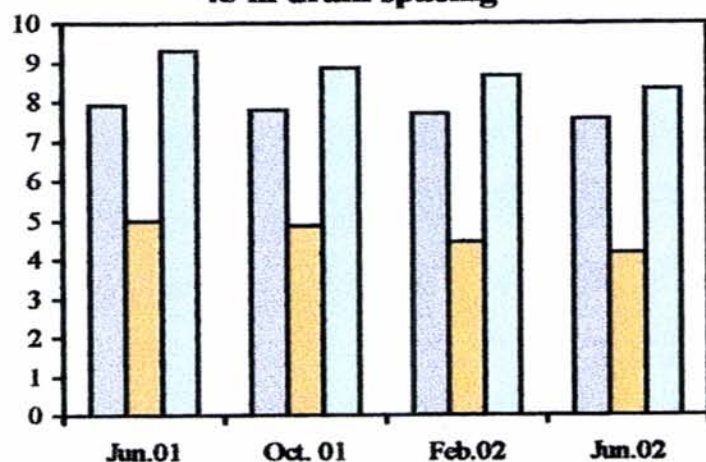
15 m drain spacing



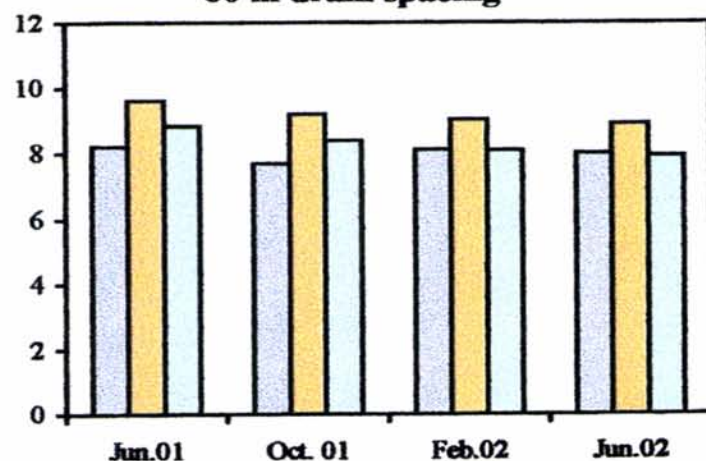
30 m drain spacing



45 m drain spacing



60 m drain spacing



X = Month
Y = E_{ce} (dSm^{-1})

Fig. 8. Effect of sub-surface drainage on E_{ce} (dSm^{-1})

The reduction in soil salinity might be due to the drainage coefficient was found quite enough in improving the leaching efficiency of soluble salts and thereby reduced the soil salinity. Lal et al. (1989) also supported these results by recording, the subsurface drainage was more efficient for improvement of problem area because the drain outflow was highest for narrowest spacing and lowest for largest spacing.

4.1.3.3 Calcium content in saturation paste extract of soil

The data in respect of calcium content in saturation paste extract of soil after installation of sub-surface drainage are given in Table 15. It would be seen from the data that calcium content in saturation extract of soil was increased in all the treatments except control.

The calcium content in saturation extract showed increasing trend by the installation of sub-surface drainage at an interval of four months. The maximum increase in calcium content were 18.0 and 23.8 per cent over initial value in the treatment with 60 m drain spacing and 60 and 90 cm drainage depths respectively. In 120 cm depth maximum calcium content i.e. 23 per cent were reported in 30 m drain spacing. The maximum calcium content with 60 m drain spacing might be due to the topography of soil. These increase in calcium content in all the treatments over initial value might be due to the release of native Ca^{2+} from these calcareous soils. Similar results were reported by Sharma et al. (1981).

Table 15. Effect of subsurface drainage on calcium content in saturation paste extract of soil (me L⁻¹)

Depth of drainage	June 2001 (Initial)	October 2001	February 2002	June 2002
Control	8.0	7.5	6.0	6.0
	15 m drain spacing			
60 cm	10.0	10.0	10.5	11.0
90 cm	8.0	8.0	8.0	9.5
120 cm	7.5	8.5	9.0	9.5
	30 m drain spacing			
60 cm	7.5	7.5	8.0	9.0
90 cm	5.5	6.0	6.5	7.0
120 cm	4.0	4.5	4.5	5.2
	45 m drain spacing			
60 cm	15.5	16.0	18.0	16.0
90 cm	6.5	6.0	8.0	8.5
120 cm	20.5	21.0	20.0	21.0
	60 m drain spacing			
60 cm	22.5	24.5	26.0	27.5
90 cm	16.0	18.0	18.0	21.0
120 cm	16.0	11.0	11.5	17.0

4.1.3.4 Magnesium content in saturation paste extract of soil

The data pertaining to the magnesium content in saturation paste extract as affected by the subsurface drainage are presented in Table 16.

The data presented in Table revealed that the increase in magnesium content in saturation paste extract of soil was observed in all the treatments except control and 30 m drain spacing with 60 cm depth. The maximum increase in magnesium content was recorded with 60 cm drain spacing at 60 and 120 cm depth i.e. 23.6 and 28.5 per cent respectively. One year after installation of subsurface drainage over initial value and at 90 cm depth the maximum increase was recorded with 45 m drain spacing i.e. 31.2 per cent. This might be due to the minimum removal of magnesium through drainage water as the outflow is smaller at these spacing.

The increase in magnesium content was decreased with drain spacing because the drainage coefficient was found sufficient to leach the magnesium as MgCl_2 and MgSO_4 through drainage water.

4.1.3.5 Sodium content in saturation paste extract of soil

The data regarding the sodium content in saturation paste extract of soil as a function of sub-surface drainage are shown in Table 17 and Fig. 9.

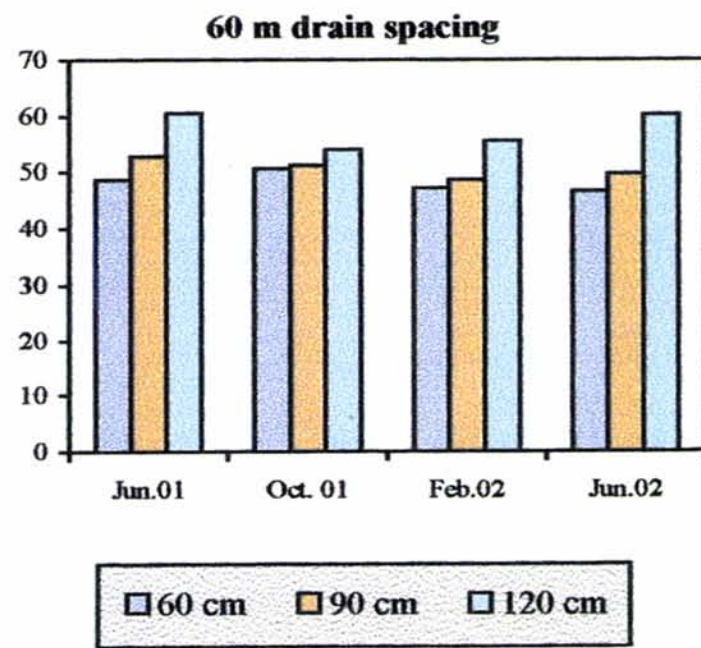
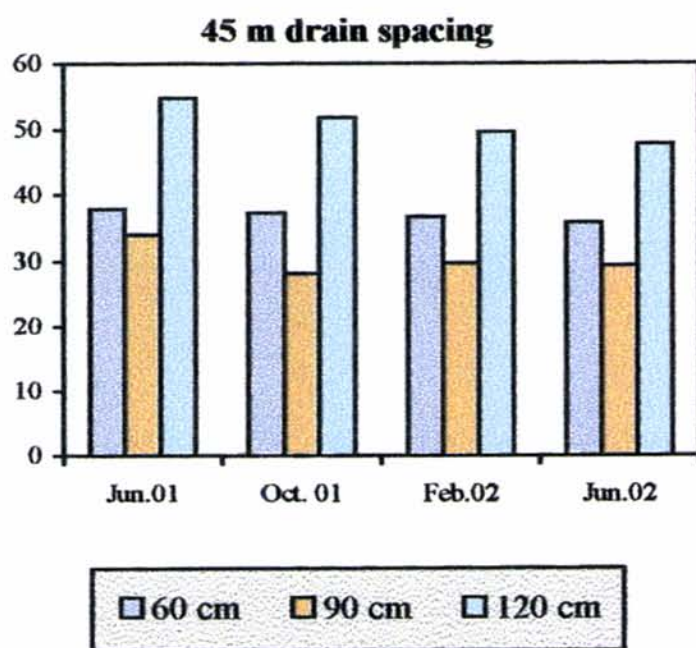
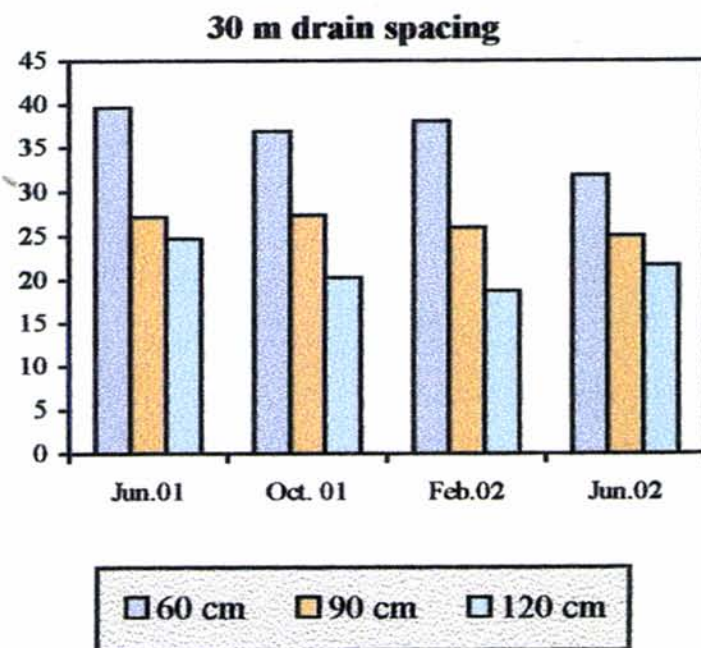
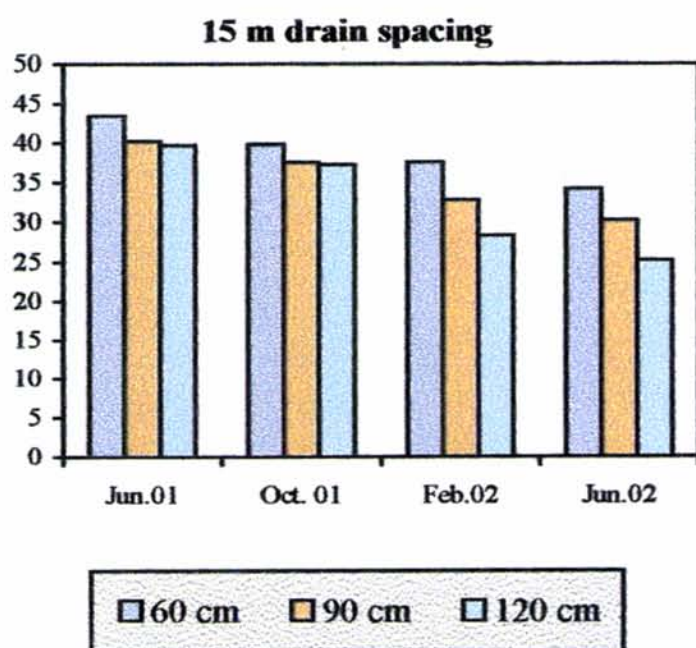
All the treatments reduced the sodium content of soil than initial sodium content of saturation paste extract of saline sodic soil at all the samplings i.e. at an interval of four months. The maximum reduction in sodium content was observed in the treatment with 15 m drain spacing i.e. 21.4, 24.9 and 36.7 per cent with 60, 90 and 120

Table 16. Effect of subsurface drainage on magnesium content in saturation paste extract of soil (meL^{-1})

Depth of drainage	June 2001 (Initial)	October 2001	February 2002	June 2002
Control	8.0	6.0	6.5	7.0
	15 m drain spacing			
60 cm	7.0	9.5	12.5	10.0
90 cm	6.0	7.0	8.5	6.5
120 cm	5.5	7.5	2.0	6.5
	30 m drain spacing			
60 cm	4.0	3.0	2.5	2.0
90 cm	2.5	3.0	2.0	3.5
120 cm	4.0	3.0	2.5	4.5
	45 m drain spacing			
60 cm	11.5	13.5	12.0	13.0
90 cm	5.5	4.0	5.0	6.0
120 cm	10.5	10.0	13.5	14.6
	60 m drain spacing			
60 cm	21.0	18.5	22.0	27.5
90 cm	10.5	12.5	10.0	12.0
120 cm	10.0	10.0	11.0	14.0

Table 17. Effect of subsurface drainage on sodium content in saturation paste extract of soil (meL^{-1})

Depth of drainage	June 2001 (Initial)	October 2001	February 2002	June 2002
Control	33.69	34.75	47.82	35.60
	15 m drain spacing			
60 cm	43.47	39.78	37.52	34.14
90 cm	40.21	37.43	32.73	30.19
120 cm	36.61	37.19	28.33	25.11
	30 m drain spacing			
60 cm	36.61	36.95	38.12	31.91
90 cm	27.17	27.39	26.00	25.06
120 cm	24.73	20.30	18.69	21.75
	45 m drain spacing			
60 cm	37.85	37.25	36.60	35.71
90 cm	35.18	28.15	25.70	29.35
120 cm	54.82	51.73	49.54	47.88
	60 m drain spacing			
60 cm	48.64	50.58	47.16	46.56
90 cm	52.85	51.23	48.64	49.64
120 cm	60.57	53.95	55.61	60.27



X = Month
Y = Na^+ (me L^{-1})

Fig. 9. Effect of sub-surface drainage on sodium content in saturation paste extract of soil (me L^{-1})

cm drainage depth respectively followed by 45 m drain spacing the reduction in sodium content was recorded 13.1 and 12.6 per cent with 90 and 120 cm drainage depth respectively. The minimum reduction in sodium content was recorded with 60 m drain spacing. The reduction in sodium content with decreasing the drainage spacing might be due to the leaching of soluble sodium was more with 15 m drain spacing due to the out flow of water was maximum. Similar results were reported by Ranade et al. (1992).

4.1.3.6 Potassium content in saturation paste extract of soil

The regarding the potassium content in saturation paste extract of saline sodic soil as influenced by the installation of subsurface drainage are presented in Table 18.

The present data showed that the potassium content in saturation paste extract of soil increased with the installation of subsurface drainage in all the treatments but the trend was not considerable. The maximum increase in potassium content was recorded with 15 m drain spacing and it was 23, 4 and 7.1 per cent at 60, 90 and 120 cm depths respectively followed by 30 m drain spacing and the less increase in potassium content was recorded with 45 and 60 m drain spacing in all three depths.

4.1.3.7 Chloride content in saturation paste extract of soil

The data pertaining to the chloride content in the saturation paste extract at all the sampling as influenced by subsurface drainage are given in Table 19.

From the data it was revealed that the chloride content in saturation paste extract of soil was considerably reduced at an

Table 18. Effect of subsurface drainage on potassium content of saturation paste extract of soil (me L⁻¹)

Depth of drainage	June 2001 (Initial)	October 2001	February 2002	June 2002
Control	0.23	0.23	0.18	0.14
	15 m drain spacing			
60 cm	0.13	0.13	0.16	0.17
90 cm	0.12	0.13	0.13	0.14
120 cm	0.13	0.12	0.12	0.14
	30 m drain spacing			
60 cm	0.10	0.11	0.11	0.11
90 cm	0.12	0.10	0.12	0.14
120 cm	0.12	0.10	0.12	0.12
	45 m drain spacing			
60 cm	0.11	0.13	0.11	0.12
90 cm	0.06	0.06	0.11	0.12
120 cm	0.12	0.15	0.11	0.14
	60 m drain spacing			
60 cm	0.10	0.14	0.10	0.11
90 cm	0.17	0.19	0.16	0.18
120 cm	0.16	0.19	0.15	0.17

Table 19. Effect of subsurface drainage on chloride content in saturation paste extract of soil (meL^{-1})

Depth of drainage	June 2001 (Initial)	October 2001	February 2002	June 2002
Control	10	13	14	14.2
	15 m drain spacing			
60 cm	23	16	12	12
90 cm	26	13	11	12
120 cm	20	14	10	11
	30 m drain spacing			
60 cm	9	8	6	5
90 cm	11	9	8	6
120 cm	10	8	6	6
	45 m drain spacing			
60 cm	35	40	38	32
90 cm	23	20	22	21
120 cm	40	45	42	38
	60 m drain spacing			
60 cm	38	40	38	34
90 cm	37	40	40	34
120 cm	20	20	21	17

interval of four months upto one year in saline sodic soil. It was observed that the reduction of chloride content was more in 15 m drain spacing at all the depths i.e. 47.8, 53.8 and 45.0 per cent at 60, 90 and 120 cm drainage depths respectively. Followed by 30 m drain spacing i.e. 44.4, 48.4 and 40.0 per cent at 60, 90 and 120 cm drainage depths respectively. The extent of reduction in chloride content was observed less in 45 and 60 m drain spacing under different depth of drainage. The reduction in chloride content might be due to more removal of chloride under 15 m drain spacing during leaching. These results are in accordance with the results recorded by Sharma and Singh (1998).

4.1.3.8 Bicarbonate content in saturation paste extract of soil

The data in respect of bicarbonate content in saturation extract as influenced by subsurface drainage with gypsum application are given in Table 20.

From Table 20 it was revealed that bicarbonate content in saturation extract was influenced by sub-surface drainage. It was observed that the bicarbonate content was reduced in all the treatment except control.

It was observed that the bicarbonate reduction increased as drain spacing decreased. Maximum reduction was recorded with 15 m drain spacing at all the depths i.e. 37.5, 37.5 and 31.2 per cent at 60, 90 and 120 cm depths respectively followed by 30 m drain spacing and minimum reduction was observed with 60 m drain spacings. The reduction in bicarbonate was might be due to the

Table 20. Effect of subsurface drainage on bicarbonate content in saturation paste extract of soil (meL^{-1})

Depth of drainage	June 2001 (Initial)	October 2001	February 2002	June 2002
Control	10.0	10.5	11.0	10.0
	15 m drain spacing			
60 cm	8.0	9.0	7.5	5.0
90 cm	8.0	7.0	6.5	5.0
120 cm	8.0	8.0	8.0	5.5
	30 m drain spacing			
60 cm	6.5	5.0	10.0	4.9
90 cm	6.0	7.0	5.5	3.0
120 cm	6.0	5.0	10.0	4.5
	45 m drain spacing			
60 cm	8.0	6.5	6.0	6.0
90 cm	7.0	5.5	1.0	5.6
120 cm	12.0	11.5	10.0	10.0
	60 m drain spacing			
60 cm	20.0	6.0	16.5	18.0
90 cm	6.5	6.5	6.0	6.0
120 cm	9.0	9.5	10.0	8.0

leaching of bicarbonate with sodium as sodium bicarbonate through drainage water.

4.1.3.9 Sulphate content in saturation paste extract of soil

From the Table 21 it was observed that the sulphate content decreased by installation of sub-surface drainage than initial sulphate content in saturation paste extract of soil.

The sulphate content in saturation paste extract of soil considerably decreased in 15 m drainage spacing i.e. 36.2, 31.8 and 20.8 per cent with 60, 90 and 120 cm drainage depth respectively followed by 30 m drain spacing i.e. 34.4, 16.3 and 17.2 per cent with 60, 90 and 120 cm drainage depth respectively one year after installation of sub-surface drains. The minimum reduction in sulphate content was recorded with 45 m drain spacing. In the control treatment the sulphate content in saturation paste extract was increased from 73.66 to 90.12 meL^{-1} after one year. The reduction in sulphate content might be due to the more removal of sulphate during leaching under the treatment of 15 m drain spacing.

4.1.3.10 SAR of the saturation paste extract of soil

The data regarding the SAR of the saturation paste extract of saline sodic soil as a function of sub-surface drainage are presented in Table 22 and Fig. 10.

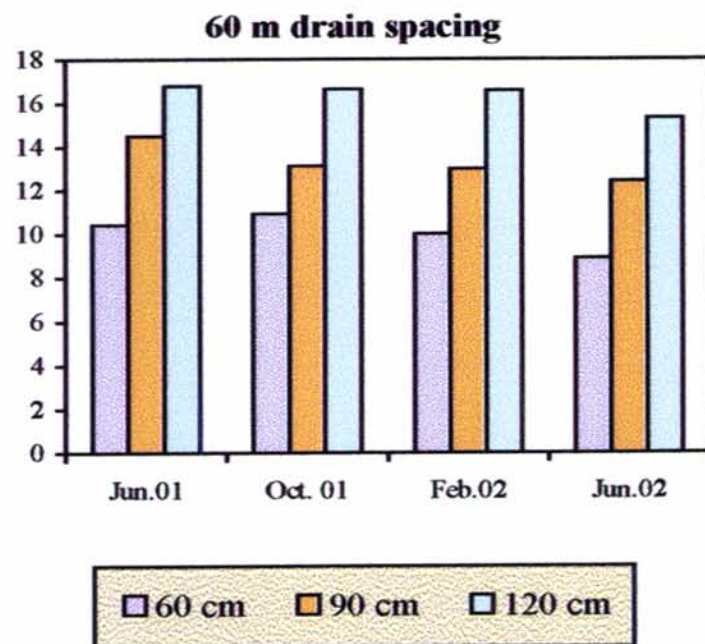
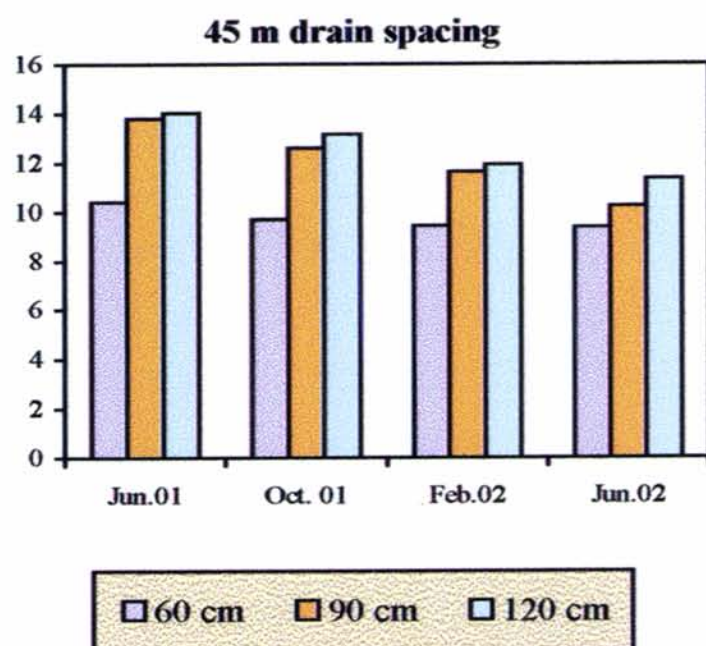
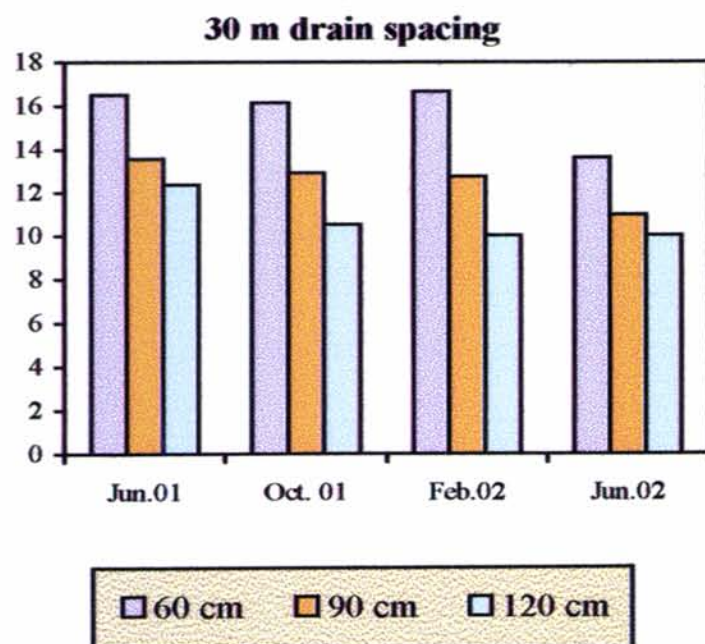
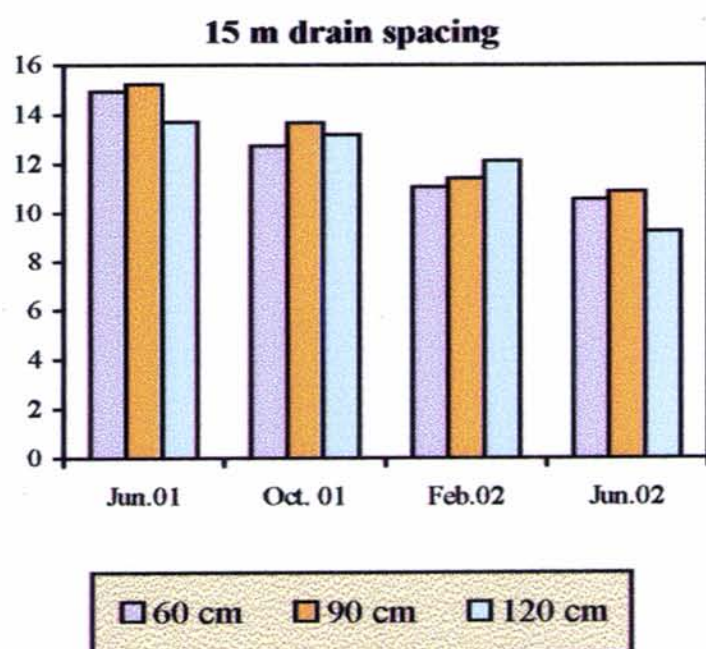
It is evident from the table that the sodium adsorption ratio decreased as the drain spacing decreased at all the sampling i.e. at an interval of four months upto one year. The maximum reduction in SAR was recorded with 15 m drain spacing and the reduction was from 14.93 to 10.54, 15.23 to 10.86 and 13.69 to 9.20 mmol at 60,

Table 21. Effect of subsurface drainage on sulphate content in saturation paste extract of soil (meL^{-1})

Depth of drainage	June 2001 (Initial)	October 2001	February 2002	June 2002
Control	12.62	12.62	14.18	19.99
	15 m drain spacing			
60 cm	32.62	32.40	31.04	20.08
90 cm	23.15	22.14	21.04	15.78
120 cm	25.25	25.00	24.20	20.04
	30 m drain spacing			
60 cm	16.05	15.25	15.26	10.36
90 cm	12.63	12.10	11.57	10.57
120 cm	12.10	11.41	11.05	10.01
	45 m drain spacing			
60 cm	25.25	25.25	23.67	20.52
90 cm	11.41	11.41	9.47	10.52
120 cm	51.56	51.56	47.56	45.99
	60 m drain spacing			
60 cm	26.31	26.31	24.20	22.62
90 cm	43.14	43.14	41.04	36.83
120 cm	45.45	45.45	42.09	38.93

Table 22. Effect of subsurface drainage on SAR of the saturation paste extract of soil ($\text{m mol}^{1/2}\text{L}^{1/2}$)

Depth of drainage	June 2001 (Initial)	October 2001	February 2002	June 2002
Control	12.57	13.16	16.43	24.50
	15 m drain spacing			
60 cm	14.93	12.75	11.07	10.54
90 cm	15.23	13.67	11.40	10.86
120 cm	13.69	13.19	12.11	9.20
	30 m drain spacing			
60 cm	16.52	16.13	16.64	13.61
90 cm	13.58	12.91	12.71	10.94
120 cm	12.36	10.51	9.99	10.01
	45 m drain spacing			
60 cm	10.40	9.70	9.45	9.38
90 cm	13.80	12.59	11.65	10.22
120 cm	14.04	13.14	11.93	11.35
	60 m drain spacing			
60 cm	10.43	10.91	10.00	8.88
90 cm	14.52	13.12	13.00	12.41
120 cm	16.80	16.65	16.58	15.31



X = Month
Y = SAR ($\text{m mol}^{1/2}\text{L}^{-1/2}$)

Fig. 10. Effect of sub-surface drainage on SAR of the saturation paste extract of soil ($\text{m mol}^{1/2}\text{L}^{-1/2}$)

90 and 120 cm drainage depths respectively followed by 30 m drain spacing. This reduction in SAR might be due to the removal of sodium from exchange phase and leaching it with drainage water. Similar results were reported by Singh (1981).

In general the reduction in SAR was also recorded with 45 m and 60 m drain spacing but reduction was minimum and with the 45 m drain spacing reduction was 9.8, 18.6 and 19.1 per cent at 60, 90 and 120 cm depths respectively.

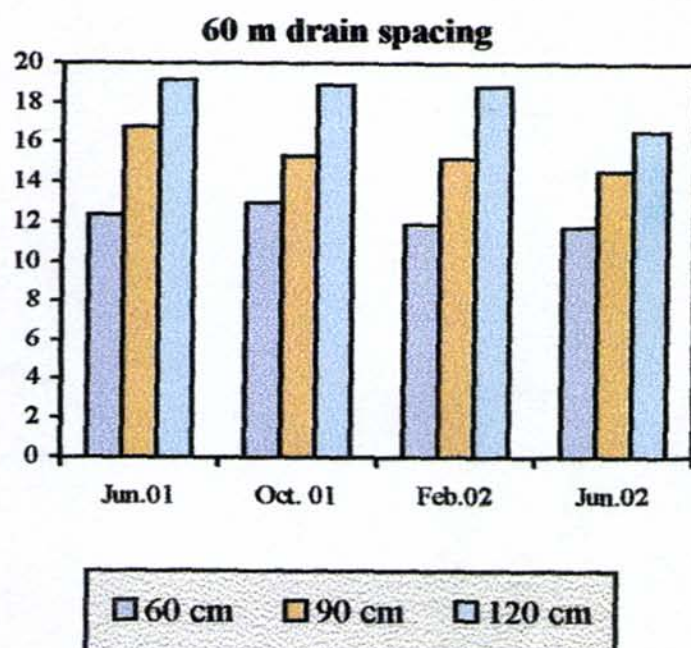
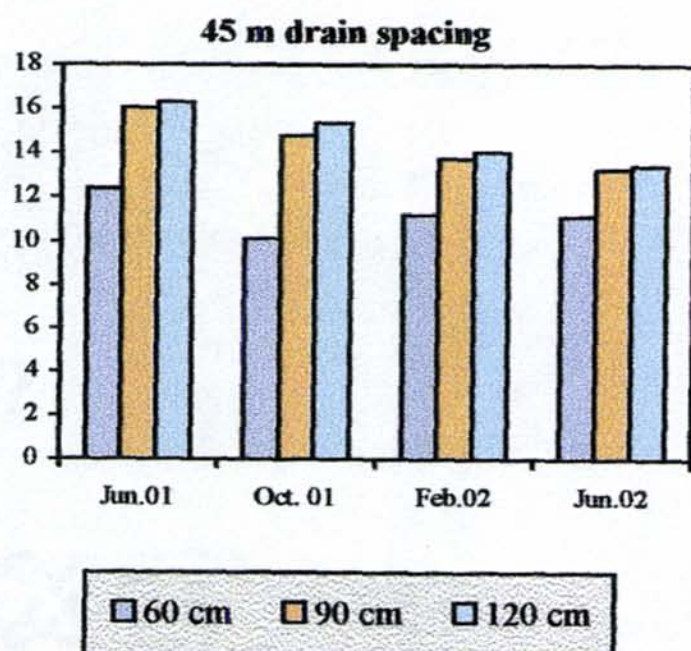
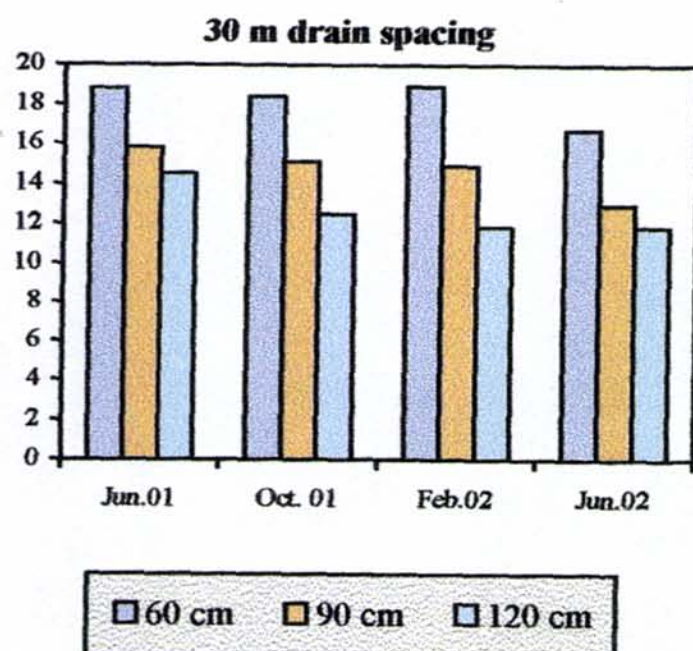
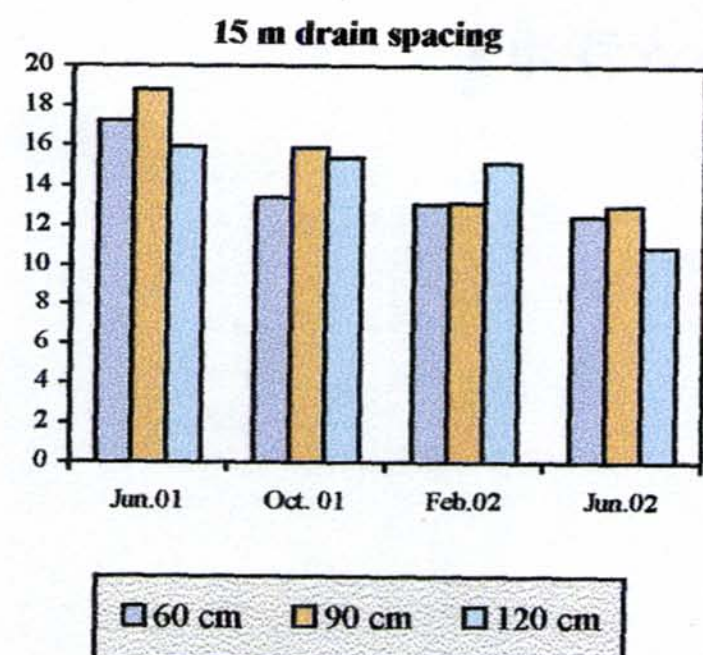
4.1.3.11 ESP of the saturation paste extract of soil

The data pertaining to the ESP value as a function of sub-surface drainage in saline sodic swell shrink soil are presented in Table 23 and Fig. 11.

The data revealed that the initial ESP value decreased considerably by leaching saline sodic soil. The ESP value was decreased in all the treatments except control at interval of four months upto one year. The maximum reduction in ESP value was observed with 15 m drain spacing i.e. 27.3, 30.8 and 31.1 per cent with 60, 90 and 120 cm drainage depth respectively followed by 45 m drain spacing. The increasing trend in ESP value was observed in control treatment. The reduction in ESP value might be due to more removal of soluble sodium through leaching. Bharambe et al. (2001) reported the reduction in ESP ascribed due to the calcareous nature of saline sodic soil. Similar results were reported by Verma and Gupta (1985).

Table 23. Effect of subsurface drainage on Exchangeable sodium per cent in soil

Depth of drainage	June 2001 (Initial)	October 2001	February 2002	June 2002
Control	14.73	15.48	18.69	25.87
	15 m drain spacing			
60 cm	17.20	13.40	13.10	12.50
90 cm	18.93	15.89	13.18	12.86
120 cm	15.92	15.40	15.16	10.96
	30 m drain spacing			
60 cm	18.77	18.39	18.89	16.72
90 cm	15.81	15.10	14.89	12.95
120 cm	14.51	12.47	11.88	11.86
	45 m drain spacing			
60 cm	12.35	10.15	11.25	11.17
90 cm	16.04	14.75	13.73	13.27
120 cm	16.28	15.34	14.04	13.41
	60 m drain spacing			
60 cm	12.37	12.91	11.88	11.74
90 cm	16.78	15.33	15.18	14.56
120 cm	19.04	18.91	18.84	16.56



X = Month
Y = Soil ESP

Fig. 11. Effect of sub-surface drainage on exchangeable sodium percentage in soil

4.1.3.12 Bulk density of soil

The results regarding the bulk density of soil as influenced by sub-surface drainage with are presented in Table 24.

The data revealed that the bulk density of soil decreased in all the treatments except control. The maximum reduction in bulk density was recorded with 30 m drain spacing i.e. 28.1, 26.7 and 16.9 per cent at 60, 90 and 120 cm drainage depths respectively followed by 15 m drain spacing i.e. 10.6, 18.0 and 14.06 per cent at 60, 90 and 120 cm drainage depth respectively. This might be due to the removal of sodium which reduced the dispersion of soil particles. Similar results were reported by Bharambe et al. (2001).

4.2 Effect of subsurface drainage on quality of drainage water

For assessing the quality of drainage water an experiment was conducted with different treatments of sub-surface drainage viz., 15, 30, 45 and 60 m spacing and 60, 90 and 120 cm depth. Monthly the leachate samples were collected from June 2001 to July 2002 and analysed for different salinity parameters. The data regarding the quality of drainage water are discussed as under.

4.2.1 pH of drainage water

The pH values of drainage water as a function of sub-surface drainage are presented in Table 25.

The presented data revealed that the pH values of drainage water collected from saline sodic soils where the sub-surface drainage system was installed, increased from July 2001 to

Table 24. Effect of subsurface drainage on bulk density (Mg m^{-3}) of soil

Depth of drainage	June 2001 (Initial)	October 2001	February 2002	June 2002
Control	1.43	1.48	1.50	1.49
	15 m drain spacing			
60 cm	1.41	1.29	1.29	1.26
90 cm	1.61	1.48	1.37	1.32
120 cm	1.28	1.28	1.18	1.10
	30 m drain spacing			
60 cm	1.53	1.36	1.30	1.10
90 cm	1.61	1.34	1.21	1.18
120 cm	1.42	1.38	1.36	1.19
	45 m drain spacing			
60 cm	1.24	1.22	1.19	1.24
90 cm	1.40	1.35	1.17	1.34
120 cm	1.44	1.35	1.26	1.33
	60 m drain spacing			
60 cm	1.55	1.46	1.49	1.45
90 cm	1.51	1.48	1.43	1.40
120 cm	1.36	1.26	1.20	1.18

Table 25. Effect of subsurface drainage on pH of drainage water

Depth of drainage	July 01	Aug. 01	Sep. 01	Oct. 01	Nov. 01	Dec. 01	Jan. 02	Feb. 02	Mar. 02	Apr. 02	May 02	June 02	July 02
15 m drain spacing													
60 cm	7.91	8.12	8.20	7.90	7.79	8.42	8.20	8.01	8.10	8.53	8.20	8.08	8.00
90 cm	8.16	8.11	8.16	7.86	7.76	8.22	8.00	8.10	8.04	8.40	8.10	8.32	8.04
120 cm	8.18	8.16	8.20	7.93	7.94	8.23	8.08	8.00	7.94	8.60	8.05	8.38	8.48
30 m drain spacing													
60 cm	8.20	8.12	8.25	7.91	8.66	8.20	8.13	8.25	7.96	8.08	8.08	8.36	8.44
90 cm	8.23	7.92	8.30	8.12	8.14	8.23	8.25	8.30	8.06	8.12	8.00	8.35	8.64
120 cm	8.26	8.36	8.36	8.07	7.77	8.30	8.22	8.39	8.02	8.10	8.08	8.42	8.25
45 m drain spacing													
60 cm	8.16	8.20	8.24	8.19	8.67	8.31	8.30	8.50	8.20	8.12	8.04	8.40	8.62
90 cm	8.29	8.24	8.24	8.23	8.16	8.28	8.32	8.48	7.94	8.02	8.00	8.18	8.65
120 cm	7.94	8.50	8.65	8.27	8.06	8.14	8.22	8.26	8.11	8.20	8.30	8.20	8.37
60 m drain spacing													
60 cm	8.21	8.20	8.40	8.38	8.52	8.15	8.20	8.11	8.34	8.50	8.10	8.30	8.04
90 cm	8.20	8.10	8.25	8.29	8.61	8.08	8.20	8.20	8.05	8.30	8.14	8.38	8.10
120 cm	8.15	8.40	8.35	8.24	8.47	8.18	8.15	7.92	8.02	8.40	8.20	8.48	8.30

December 2001 and it decreased from January 2002 to July 2002 in all the four treatment combinations of subsurface drainage.

From this data it is observed that the pH values of leachate increased with 45 m drain spacing at all its three depths i.e. 60, 90 and 120 cm. The removal of soluble salts through drainage water had reflected variation in pH at different depths. Similar results were reported by Bharambe et al. (1992).

4.2.2 Electrical conductivity of drainage water

The values of electrical conductivity of drainage water as influenced by the different treatments of subsurface drainage are given in Table 26 and Fig. 12.

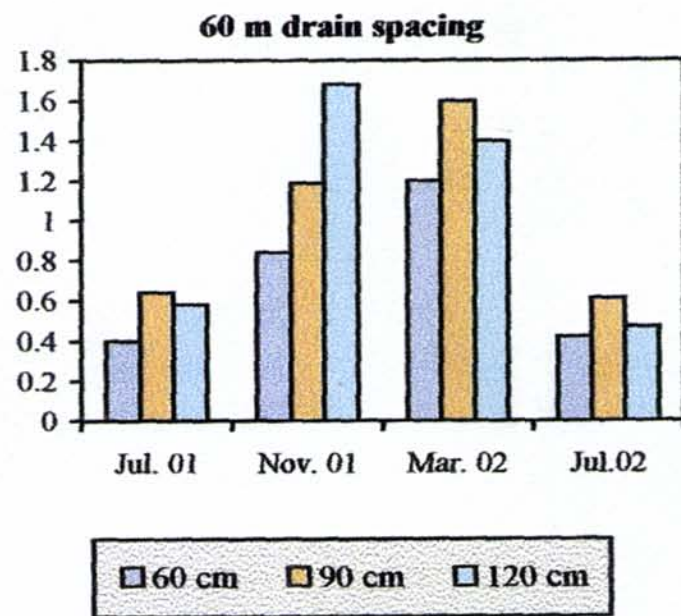
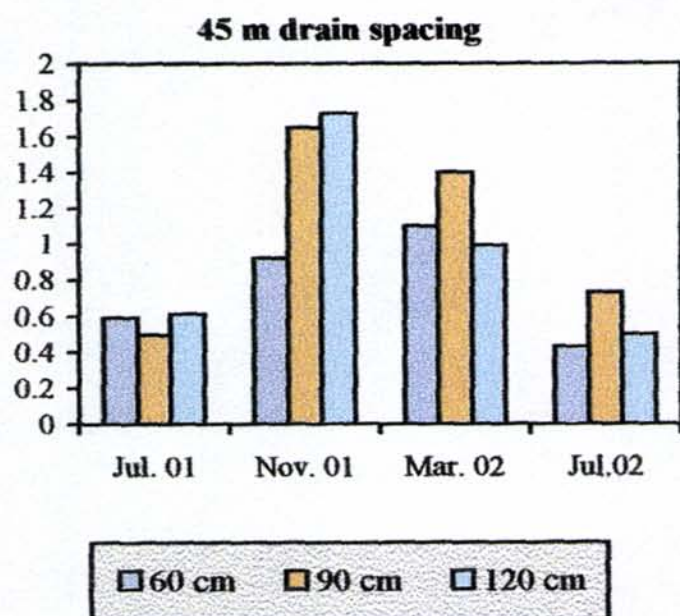
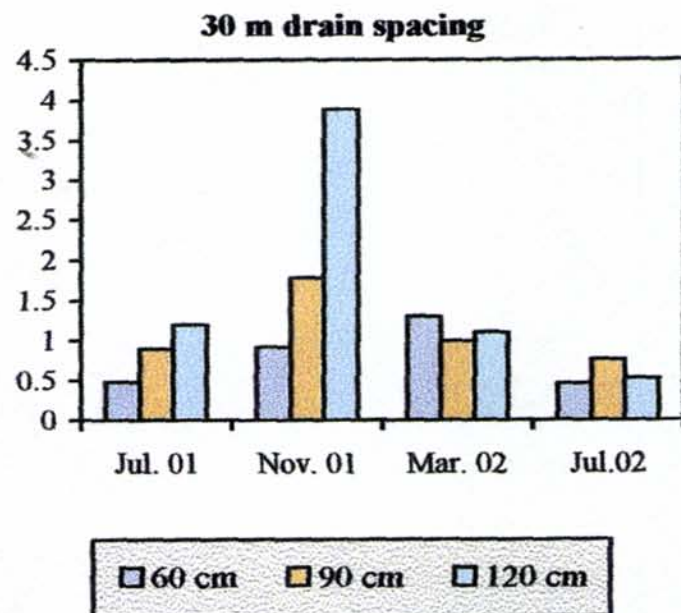
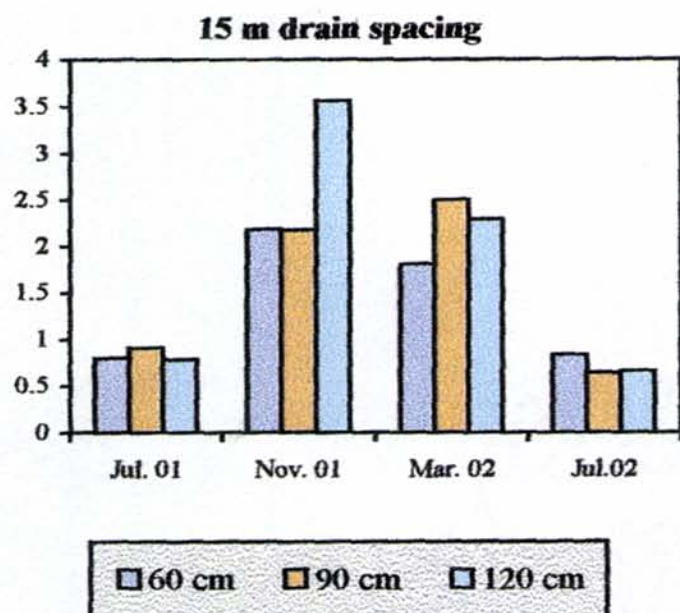
The presented data showed that the electrical conductivity of the drainage water showed increasing trend from July 2001 to January 2002 and decreased thereafter i.e. from February 2002 to July 2002 in all the treatments of subsurface drainage with respect to spacing and depth. This fluctuation in the electrical conductivity of drainage water might be due to the opening and closing of canal. This reflects that upto the month of January the canal was closed hence the drainage out flow was less and concentration of salt was more and from February to July the canal was open and the drainage outflow was more and the concentration of salt was less.

The removal of salts was more with 15 m drain spacing at all the three depths i.e. 60, 90 and 120 cm followed by 30 m drain spacings. Similar results were reported by Mark and Grismer (1993).

Table 26. Effect of subsurface drainage on Electrical conductivity of drainage water (dSm⁻¹)

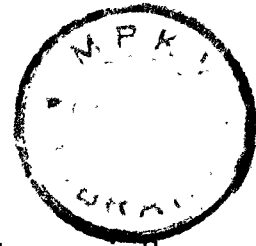
Depth of drainage	July 01	Aug. 01	Sep. 01	Oct. 01	Nov. 01	Dec. 01	Jan. 02	Feb. 02	Mar. 02	Apr. 02	May 02	June 02	July 02	Total	Mean	S.D. ±	CV %
15 m drain spacing																	
60 cm	0.80	1.44	1.53	1.83	2.18	4.20	4.90	3.10	1.80	1.50	0.89	0.85	0.83	25.85	1.98	1.26	63.63
90 cm	0.91	1.22	1.32	1.40	2.17	3.40	2.57	2.50	2.50	2.36	0.68	0.66	0.65	24.34	1.87	1.23	65.99
120 cm	0.78	0.91	1.19	1.41	1.56	3.90	2.30	2.30	2.29	2.20	0.77	0.62	0.66	27.54	2.11	1.13	53.84
30 m drain spacing																	
60 cm	0.48	0.50	0.59	0.83	0.91	1.42	1.45	1.42	1.30	0.87	0.89	0.67	0.46	11.79	0.90	0.35	39.67
90 cm	1.20	2.80	2.98	3.78	3.89	1.71	3.00	1.63	1.10	0.96	0.76	0.72	0.53	15.47	1.19	0.83	70.53
120 cm	0.89	1.02	1.07	1.30	1.78	1.62	1.90	1.41	1.00	1.10	0.82	0.80	0.76	25.05	1.92	1.15	60.25
45 m drain spacing																	
60 cm	0.59	0.78	0.85	0.89	0.92	1.92	0.92	0.90	1.10	0.83	0.78	0.68	0.43	11.59	0.89	0.33	37.78
90 cm	0.61	1.06	1.09	1.68	1.73	1.68	1.97	1.63	0.99	0.88	0.81	0.78	0.50	14.95	1.15	0.42	36.89
120 cm	0.50	0.58	0.66	0.70	1.65	1.91	1.99	1.84	1.40	0.93	0.86	0.80	0.73	15.41	1.18	0.48	60.25
60 m drain spacing																	
60 cm	0.40	0.42	0.50	0.71	0.84	1.82	0.94	0.88	1.20	0.80	0.98	0.72	0.42	10.55	0.81	0.38	47.59
90 cm	0.58	0.81	0.87	1.48	1.68	2.01	1.74	1.66	1.40	0.81	0.69	0.60	0.47	14.41	1.10	0.51	47.23
120 cm	0.64	0.69	0.74	0.76	1.19	2.16	1.88	1.72	1.60	0.96	0.74	0.72	0.61	14.80	1.13	0.50	45.12

7-5319



X = Month
Y = EC dSm⁻¹

Fig. 12. Effect of sub-surface drainage on Electrical conductivity of drainage water (dSm⁻¹)



4.2.3 Calcium content in drainage water

The calcium content in drainage water as influenced by the installation of subsurface drainage on saline sodic soil are presented in Table 27.

It would be seen from the table that there was no specific trend was observed in the calcium content in drainage water from July 2001 to July 2002 with the installation of subsurface drainage for reclamation of saline sodic swell shrink soil. But the removal of calcium was more in the treatment of 15 m drain spacing and 60 cm depth followed by 90 cm depth and least removal of calcium was recorded with 60 m drain spacing. This might be due to the release of native calcium in these calcareous soil.

4.2.4 Magnesium content in drainage water

The data regarding the magnesium content in drainage water as a function of sub-surface drainage are presented in Table 28.

The data presented in the table showed that the removal of magnesium started from July 2001 but there was no any specific trend in removing of magnesium through drainage water was recorded from July 2001 to July 2002. The maximum removal of magnesium was recorded with 15 m drain spacing and it was total 68.6, 57.4 and 57.3 meL^{-1} at 60, 90 and 120 cm drainage depths respectively.

The minimum removal of magnesium was recorded with 60 m drain spacing. The removal of magnesium through drainage water might be due to the release of more magnesium from soil.

Table 27. Effect of subsurface drainage on calcium content in drainage water (meL^{-1})

Depth of drainage	July 01	Aug. 01	Sep. 01	Oct. 01	Nov. 01	Dec. 01	Jan. 02	Feb. 02	Mar. 02	Apr. 02	May 02	June 02	July 02	Total
15 m drain spacing														
60 cm	2.4	2.2	2.0	1.4	4.0	2.3	3.0	2.9	2.2	3.0	1.8	1.0	0.6	28.8
90 cm	2.6	2.8	2.5	2.5	3.8	3.2	2.7	3.0	4.0	1.9	1.5	1.4	1.0	32.9
120 cm	2.5	2.4	2.0	1.9	1.4	2.9	1.0	2.5	4.7	5.3	2.0	1.4	1.0	31.0
30 m drain spacing														
60 cm	1.9	2.6	2.5	2.4	2.2	3.2	2.0	2.0	2.5	2.2	2.0	1.0	0.5	27.0
90 cm	1.9	4.0	4.0	3.2	1.9	6.0	1.7	2.1	2.0	1.9	2.0	1.0	0.9	32.6
120 cm	1.4	1.2	1.2	1.2	3.0	5.2	2.6	2.5	3.0	1.3	2.4	1.4	0.5	26.9
45 m drain spacing														
60 cm	1.8	1.3	1.5	1.7	1.1	3.3	1.0	1.4	2.1	2.7	1.4	1.3	0.6	21.2
90 cm	5.0	4.8	3.0	2.2	2.1	2.1	1.9	1.0	1.4	1.9	1.2	1.2	0.9	28.7
120 cm	1.6	1.4	1.2	1.0	1.2	1.8	2.2	1.4	1.2	1.0	1.0	0.8	0.6	16.4
60 m drain spacing														
60 cm	0.8	1.4	0.8	1.1	1.0	2.2	1.1	1.8	2.3	1.8	2.0	2.0	0.7	29.0
90 cm	1.4	2.4	2.3	2.3	2.2	3.1	2.1	1.4	2.5	1.6	2.1	1.1	0.5	25.0
120 cm	2.3	2.2	2.0	1.9	1.3	2.8	1.3	1.6	1.5	1.5	1.3	1.0	0.8	21.5

Table 28. Effect of subsurface drainage on magnesium content
drainage water (meL^{-1})

Depth of drainage	July 01	Aug. 01	Sep. 01	Oct. 01	Nov. 01	Dec. 01	Jan. 02	Feb. 02	Mar. 02	Apr. 02	May 02	June 02	July 02	Total
15 m drain spacing														
60 cm	4.0	5.8	4.0	6.7	10.4	5.9	12.9	5.4	3.3	2.8	2.0	3.0	2.4	68.6
90 cm	3.1	4.0	3.9	3.9	5.7	7.0	4.1	7.0	9.2	1.7	2.9	2.7	2.2	57.4
120 cm	2.5	4.8	5.0	4.1	5.4	6.5	5.6	6.7	6.8	2.4	2.4	2.0	3.1	57.3
30 m drain spacing														
60 cm	2.1	2.4	2.2	4.7	4.7	4.8	4.5	5.7	3.2	2.8	4.2	3.1	3.0	47.4
90 cm	3.6	3.4	2.2	2.2	3.7	5.0	5.2	4.2	2.4	3.0	4.4	3.3	2.6	45.2
120 cm	4.1	3.5	3.1	2.4	4.3	7.3	5.4	5.7	2.5	1.6	2.8	3.1	2.1	47.9
45 m drain spacing														
60 cm	1.8	1.4	1.6	5.2	3.0	6.3	4.3	2.2	2.7	2.6	2.5	2.5	1.6	37.7
90 cm	3.9	3.8	2.6	3.3	3.4	4.8	4.4	4.6	2.6	2.8	3.0	2.2	2.4	43.8
120 cm	2.5	2.6	2.4	4.4	5.5	5.8	5.5	4.6	3.4	3.2	3.4	2.6	2.2	48.1
60 m drain spacing														
60 cm	2.4	2.3	2.2	3.7	3.0	6.7	3.1	2.2	2.5	2.0	3.1	2.6	2.4	38.2
90 cm	2.9	2.9	2.3	2.2	3.5	2.9	2.3	4.9	3.2	2.7	2.7	2.8	1.9	40.2
120 cm	1.8	1.6	2.0	4.7	5.1	3.8	3.1	3.8	2.0	3.7	3.0	3.0	2.7	40.3

Hence the removal of magnesium increased as the drainage spacing decreased.

4.2.5 Sodium content in drainage water

The data pertaining to the sodium content in drainage water as a function of subsurface drainage are given in Table 29 and Fig. 13.

The removal of water soluble sodium in drainage water showed increasing trend from July 2001 to December 2001 and decreased thereafter from January 2002 to July 2002 in all the four sub-surface drainage treatments. This might be due to the opening and closing of canal.

The maximum removal of sodium through leachate was recorded with 15 m drain spacing i.e. 102.7, 108.2 and 134.4 meL^{-1} in 60, 90 and 120 cm drainage depth respectively but the 120 cm depth found superior over 60 and 90 cm. This maximum removal of sodium in this treatment might be due to the drainage coefficient was found enough in removal of water soluble sodium through leachate. Similar results were reported by Sharma et al. (1994). The removal of sodium in 30 m drain spacing was 69.8, 89.4 and 109.2 meL^{-1} with 60, 90 and 120 cm depth respectively. The minimum removal was recorded with 60 m drain spacing.

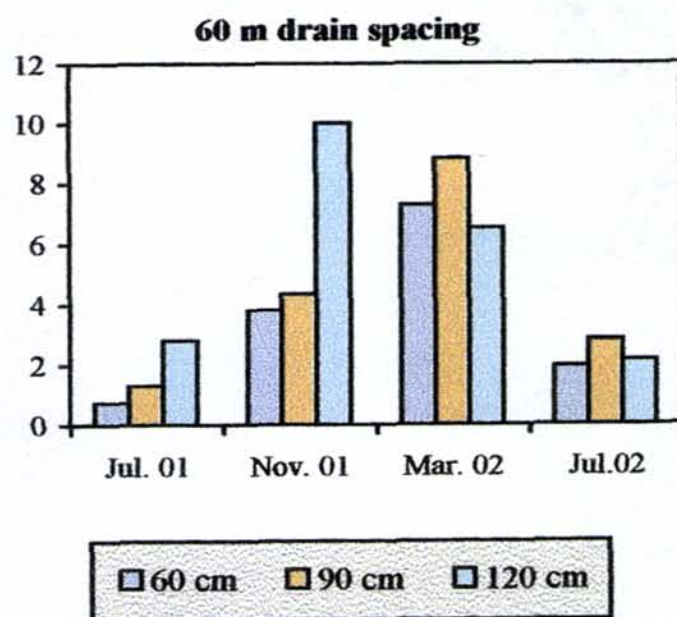
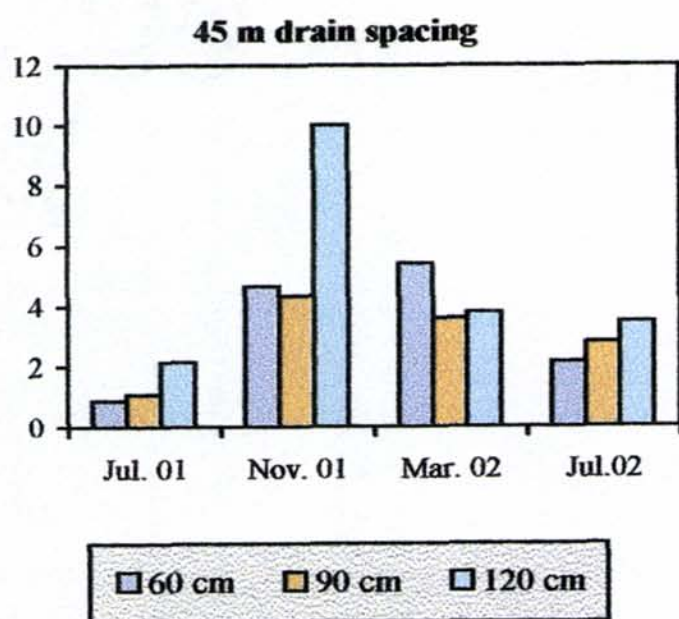
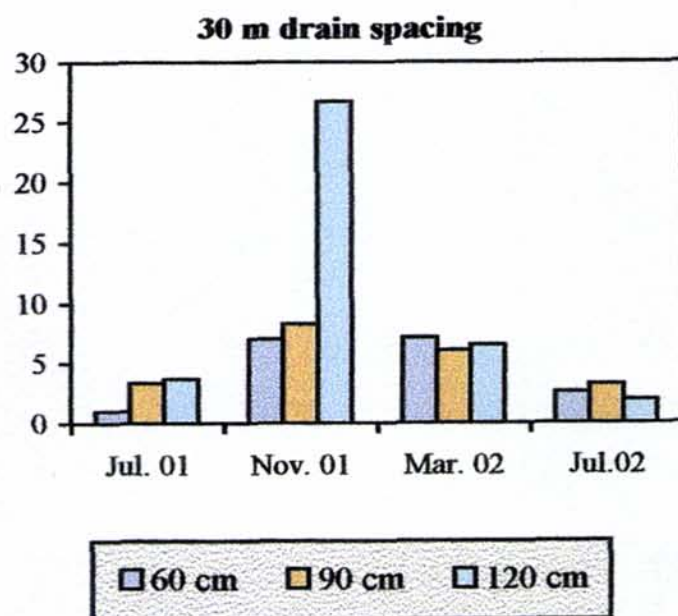
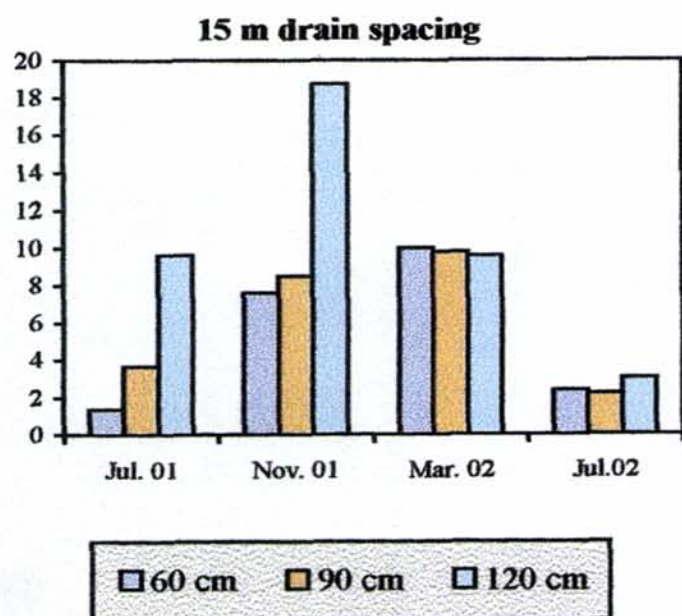
In a nutshell it was observed that removal of sodium was more with narrowest spacing and minimum with widest spacings.

4.2.6 Potassium content in drainage water

The potassium content in drainage water as a function of subsurface drainage are presented in Table 30.

Table 29. Effect of subsurface drainage on sodium content in drainage water (meL^{-1})

Depth of drainage	July 01	Aug. 01	Sep. 01	Oct. 01	Nov. 01	Dec. 01	Jan. 02	Feb. 02	Mar. 02	Apr. 02	May 02	June 02	July 02	Total	Mean	S.D. $\pm$	CV %
15 m drain spacing																	
60 cm	1.36	3.36	5.65	6.73	7.60	20.90	17.80	11.30	10.00	9.56	3.26	2.82	2.39	102.7	7.90	5.70	73.00
90 cm	3.69	3.47	6.34	7.17	8.47	19.60	19.10	13.90	9.78	9.02	2.93	2.60	2.17	108.2	8.32	5.73	68.87
120 cm	9.60	8.30	7.06	10.80	18.70	17.00	20.00	17.00	9.56	5.56	4.13	3.69	3.04	134.4	10.34	5.73	55.43
30 m drain spacing																	
60 cm	0.98	0.98	1.73	3.36	7.06	17.6	8.47	8.47	7.17	5.00	3.15	3.26	2.60	69.83	5.37	4.36	81.29
90 cm	3.36	4.78	4.34	7.82	8.26	19.10	8.69	9.13	6.08	6.3	4.34	4.02	3.26	89.48	6.88	3.99	58.04
120 cm	3.69	5.20	4.67	13.90	16.70	15.70	19.10	10.4	6.52	5.97	3.04	2.39	1.95	109.2	8.40	5.77	68.70
45 m drain spacing																	
60 cm	0.87	1.95	4.02	2.50	4.67	17.80	5.43	3.58	5.43	3.80	2.93	3.04	2.17	58.19	4.47	4.05	90.60
90 cm	1.08	3.58	4.67	3.69	4.34	11.30	9.56	10.90	3.58	4.45	2.26	2.60	2.82	64.83	4.98	3.22	64.75
120 cm	2.17	2.60	2.93	4.45	10.00	13.50	9.34	13.00	3.80	4.34	3.26	3.26	3.47	76.12	5.85	3.91	66.90
60 m drain spacing																	
60 cm	0.76	0.54	1.95	0.87	3.80	12.20	7.39	2.93	7.28	3.80	4.45	2.39	1.95	50.31	3.87	3.15	81.26
90 cm	1.30	1.84	1.95	0.98	4.34	17.20	7.82	10.40	8.80	3.69	2.6	2.60	2.82	75.19	5.78	3.63	62.81
120 cm	2.82	1.95	4.34	7.06	10.00	17.00	8.04	8.04	6.52	2.58	2.17	2.50	2.17	66.34	5.10	5.00	98.03



X = Month
Y = Na, me L⁻¹

Fig. 13. Effect of sub-surface drainage on sodium content (me L⁻¹) in drainage water

Table 30. Effect of subsurface drainage on potassium content in drainage water (meL^{-1})

Depth of drainage	July 01	Aug. 01	Sep. 01	Oct. 01	Nov. 01	Dec. 01	Jan. 02	Feb. 02	Mar. 02	Apr. 02	May 02	June 02	July 02	Total
15 m drain spacing														
60 cm	0.14	1.51	0.06	0.12	0.17	0.12	0.15	0.15	0.23	0.04	0.02	0.02	0.03	1.76
90 cm	0.11	0.23	0.07	0.11	0.14	0.12	0.15	0.08	0.04	0.03	0.02	0.02	0.03	1.15
120 cm	0.05	0.10	0.08	0.09	0.04	0.13	0.13	0.05	0.03	0.04	0.02	0.01	0.02	0.79
30 m drain spacing														
60 cm	0.07	0.10	0.08	0.07	0.05	0.07	0.05	0.08	0.17	0.01	0.01	0.02	0.01	0.79
90 cm	0.04	0.18	0.08	0.08	0.06	0.07	0.03	0.05	0.02	0.01	0.02	0.02	0.02	0.68
120 cm	0.06	0.15	0.08	0.10	0.17	0.08	0.05	0.08	0.01	0.02	0.03	0.02	0.03	0.88
45 m drain spacing														
60 cm	0.17	0.08	0.07	0.06	0.07	0.05	0.05	0.02	0.02	0.01	0.01	0.02	0.01	0.64
90 cm	0.04	0.23	0.07	0.07	0.09	0.06	0.07	0.06	0.02	0.01	0.01	0.01	0.01	0.75
120 cm	0.04	0.10	0.07	0.06	0.04	0.06	0.08	0.08	0.02	0.02	0.02	0.02	0.04	0.73
60 m drain spacing														
60 cm	0.08	0.21	0.06	0.05	0.06	0.04	0.05	0.01	0.01	0.01	0.02	0.01	0.02	0.63
90 cm	0.06	0.20	0.07	0.06	0.07	0.04	0.04	0.03	0.02	0.01	0.01	0.02	0.02	0.65
120 cm	0.06	0.05	0.06	0.06	0.07	0.04	0.07	0.05	0.01	0.01	0.02	0.02	0.03	0.55

From the data it is observed that the removal of potassium was more from July 2001 to January 2002 and less from February 2002 onwards but there was no specific trend was observed regarding the potassium content in drainage water with respect to time.

The presented data revealed that the potassium content in leachate was maximum with 15 m drainage spacing and 60 cm depth i.e. 1.76 meL^{-1} , followed by 90 cm depth i.e. 1.15 meL^{-1} and with 120 cm the potassium content was 0.79 meL^{-1} . This might be due to the least solubility of potassium. The minimum removal of potassium was observed with 60 m drain spacing indicating the drainage out flow was decreased as the drain spacing increased.

4.2.7 Chloride content in drainage water

The removal of chloride through drainage water as a function of sub-surface drainage are presented in Table 31 and Fig. 14.

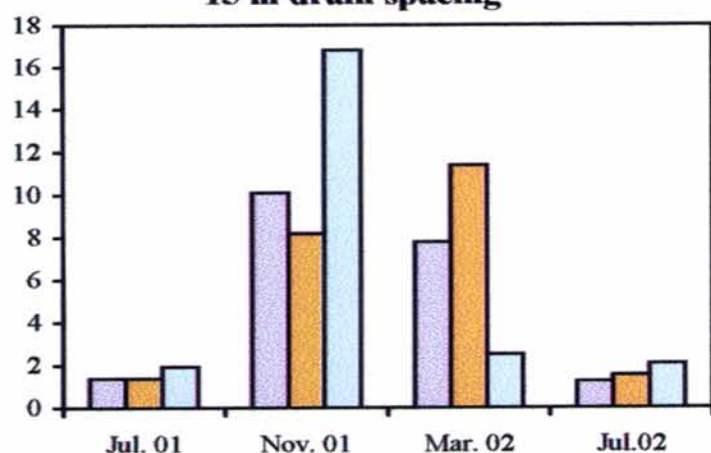
The data showed that the removal of chloride through drainage water was increased from July 2001 to January 2002 and it showed decreasing trend from February 2002 to July 2002 in all the treatments of subsurface drainage. This fluctuation in the removal of chloride through drainage water might be due to the outflow of drainage water, when the outflow was smaller the concentration of chloride was highest and lowest with largest outflow.

The removal of chloride was recorded highest with 15 m drain spacing i.e. 66.2, 69.0 and 154.3 meL^{-1} with 60, 90 and 120 cm drainage depths, respectively followed by 30 m drain spacing i.e.

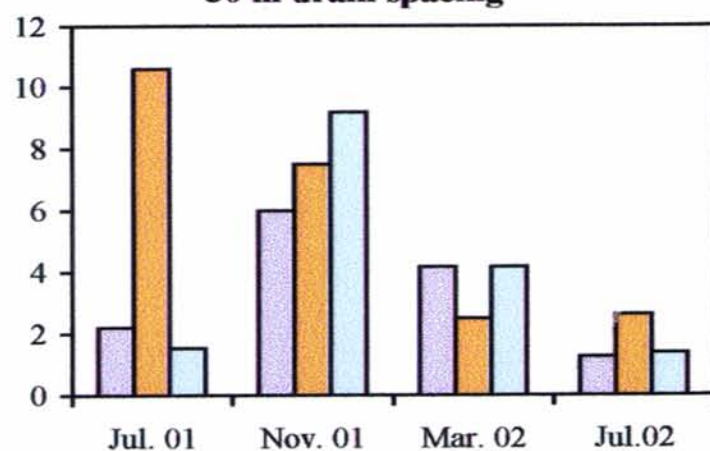
Table 31. Effect of subsurface drainage on chloride content in drainage water (meL⁻¹)

Depth of drainage	July 01	Aug. 01	Sep. 01	Oct. 01	Nov. 01	Dec. 01	Jan. 02	Feb. 02	Mar. 02	Apr. 02	May 02	June 02	July 02	Total
15 m drain spacing														
60 cm	1.38	2.36	2.5	2.91	10.10	13.60	18.75	9.30	7.77	3.05	1.66	1.66	1.25	66.23
90 cm	1.38	1.52	1.66	4.16	8.20	14.20	18.33	9.58	11.40	4.72	1.25	1.11	1.52	69.03
120 cm	1.94	13.80	14.70	16.70	16.80	13.90	20.10	8.33	2.50	1.25	1.66	1.52	2.08	154.36
30 m drain spacing														
60 cm	2.22	1.25	1.38	2.77	6.00	11.40	13.88	6.25	4.16	1.52	1.66	1.66	1.25	45.4
90 cm	1.60	2.08	2.63	3.61	7.50	12.40	11.94	5.97	2.50	3.33	2.08	1.80	2.63	59.07
120 cm	1.52	7.91	10.40	18.10	9.2	10.80	17.91	6.25	4.16	1.94	1.94	1.94	1.38	83.45
45 m drain spacing														
60 cm	1.25	1.38	1.52	1.52	4.20	11.70	12.50	2.91	3.88	1.25	2.50	2.08	1.25	37.94
90 cm	1.25	1.38	1.25	1.38	8.00	13.50	16.94	4.44	3.88	1.38	1.25	1.25	1.66	47.56
120 cm	1.66	1.52	1.38	4.86	7.20	12.40	15.69	3.88	3.88	1.80	1.25	1.25	1.25	48.02
60 m drain spacing														
60 cm	1.52	1.52	1.52	1.38	6.90	12.50	11.52	2.91	5.83	1.38	1.38	1.11	1.66	41.13
90 cm	0.97	1.66	1.94	6.25	7.20	9.44	19.86	3.88	4.30	1.38	2.22	2.08	1.25	52.43
120 cm	1.25	1.38	1.52	1.25	9.30	10.00	15.00	6.66	1.25	1.38	2.08	2.22	1.52	44.81

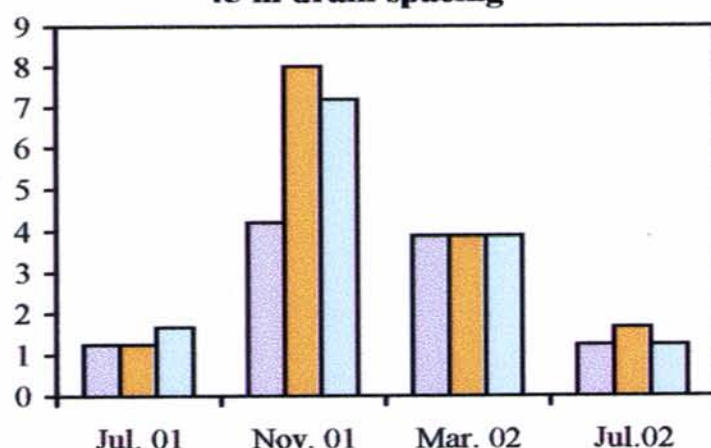
15 m drain spacing



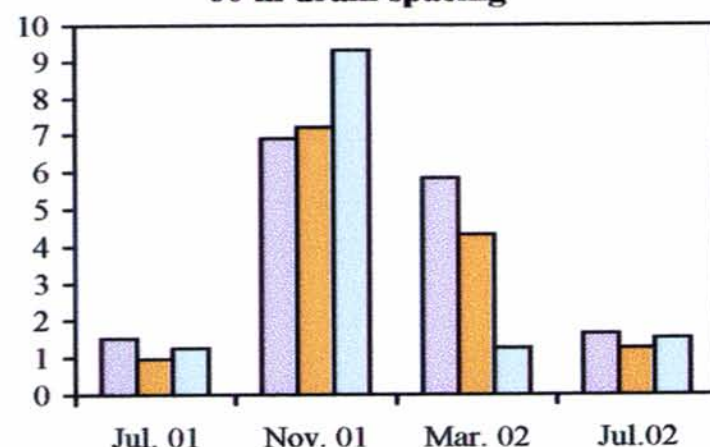
30 m drain spacing



45 m drain spacing



60 m drain spacing



X = Month
Y = Chloride content (me L^{-1})

Fig. 14. Effect of sub-surface drainage on chloride content (me L^{-1}) in drainage water

45.4, 59.0 and 83.4 meL^{-1} with 60, 90 and 120 cm drain depths respectively. This might be due to the drain out flow was highest for narrowest spacing and lowest for largest spacing and because of the more solubility of chloride. This findings are in accordance with the findings of Sharma et al. (1994).

4.2.8 Bicarbonate content in drainage water

The data regarding to the bicarbonate content in drainage water as influenced by the different treatments of sub-surface drainage was presented in Table 32.

The presented data in this table revealed that the bicarbonate content in drainage water showed increasing trend from July 2001 to December 2001 and it showed decreasing trend from January 2002 to onward in all the treatments with respect to spacing and depth. This fluctuation may be due to the opening and closing of canal.

From this data it is observed that the removal of bicarbonate was more with 15 m drain spacing i.e. 114.2, 106 and 108.7 meL^{-1} with 60, 90 and 120 cm drainage depths respectively, followed by 30 m drain spacing and the removal of bicarbonate in this treatment was 97.4, 95.4 and 79.1 meL^{-1} with 60, 90 and 120 cm drainage depths respectively. Similar observations were reported by Kundu and Singh (2001).

In short the subsurface drainage found beneficial in removing of bicarbonate through drainage water and 15 m drain spacing was superior in this regard.

Table 32. Effect of subsurface drainage on Bicarbonate content in drainage water (meL^{-1})

Depth of drainage	July 01	Aug. 01	Sep. 01	Oct. 01	Nov. 01	Dec. 01	Jan. 02	Feb. 02	Mar. 02	Apr. 02	May 02	June 02	July 02	Total
15 m drain spacing														
60 cm	10.0	9.3	9.0	10.1	16.8	9.8	18.8	13.1	6.9	6.0	5.2	4.2	5.0	114.2
90 cm	6.0	7.2	8.1	8.1	10.1	11.2	11.0	10.4	13.0	8.0	5.0	4.0	3.9	106.0
120 cm	5.3	7.8	8.0	8.0	8.2	14.1	9.0	7.1	14.0	14.0	5.1	4.2	3.9	108.7
30 m drain spacing														
60 cm	1.0	3.0	2.0	6.8	4.2	6.9	6.0	3.2	6.0	6.3	5.8	4.1	3.0	97.4
90 cm	5.6	6.0	6.2	9.2	10.2	7.9	8.0	6.4	6.0	5.2	5.2	5.9	3.6	95.4
120 cm	4.9	5.	5.6	6.8	8.0	8.3	7.9	6.8	6.0	5.0	6.0	4.9	3.9	79.1
45 m drain spacing														
60 cm	4.0	4.8	3.9	5.1	6.0	7.7	6.5	6.4	6.0	5.3	6.2	5.4	3.6	70.9
90 cm	9.0	9.9	7.1	8.2	9.2	9.7	10.0	6.2	4.9	6.2	5.2	4.2	3.8	93.6
120 cm	5.3	5.1	6.2	5.0	7.5	10.3	9.0	6.0	5.0	6.0	5.0	4.0	3.4	77.8
60 m drain spacing														
60 cm	4.4	5.2	5.9	6.8	6.9	7.2	6.2	5.4	6.2	5.0	5.9	4.9	3.6	73.6
90 cm	5.0	7.8	7.6	6.8	7.2	6.5	6.0	5.3	6.1	6.1	5.3	4.8	4.0	78.5
120 cm	3.6	3.8	4.9	6.0	9.3	6.9	7.5	7.2	6.3	5.0	7.2	6.0	5.0	78.7

4.2.9 Sulphate content in drainage water

The presented data in Table 33 and Fig. 15 showed the effect of subsurface drainage on removal of sulphate through drainage water.

The data showed that the sulphate removal was increased from July 2001 to January 2002 and it decreased from February 2002 to July 2002.

The removal of sulphate was highest with 15 m drain spacing and the concentration of sulphate was 44.6, 55.4 and 96.4 meL^{-1} at 60, 90 and 120 cm drainage depths respectively during the period of one year and 120 cm depth found superior over all other depths. With 30 m drain spacing the concentration of sulphate was 26.8, 42.4 and 76.4 meL^{-1} at 60, 90 and 120 cm drainage depths respectively. The minimum removal of sulphate was recorded with 60 m drain spacing i.e. 20.8, 23.4 and 26.84 meL^{-1} at 60, 90 and 120 cm drainage depths respectively. This might be due to the more solubility with Na_2SO_4 .

In general it was observed that the removal of sulphate through drainage water was increased with decreasing drainage spacing.

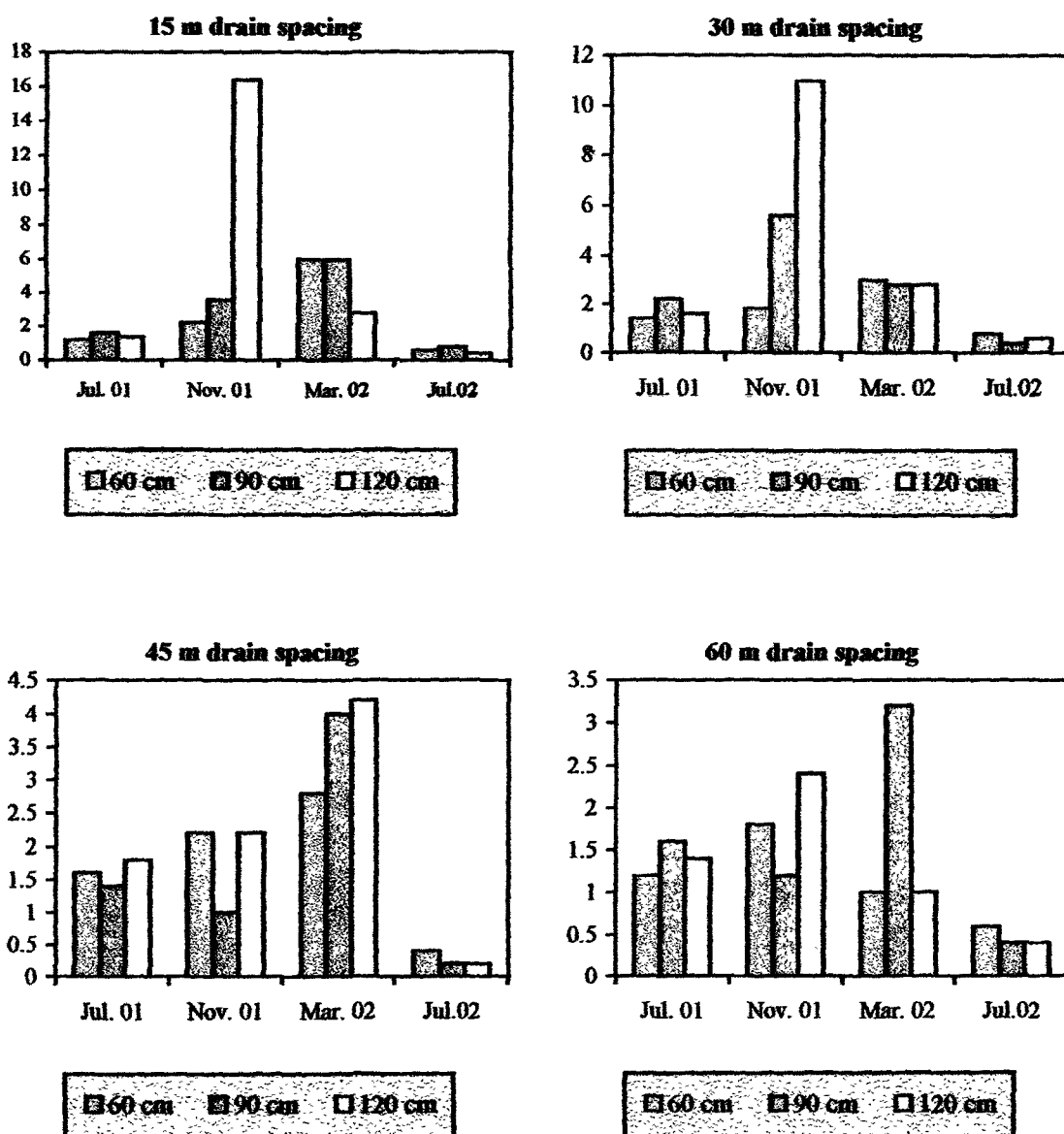
4.2.10 Adjusted SAR of drainage water

The data in respect of adjusted SAR of drainage water are presented in Table 34.

The presented data revealed that the adjusted SAR increased from July 2001 to Jan. 2002 in 15 m drain spacing and from July 2001 to Dec. 2001 in rest of the treatments. The maximum

Table 33. Effect of subsurface drainage on sulphate content in drainage water (meL⁻¹)

Depth of drainage	July 01	Aug. 01	Sep. 01	Oct. 01	Nov. 01	Dec. 01	Jan. 02	Feb. 02	Mar. 02	Apr. 02	May 02	June 02	July 02	Total
15 m drain spacing														
60 cm	1.2	1.8	1.8	2.0	2.2	18.0	22.4	4.2	6.0	2.8	1.0	0.6	0.6	44.6
90 cm	1.6	2.2	3.2	3.4	3.6	17.6	23.4	5.6	6.0	6.0	1.2	0.8	0.8	55.4
120 cm	1.4	8.8	10.0	11.6	16.4	14.4	17.0	9.0	2.8	2.6	1.2	0.8	0.4	96.4
30 m drain spacing														
60 cm	1.4	1.4	1.8	1.2	1.8	8.6	2.8	1.2	3.0	1.2	0.8	0.8	0.8	26.8
90 cm	2.2	2.2	2.6	5.0	5.6	8.4	3.4	3.6	2.8	2.4	2.0	1.8	0.4	42.4
120 cm	1.6	10.6	8.8	9.0	11.0	11.4	12.0	3.2	2.8	1.8	1.8	1.8	0.6	76.4
45 m drain spacing														
60 cm	1.6	1.4	1.6	1.9	2.2	12.4	1.6	2.8	2.8	1.4	0.4	0.4	0.4	28.1
90 cm	1.4	0.4	1.0	0.6	1.0	5.8	2.4	5.2	4.0	1.4	1.0	0.4	0.2	24.8
120 cm	1.8	1.4	2.2	2.0	2.2	14.2	2.8	4.8	4.2	1.4	0.6	0.6	0.2	38.4
60 m drain spacing														
60 cm	1.2	1.0	1.8	1.8	1.8	6.0	2.4	1.0	1.0	1.2	0.6	0.4	0.6	20.8
90 cm	1.6	0.6	0.4	0.6	1.2	7.8	2.2	2.4	3.2	1.6	0.8	0.6	0.4	23.4
120 cm	1.4	1.2	1.4	2.4	2.4	6.2	2.2	6.4	1.0	1.4	0.4	0.4	0.4	26.8



X = Month
Y = $\text{SO}_4^- \text{ me L}^{-1}$

Fig. 15. Effect of sub-surface drainage on sulphate content in drainage water (me L⁻¹)

Table 34. Effect of subsurface drainage on adj.SAR of drainage water

Depth of drainage	July 01	Aug. 01	Sep. 01	Oct. 01	Nov. 01	Dec. 01	Jan. 02	Feb. 02	Mar. 02	Apr. 02	May 02	June 02	July 02
15 m drain spacing													
60 cm	2.06	4.53	8.47	9.68	9.05	27.00	26.00	16.12	14.54	12.92	5.21	4.20	4.09
90 cm	5.69	3.53	8.90	10.45	10.92	25.25	26.98	17.44	11.84	15.47	4.53	3.98	3.44
120 cm	13.69	10.93	9.80	15.60	26.41	22.82	28.70	20.64	12.00	8.20	6.41	5.94	4.45
30 m drain spacing													
60 cm	0.82	1.17	2.14	4.62	9.14	22.00	12.22	9.93	10.22	7.90	4.45	5.22	3.92
90 cm	4.87	6.44	6.39	11.90	13.33	24.48	11.25	13.39	9.43	9.26	6.07	6.32	4.92
120 cm	5.35	8.13	15.43	22.81	21.85	17.58	23.87	11.82	9.08	9.94	4.70	3.65	3.42
45 m drain spacing													
60 cm	1.36	3.86	6.48	3.37	7.01	21.11	8.37	6.14	8.40	5.61	4.83	5.08	4.16
90 cm	1.42	4.47	6.41	5.79	6.83	15.86	14.04	15.64	5.52	6.96	3.43	4.60	4.40
120 cm	3.77	4.41	5.01	6.50	13.65	18.76	11.42	17.27	5.52	6.87	4.62	5.75	5.58
60 m drain spacing													
60 cm	1.32	0.92	2.36	1.40	6.18	15.08	12.31	5.52	11.25	5.81	6.62	3.63	3.29
90 cm	2.04	2.81	3.09	1.62	6.45	23.85	12.14	14.08	13.07	6.04	3.86	3.92	4.90
120 cm	4.13	3.12	4.62	9.75	14.58	23.47	13.03	12.25	11.33	3.68	3.55	3.89	3.60



A) Laying of drain Pipe



B) Covering of drain Pipe with Sand



C) Collector drain discharging drain water in sump well on research field



D) Leaching of Soil column with different amendments

adj. SAR was recorded with 15 m drain spacing followed by 30 m drain spacing indicating the drainage outflow was maximum for less spacing which was found better in removing of sodium through leachate.

4.3 Effect of leaching on quality of leachate and on soil properties

In order to study the leaching behaviour of saline sodic soils from the study area a column study was conducted for 120 days with different amendments viz., FYM, FeSO_4 , PMC, sulphur, FeS_2 + PMC and sulphur + PMC. For this pore volume was calculated and it was 8.4 lit and the canal EC (0.4 dSm^{-1}) water was allowed to pass through the soil column and it was observed that 7, 8, 9, 10, 15, 14 and 13 pore volume water was leached out with control, FYM, FeS_2 , PMC, sulphur FeS_2 + PMC and sulphur + PMC respectively and there was no rise and fall of mercury was observed. The data regarding the composition of leachate and effect of leaching on soil is discussed under the following heads.

4.3.1 Quality of leachate

4.3.1.1 pH of leachate

The pH values of leachate as influenced by FYM, iron pyrite, PMC, sulphur, iron pyrite + PMC and sulphur + PMC during leaching of saline sodic soil with canal water are presented in Table 35.

From the presented data it would be seen that the pH values of leachate collected from the saline sodic soils treated with FYM, iron pyrite, PMC, sulphur and their combination were more than the leachate collected from untreated soil. The pH value of leachate

Table 35. Effect of addition of amendments in soil column on pH of leachate

No. of pore volumes	Control	FYM	Iron pyrite	PMC	Sulphur	Iron pyrite + PMC	Sulphur + PMC
1.	8.44	8.62	8.47	8.44	8.76	8.50	8.47
2.	8.80	9.50	8.36	8.40	8.94	8.43	8.47
3.	8.04	8.60	8.21	8.43	8.94	8.80	8.50
4.	8.70	8.80	8.40	8.40	8.94	8.72	8.55
5.	8.60	8.90	8.48	8.50	8.72	8.64	8.60
6.	8.00	8.80	8.65	8.62	8.80	8.40	8.60
7.	8.00	8.61	8.95	8.62	8.40	8.64	8.80
8.	-	8.40	8.68	8.49	8.80	8.42	8.51
9.	-	-	8.64	8.73	9.04	8.41	8.40
10.	-	-	-	8.72	8.88	8.40	8.70
11.					8.68	8.60	8.87
12.					8.43	8.60	8.68
13.					8.40	8.43	8.48
14.					8.88	8.38	-
15.					8.68	-	-

increased by the application of sulphur > Sulphur + PMC > FYM > PMC > Iron pyrite > Iron pyrite + PMC > control. The increase in pH value of leachate might be due to the content of more soluble salts in the leachates collected from saline sodic soil treated with amendments.

4.3.1.2 Electrical conductivity of leachate

The values of electrical conductivity (EC) of leachate as influenced by different treatments of amendments are given in Table 36.

The data revealed that the electrical conductivity of leachate was increased by the addition of amendments in the soil than simple leaching. The maximum removal of soluble salts (45.1 dSm^{-1}) in the leachate was observed by the addition of sulphur followed by sulphur + PMC. The EC value was highest in the first leachate in all the treatments and it decreased with time. The removal of more soluble salts through leachate might be due to the improvement of soil permeability by the addition of amendments and it creates flocculated conditions in which native Ca^{2+} might have helped in formation of CaSO_4 which might have created favorable conditions for leaching of soil. The removal of soluble salts from saline sodic soil was more under the soil treated with FYM, iron pyrite, PMC, sulphur and their combinations than simple leaching.

4.3.1.3 Calcium content in leachate

It would be seen from Table 37 that the removal of calcium through leachate was influenced by the addition of amendments in soil column. The calcium content was recorded highest with Iron pyrite alone and its combination with PMC than all

Table 36. Effect of addition of amendments in soil column on electrical conductivity of leachate (dSm^{-1})

No. of pore volumes	Control	FYM	Iron pyrite	PMC	Sulphur	Iron pyrite + PMC	Sulphur + PMC
1.	3.70	6.36	5.52	5.41	8.82	6.41	8.32
2.	3.55	5.74	5.03	4.37	6.08	5.37	6.36
3.	3.10	4.89	5.00	4.06	5.43	4.89	5.59
4.	2.38	2.11	3.58	3.90	4.82	4.50	4.80
5.	1.28	1.40	2.39	2.94	4.00	3.32	4.00
6.	0.98	0.86	1.90	1.41	3.25	3.05	3.59
7.	0.81	0.44	0.72	1.10	2.80	2.40	2.20
8.	-	0.40	0.67	0.69	2.51	1.08	1.89
9.	-	-	0.61	0.44	2.00	1.89	1.56
10.	-	-	-	0.40	2.25	1.54	1.20
11.					1.06	1.32	0.54
12.					0.88	0.96	0.46
13.					0.65	0.41	0.35
14.					0.34	0.37	-
15.					0.30	-	-

Table 37. Effect of addition of amendments in soil column on calcium content in leachate (me L⁻¹)

No. of pore volumes	Control	FYM	Iron pyrite	PMC	Sulphur	Iron pyrite + PMC	Sulphur + PMC
1.	24.0	36.0	20.0	28.0	14.0	16.4	15.2
2.	19.0	18.6	20.5	8.4	10.2	13.3	13.1
3.	19.2	4.5	16.5	6.2	13.6	10.2	10.4
4.	18.9	2.6	14.2	5.9	11.2	8.3	10.1
5.	8.4	1.8	8.6	4.9	10.4	7.9	9.1
6.	7.4	1.9	8.2	3.6	6.7	8.1	8.4
7.	4.3	1.0	3.2	3.4	4.1	6.8	7.1
8.	-	0.6	2.1	1.4	3.6	5.4	6.3
9.	-	-	2.0	1.1	2.9	6.7	5.5
10.	-	-	-	0.5	1.6	3.3	3.5
11.					1.3	2.9	1.9
12.					1.2	1.4	1.5
13.					1.0	1.2	1.0
14.					0.8	1.4	-
15.					0.5	-	-

the treatments. It might be due to the release of calcium from CaCO_3 by the action of sulphuric acid occurred during the oxidation of iron pyrites. The total calcium content in leachate was less in all the treatments than control and in control treatment the removal of calcium was 101.2 me L^{-1} within 120 days of leaching.

The removal of calcium was less with FYM and PMC than other treatments. It indicated that the released calcium might be adsorbed on exchange complex. Hence the organic amendments minimized the calcium losses due to leaching.

4.3.1.4 Magnesium content in leachate

The data pertaining to the magnesium content in leachate as influenced by FYM, FeS_2 , PMC, sulphur and their combinations are presented in Table 38.

It was revealed that maximum amount of magnesium leached with from pyrite i.e. 98.4 meL^{-1} with 120 days of leaching. The maximum magnesium leached out in the first leaching and it decreased thereafter among all the treatments minimum leaching of magnesium was recorded with FYM i.e. 48.9 meL^{-1} and PMC 57 meL^{-1} respectively.

Further it was observed that in the combination treatments of FeS_2 + PMC and sulphur + PMC the removal of magnesium was 94.8 and 95.9 meL^{-1} respectively. It might be due to the release of magnesium from soil and removal of magnesium as MgCl_2 through leachate.

Table 38. Effect of addition of amendments in soil column on magnesium content in leachate (me L⁻¹)

No. of pore volumes	Control	FYM	Iron pyrite	PMC	Sulphur	Iron pyrite + PMC	Sulphur + PMC
1.	15.0	16.6	22.2	14.0	14.2	19.2	20.6
2.	11.0	11.0	22.1	12.0	10.6	18.9	16.0
3.	10.2	7.6	21.5	7.4	2.2	18.2	11.2
4.	9.3	5.7	10.9	4.9	9.2	7.9	12.0
5.	8.1	2.4	8.5	3.9	10.4	6.9	5.4
6.	5.1	1.9	7.1	5.5	9.5	4.3	9.3
7.	3.9	2.1	2.6	4.7	2.1	3.5	7.7
8.	-	1.6	2.0	2.1	2.2	7.4	4.8
9.	-	-	1.5	1.2	1.6	1.5	2.8
10.	-	-	-	1.3	1.4	1.9	3.9
11.					1.2	1.7	0.8
12.					1.2	1.4	0.8
13.					1.1	1.2	0.6
14.					1.0	0.8	-
15.					1.0	-	-
Total	62.6	48.9	98.4	57.0	78.9	94.8	95.9

4.3.1.5 Sodium content in leachate

The data pertaining to the sodium content in leachate as influenced by organic and inorganic amendments are given in Table 39.

The presented data indicates that the removal of total sodium through leachate was more when the soil treated with amendments than simple leaching.

Initially the removal of sodium was higher in all the treatments but it decreased with time of leaching. The maximum removal of sodium through leachate was more i.e. 174.4 mL^{-1} within 120 days of leaching, when the soil was amended with sulphur (400 kg ha^{-1}). This might be due to the reaction between CaCO_3 and formation of H_2SO_4 which improves soil permeability which allows maximum passage of water and ultimately the removal of sodium was more.

Further, other treatments i.e. FYM, FeS_2 , PMC, $\text{FeS}_2 + \text{PMC}$ and sulphur + PMC were also found effective in removing of sodium through leachate but maximum removal was recorded among these treatments with sulphur + PMC i.e. 169.1 mL^{-1} . The removal of sodium was 72.4, 111.0, 128.3 and 167.4 in the treatment of FYM, FeS_2 , PMC and $\text{FeS}_2 + \text{PMC}$ respectively. Similar results were reported by Singh et al. (1990a) with application of pyrites.

In general it was observed that the addition of amendments in soil column found beneficial in removing of sodium and sulphur treated column was superior in leaching of sodium.

Table 39. Effect of addition of amendments in soil column on sodium content in leachate (me L⁻¹)

No. of pore volumes	Control	FYM	Iron pyrite	PMC	Sulphur	Iron pyrite + PMC	Sulphur + PMC
1.	13.91	18.47	26.08	30.43	32.60	39.13	34.52
2.	10.65	16.30	21.73	25.00	35.86	28.26	28.26
3.	11.73	14.13	20.65	21.73	15.21	21.73	20.56
4.	9.56	14.13	16.30	13.04	15.21	15.21	17.21
5.	8.62	10.86	11.95	14.13	14.13	14.13	14.86
6.	7.39	8.69	8.69	10.86	13.04	10.86	12.69
7.	3.04	2.17	2.60	7.60	11.95	9.78	10.78
8.	-	1.86	1.50	2.60	10.86	8.69	9.60
9.	-	-	1.50	1.73	8.69	7.6	8.60
10.	-	-	-	1.25	6.52	5.78	5.80
11.					5.43	2.47	3.73
12.					2.17	1.60	1.55
13.					2.00	1.10	1.00
14.					0.60	1.10	-
15.					0.20	-	-
Total	64.9	72.48	111.00	128.37	174.47	167.44	169.16

4.3.1.6 Potassium content in leachate

The data presented in Table 40 showed that there was no much effect of application of amendments on the removal of potassium through leachate. The potassium content in leachate was influenced by the application of FYM, Iron pyrite, PMC, sulphur and their combinations to saline sodic soils. The addition of amendments to the soil was more effective in removal of potassium leachate than simple leaching. There was very little difference in the removal of potassium under the soil treated with amendments. It was observed that the removal of potassium was slightly more under the soil treated with sulphur followed by FYM.

4.3.1.7 Chloride content in leachate

The chloride content in leachate as influenced by FYM, FeS_2 , PMC, sulphur, FeS_2 + PMC and sulphur + PMC in saline sodic swell shrink soil are presented in Table 41.

The data the removal of chloride was more in first leachate in all the treatments and it decreased with time and after four months the chloride content in leachate was less as compared to initial value.

The maximum removal of chloride through leachate was under the treatment of sulphur and the removal was 177.7 meL^{-1} within 120 days of leaching followed by sulphur + PMC i.e. 175.04 meL^{-1} . This indicated the improvement in soil after addition of sulphur by which maximum amount of leachate were collected and due to the more solubility of chloride the removal was maximum.

Table 40. Effect of addition of amendments in soil column on potassium content in leachate (me L^{-1})

No. of pore volumes	Control	FYM	Iron pyrite	PMC	Sulphur	Iron pyrite + PMC	Sulphur + PMC
1.	0.220	0.210	0.184	0.184	0.174	0.123	0.123
2.	0.210	0.210	0.205	0.158	0.153	0.117	0.123
3.	0.190	0.200	0.200	0.153	0.110	0.123	0.097
4.	0.170	0.20	0.194	0.128	0.123	0.120	0.102
5.	0.170	0.194	0.189	0.148	0.123	0.115	0.087
6.	0.140	0.184	0.112	0.141	0.128	0.120	0.097
7.	0.130	0.179	0.123	0.123	0.120	0.115	0.102
8.	-	0.125	0.120	0.115	0.117	0.17	0.082
9.	-	-	0.120	0.102	0.110	0.082	0.061
10.	-	-	-	0.102	0.110	0.082	0.061
11.					0.097	0.056	0.028
12.					0.071	0.051	0.025
13.					0.058	0.035	0.013
14.					0.056	0.012	-
15.					0.025	-	-
Total	1.23	1.50	1.44	1.35	1.57	1.32	1.00

Table 41. Effect of addition of amendments in soil column on chloride content in leachate (me L⁻¹)

No. of pore volumes	Control	FYM	Iron pyrite	PMC	Sulphur	Iron pyrite + PMC	Sulphur + PMC
1.	20.83	26.31	26.25	24.20	28.94	22.10	27.36
2.	20.25	19.99	25.31	17.89	17.89	19.99	26.31
3.	20.10	16.83	24.83	14.73	17.36	19.99	19.99
4.	10.99	15.78	11.57	14.73	16.83	15.78	15.78
5.	10.41	14.73	9.47	13.68	15.78	14.73	14.20
6.	9.73	12.62	7.36	7.36	15.78	12.62	14.20
7.	8.57	11.57	4.73	6.84	14.73	10.52	13.68
8.	-	2.10	3.10	5.78	12.10	9.99	11.57
9.	-	-	2.10	5.26	9.47	8.94	10.52
10.	-	-	-	3.15	8.41	8.41	8.41
11.					7.89	6.31	5.26
12.					4.73	4.73	4.20
13.					3.15	3.15	3.56
14.					2.10	2.10	-
15.					2.01	-	-
Total	100.88	119.93	115.24	113.02	177.17	159.3	175.04

Further it was observed that the FYM, FeS_2 , PMC and FeS_2 + PMC also found effective in removing of chloride and the removal was 119.93, 115.24, 113.02 and 159.3 meL^{-1} with FYM, FeS_2 , PMC and FeS_2 + PMC respectively. This removal indicates the beneficial effect of these amendments in improving the soil. These findings are in accordance with the results of Singh (1997).

On the whole, the leaching of soil with these amendments was effective in reclamation of saline sodic soil.

4.3.1.8 Bicarbonate content in leachate

The data pertaining to the bicarbonate content in leachate as influenced by FYM, Iron pyrite, PMC sulphur and its combinations are given in Table 42.

The data revealed that the removal of HCO_3^- was more under FYM treatment than any other treatments, followed by iron pyrites treatments. In case of combinations of iron pyrite with PMC and sulphur with PMC treatments the removal of HCO_3^- was more under the treatment of iron pyrite + PMC than sulphur + PMC than simple leaching. The trend of removal of bicarbonate was $\text{FYM} > \text{iron pyrite} + \text{PMC} > \text{sulphur} + \text{PMC} > \text{iron pyrite} > \text{sulphur} > \text{PMC} > \text{Control}$.

4.3.1.9 Sulphate content in leachate

The data pertaining to the sulphate content in leachate as a function of FYM, FeS_2 , PMC, sulphur and their combinations are presented in Table 43.

The removal of sulphate was found superior over control when the soil was amended with these amendments. But the

Table 42. Effect of addition of amendments in soil column on bicarbonate content in leachate (me L⁻¹)

No. of pore volumes	Control	FYM	Iron pyrite	PMC	Sulphur	Iron pyrite + PMC	Sulphur + PMC
1.	11.5	38.0	28.4	23.4	15.9	19.4	16.2
2.	10.0	19.1	22.6	8.6	11.9	15.8	16.1
3.	9.8	18.1	19.7	8.3	11.9	12.4	14.6
4.	9.6	17.0	16.9	6.0	11.2	10.9	14.2
5.	8.6	12.8	13.2	5.4	10.5	10.4	13.0
6.	8.2	9.0	9.3	4.9	9.6	9.7	10.1
7.	7.6	8.5	7.3	5.0	2.8	9.6	9.7
8.	-	1.2	7.0	3.2	2.5	8.2	6.4
9.	-	-	3.2	1.7	2.0	7.5	4.9
10.	-	-	-	0.4	1.0	2.9	4.4
11.					1.0	2.6	0.6
12.					0.9	2.3	0.4
13.					0.8	1.5	0.4
14.					0.6	1.2	-
15.					0.2	-	-
Total	68.3	123.7	107.6	75.9	82.8	114.4	111.0

Table 43. Effect of addition of amendments in soil column on sulphate content in leachate (me L^{-1})

No. of pore volumes	Control	FYM	Iron pyrite	PMC	Sulphur	Iron pyrite + PMC	Sulphur + PMC
1.	10.0	9.4	14.4	16.8	14.4	12.8	10.4
2.	9.0	9.2	12.2	10.4	10.8	10.6	9.4
3.	8.0	8.4	8.4	9.8	9.6	7.8	9.8
4.	7.0	7.2	7.6	8.0	8.4	5.8	9.2
5.	6.6	6.4	3.8	6.8	7.6	5.4	8.8
6.	5.4	6.0	3.2	5.2	6.4	5.4	8.8
7.	4.0	4.8	1.2	2.4	3.6	5.4	6.4
8.	-	3.2	1.0	2.4	3.2	5.0	5.6
9.	-	-	1.0	1.0	2.8	4.4	5.4
10.	-	-	-	0.6	2.2	3.2	4.6
11.					1.8	3.6	2.4
12.					1.4	2.2	1.2
13.					1.0	1.2	1.0
14.					0.6	0.8	-
15.					0.4	-	-
Total	50.0	54.6	52.9	63.4	74.2	73.6	83.0

maximum removal of sulphate was recorded with sulphur + PMC i.e. 83 meL^{-1} . This might be due to the 0.58 per cent sulphur contains in PMC and removal of sulphate from soil as Na_2SO_4 through leachate followed by sulphur alone i.e. 74.2 me L^{-1} in 120 days. Similar results were reported by Singh (1997) with amending with FYM.

Similarly, the removal of sulphate was more in all the remaining treatments as compared to simple leaching and it was 54.6, 52.9, 63.4 and 73.6 meL^{-1} with FYM, FeS_2 , PMC and FeS_2 + PMC respectively 120 days after leaching of soil column.

Hence, it was observed from the table that the amendments were effective in removing the sulphate through leachate and sulphur + PMC treatment found superior over other treatments followed by sulphur in removing the sulphate through leachate.

4.3.2 Soil properties

After 120 days to soil leaching the soil column were cut at 0-30, 30-60 and 60-90 cm depth and analysed if for salinity parameter and the results obtained before and after leaching are discussed as under.

4.3.2.1 pH of saturation paste of soil

The data regarding to the pHs of saline sodic soil as influenced by leaching with FYM, FeS_2 , PMC, sulphur FeS_2 + PMC and sulphur + PMC after 120 days of leaching are presented in Table 44.

The data showed that the pHe of saline sodic soil decreased in all the treatments at all three depths as compared to initial value. The pHe considerably decreased by the application

sulphur at all three depths, which was superior over all other treatments and the decrease in pHe was 8.42 to 7.94, 8.55 to 8.10 and 8.66 to 8.14 at 0-30, 30-60 and 60-90 cm depths respectively. Similar results were reported by Moazed and Sepaskha (1987).

The pHe was also decreased in other treatments FYM, FeS_2 , PMC and maximum reduction was recorded when the soil was amended with FeS_2 and the reduction was from 8.43 to 8.05, 8.55 to 8.06 and 8.66 to 8.16 at 0-30, 30-60, 60-90 cm depths. The FYM and PMC also found beneficial in reducing of pHe.

In the combination treatments the reduction in pHe was recorded maximum with sulphur + PMC and it was 8.42 to 8.00, 8.55 to 8.12, 8.66 to 8.18 at 0-30, 30-60 and 60-90 cm depths.

In general, it was observed that pHe decreased under all the treatments of amendments.

4.3.2.2 EC of saturation paste extract of soil

The data pertaining to the ECe values as affected by FYM, FeS_2 , PMC, Sulphur and their combinations upto 120 days after leaching process are presented in Table 45.

The data revealed that after the leaching process the electrical conductivity of saturation paste extract decreased under all the treatments than initial values at all the three depths. The maximum decrease in ECe was recorded with sulphur and the decrease was from 15.65 to 0.868, 13.33 to 0.967 and 11.81 to 1.01 dSm^{-1} at 0-30, 30-60 and 60-90 cm depths respectively. This decrease in ECe might be due to the removal of more salts through leachate by which soluble salts were leached out.

The ECe decreased in other treatments i.e. FYM, FeS_2 and PMC and it was observed that the reduction was higher with FeS_2 at all three depths and it was 15.65 to 1.15, 13.30 to 1.36 and 11.81 to 1.42 dSm^{-1} at 0-30, 30-60 and 60-90 cm depths respectively followed by FYM and PMC.

In the combination treatments of FeS_2 + PMC and sulphur + PMC, the FeS_2 + PMC was found superior over sulphur + PMC in reducing of ECe and the reduction was from 15.65 to 0.928, 13.33 to 1.00 and 11.81 to 1.19 dSm^{-1} at 0-30, 30-60 and 60-90 cm depths respectively. It showed that the leaching of saline-sodic soil with FeS_2 + PMC was more effective in the removal of soluble salts.

4.3.2.3 Calcium content in saturation paste extract of soil

The data in respect of calcium content in saturation paste extract of soil after the leaching of soil with FYM, FeS_2 , PMC, sulphur, FeS_2 + PMC and sulphur + PMC are given in Table 46.

The calcium content in saturation paste extract of soil was increased by the application of FYM, FeS_2 and PMC over initial value except at 0-30 cm depth. The maximum increase was recorded with the application of PMC and the increase was from 5.5 to 6.0 and 3.0 to 5.5 meL^{-1} at 30-60 and 60-90 cm depth, respectively, but at 0-30 cm depth it decreased from 10.5 to 7.0 meL^{-1} it might be due to the leaching of calcium in the lower depth of soil and with the FYM the increase was from 5.0 to 5.5 and 3.0 to 5.0 meL^{-1} at 30-60 cm and 60-90 cm depth respectively. Similar trend in calcium content was observed with FeS_2 and this might be due to release of calcium from CaCO_3 by the action of H_2SO_4 released from oxidation of pyrites.

Table 44. Effect of leaching on pH of saturation paste extract of soil

Depth (cm)	Initial	Control	FYM	Iron pyrite	PMC	Sulphur	Iron pyrite + PMC	Sulphur + PMC
0-30	8.42	8.28	8.03	8.05	8.00	7.94	8.01	8.00
30-60	8.55	8.30	8.17	8.06	8.14	8.10	8.14	8.12
60-90	8.66	8.34	8.24	8.16	8.20	8.14	8.19	8.18

Table 45. Effect of leaching on electrical conductivity of saturation paste extract of soil (dSm^{-1})

Depth (cm)	Initial	Control	FYM	Iron pyrite	PMC	Sulphur	Iron pyrite + PMC	Sulphur + PMC
0-30	6.65	5.90	1.22	1.15	1.19	0.86	0.92	0.94
30-60	4.33	4.00	1.65	1.36	1.71	0.96	1.00	1.01
60-90	3.81	3.10	1.70	1.42	1.91	1.01	1.19	1.20

Table 46. Effect of leaching on calcium content in saturation paste extract of soil (meL^{-1})

Depth (cm)	Initial	Control	FYM	Iron pyrite	PMC	Sulphur	Iron pyrite + PMC	Sulphur + PMC
0-30	10.5	4.0	6.5	5.5	7.0	4.5	4.5	5.0
30-60	5.0	3.5	5.5	5.5	6.0	4.0	4.5	4.5
60-90	3.0	3.0	5.0	5.0	5.5	3.0	4.0	4.5

In other treatments i.e. sulphur, FeS_2 + PMC and sulphur + PMC the Ca^{2+} was slightly decreased over initial value at 0-30 and 30-60 cm depth but it increased at 60-90 cm depth in all the cases. The might be due to the passing of more water through soil column which leached out calcium from soil.

4.3.2.4 Magnesium content in saturation paste extract of soil

The magnesium content in saturation paste extract of saline sodic soil upto 120 days after leaching with FYM, FeS_2 , PMC, sulphur and their combinations are presented in Table 47.

The magnesium content in saturation paste extract of soil decreased in all the treatments over initial values at 0-30 and 30-60 cm depth; but at 60-90 cm depth it showed slight increase over initial value of magnesium content. This increase in magnesium content at lower depth due to accumulation of magnesium as affected by leaching functions. The maximum increase in magnesium content in saturation paste extract was recorded with FYM and FeS_2 i.e. 5 meL^{-1} over 3.0 meL^{-1} initial value. In other treatments the magnesium content at 60-90 cm depth was 4.0, 3.0, 4 and 4.0 meL^{-1} with PMC, sulphur, FeS_2 + sulphur and sulphur + PMC respectively.

In general, it was observed that the amendments found effective in leaching of magnesium at lower depth of soil.

4.3.2.5 Sodium content in saturation paste extract of soil

The data pertaining to the sodium content in saturation paste extract of soil as a function of leaching the soil with FYM, FeS_2 , PMC, sulphur and their combinations are presented in Table 48.

It was revealed that the sodium content in saturation paste extract of soil reduced in all the treatments than initial value but it increased with depth. The highest reduction in sodium content was recorded with sulphur and the reduction was from 43.26 to 0.87, 34.53 to 1.73, 25.58 to 2.39 meL^{-1} respectively upto 120 days after leaching process. This might be due to improvement of soil permeability by the addition of sulphur which allows maximum passage of water by which concurrently removes more water soluble sodium. Similar results were reported by Shehata (1983) with CaSO_4 .

It was also observed that the sodium content in saturation paste extract showed decrease with FYM, PMC, FeS_2 and the maximum decrease was recorded with PMC i.e. 1.84, 2.17 and 4.45 meL^{-1} at 0-30, 30-60 and 60-90 cm depth respectively.

In the combination treatments the reduction in sodium content was maximum with sulphur + PMC than FeS_2 + PMC into 120 days after leaching.

4.3.2.6 Potassium content in saturation paste extract of soil

The data regarding the potassium content in saturation paste extract of saline sodic soil as influenced by FYM, FeS_2 , PMC, sulphur and their combination are presented in Table 49.

From the present table it was observed that the potassium content in saturation paste extract of soil was more than the control treatment but the maximum increase in potassium content was recorded with sulphur treatment and the potassium content in this treatment was 0.082, 0.079 and 0.076 me L^{-1} at 0-30, 30-60 and 60-90 cm depths respectively, followed by PMC i.e. 0.079, 0.074 and

Table 47. Effect of leaching on magnesium content in saturation paste extract of soil (meL^{-1})

Depth (cm)	Initial	Control	FYM	Iron pyrite	PMC	Sulphur	Iron pyrite + PMC	Sulphur + PMC
0-30	7.5	3.0	3.5	4.0	4.5	4.0	3.5	3.5
30-60	6.0	3.0	4.0	5.0	4.0	3.5	3.0	4.0
60-90	3.0	2.5	5.0	5.0	4.0	3.0	4.0	4.0

Table 48. Effect of leaching on sodium content in saturation paste extract of soil (meL^{-1})

Depth (cm)	Initial	Control	FYM	Iron pyrite	PMC	Sulphur	Iron pyrite + PMC	Sulphur + PMC
0-30	43.26	40.00	2.17	3.47	1.84	0.87	1.30	1.52
30-60	34.53	32.60	5.97	3.69	2.17	1.73	2.39	1.95
60-90	25.58	25.21	6.52	4.2	4.45	2.39	4.02	2.82

Table 49. Effect of leaching on potassium content in saturation paste extract of soil (meL^{-1})

Depth (cm)	Initial	Control	FYM	Iron pyrite	PMC	Sulphur	Iron pyrite + PMC	Sulphur + PMC
0-30	0.120	0.051	0.071	0.076	0.079	0.082	0.076	0.071
30-60	0.110	0.038	0.053	0.071	0.074	0.079	0.071	0.056
60-90	0.080	0.030	0.061	0.056	0.071	0.076	0.056	0.060

0.071 me L⁻¹ at 0-30, 30-60 and 60-90 cm depths upto 120 days after leaching of soil with tap water.

In the combination treatment, the maximum increase in potassium content in saturation paste extract was recorded with iron pyrite + PMC than sulphur + PMC.

4.3.2.7 Chloride content in saturation paste extract of soil

The data pertaining to the chloride content in saturation paste extract of soil as affected by different amendments are given in Table 50.

The data revealed that the chloride content in saturation paste extract of soil reduced over initial value when the soil was leached with FYM, FeS₂, PMC, sulphur, FeS₂ + PMC and sulphur + PMC for 120 days. It was observed that the reduction in chloride content in saturation extract was more when the soil was amended with sulphur and the reduction was from 30 to 1, 24 to 2.0, 20 to 2 meL⁻¹ at 0-30, 30-60 and 60-90 cm depths respectively. This might be due to the sulphur created flocculated conditions it release native Ca²⁺ from soil which help in formation of CaSO₄ and created favorable conditions for leaching and salts.

In combination treatment the chloride content in FeS₂ + PMC was 2 meL⁻¹ at all three depths and it was 1.0, 3.0 and 2.0 meL⁻¹ at 0-30, 30-60 and 60-90 cm depths respectively when the soil was leached with sulphur + PMC.

Hence it was observed that the amendments found beneficial in removing of chloride from soil and sulphur treatment found superior.

4.3.2.8 Bicarbonate content in saturation paste extract of soil

The data pertaining to the bicarbonate content in saturation paste extract of saline-sodic soil as a function of different amendments are shown in Table 51.

The data presented in this table revealed that the bicarbonate content in saturation paste extract of soil reduced with FYM, FeS_2 , PMC, sulphur, FeS_2 + PMC, sulphur + PMC and simple leaching upto 120 days after leaching of soil. The maximum reduction was recorded with sulphur i.e. 77.7, 78.7 and 75.6 per cent at 0-30, 30-60 and 60-90 cm depths respectively followed by PMC treatment. This might be due to the removal of HCO_3^- with Na^+ as NaHCO_3 through leachate.

In the combination effect the removal of bicarbonate was more with sulphur + PMC than FeS_2 + PMC.

4.3.2.9 Sulphate content in saturation paste extract of soil

The data in respect of sulphate content in saturation paste extract of saline-sodic soil when the soil was amended with FYM, FeS_2 , PMC, sulphur and its combinations are presented in Table 52.

The sulphate content in saturation paste extract of soil decreased over initial value in all the treatments except control. The sulphate content decreased more when the soil was amended with FYM and the reduction was from 26.50 to 11.52, 24.50 to 12.10 and 21.00 to 13.10 me L^{-1} at 0-30, 30-60 and 60-90 cm depths respectively, followed by PMC and reduction was from 26.50 to 12.03, 24.50 to 13.00 and 21.00 to 13.26 meL^{-1} at 0-30, 30-60 and

Table 50. Effect of leaching on chloride content in saturation paste extract of soil (meL^{-1})

Depth (cm)	Initial	Control	FYM	Iron pyrite	PMC	Sulphur	Iron pyrite + PMC	Sulphur + PMC
0-30	30.0	9.0	2.0	3.0	2.0	1.0	2.0	1.0
30-60	24.0	9.0	3.0	4.0	2.0	2.0	2.0	3.0
60-90	20.0	10.0	5.0	6.0	3.0	2.0	2.0	2.0

Table 51. Effect of leaching on bicarbonate content in saturation paste extract of soil (meL^{-1})

Depth (cm)	Initial	Control	FYM	Iron pyrite	PMC	Sulphur	Iron pyrite + PMC	Sulphur + PMC
0-30	18.0	12.5	8.5	9.5	7.5	4.0	5.0	5.0
30-60	19.0	13.6	8.5	8.0	7.0	4.0	5.5	5.2
60-90	18.5	15.2	8.0	9.5	7.0	4.5	6.0	5.8

Table 52. Effect of leaching on sulphate content in saturation paste extract of soil (meL^{-1})

Depth (cm)	Initial	Control	FYM	Iron pyrite	PMC	Sulphur	Iron pyrite + PMC	Sulphur + PMC
0-30	26.50	22.57	11.52	12.10	12.03	13.15	13.26	13.16
30-60	24.50	23.05	12.10	13.10	13.00	13.26	13.57	13.47
60-90	21.00	25.10	13.10	14.85	13.26	13.57	13.68	13.57

60-90 cm depths respectively. This might be due to more removal of sulphate as Na_2SO_4 during leaching it with FYM and PMC.

In the interaction effect of FeS_2 + PMC and sulphur + PMC, the sulphur + PMC treatment found superior in reduction of sulphate in saturation paste extract of soil at all three depths.

4.4 Predictive approaches for sodicity

In the present study of predictive approaches for sodicity of the soil, soil samples were collected from five soil profiles at 0-30, 30-60 and 60-90 cm depth and prepared one composite sample for each depth and equilibrated with different quality synthetic water. After equilibration the solution were analysed for various salinity parameters and the results obtained from this equilibration study are discussed as under.

4.4.1 pH of equilibrium solution

Data pertaining to the pH of equilibrium solution are presented in Table 53.

The results presented in Table 53 revealed that the pH showed regular increase with increasing SAR and a regular decrease with increasing total electrolyte concentration of the equilibrating solution. The pH showed increasing trend with depth of soil. The range of variation in pH was narrow in clay soil because of its high buffering capacity.

An increasing in SAR of equilibrating solution from 2.5 to $3.0 \text{ mmol}^{1/2}\text{L}^{1/2}$ increases the pH of equilibrium solution from 8.25 to 8.56. On the contrary an increase in TEC of equilibrating solution from 5 to 50 meL^{-1} resulted in decline in pH of equilibrium solution. An

Table 53. Effect of water qualities on pH of equilibrium solution at different depths of soil

Depth (cm)	TEC meL ⁻¹	SAR mmol ^{1/2} L ^{1/2}					
		2.5	5	10	15	20	30
0-30	5	8.25	8.28	8.32	8.32	8.40	8.56
	10	8.09	8.10	8.12	8.28	8.42	8.50
	20	8.00	8.10	8.10	8.10	8.24	8.46
	50	7.92	8.02	8.06	8.10	8.18	8.22
30-60	5	8.40	8.46	8.60	8.75	8.80	8.86
	10	8.60	8.72	8.64	8.67	8.46	8.34
	20	8.64	8.88	8.88	9.01	9.01	9.10
	50	8.37	8.38	8.50	8.53	8.58	8.54
60-90	5	8.60	8.62	8.80	8.80	8.60	8.92
	10	8.80	8.72	8.92	9.06	9.40	9.40
	20	8.64	8.90	9.00	9.20	9.28	8.80
	50	8.60	8.72	8.92	9.18	9.30	9.32

increase in pH under high SAR water is mainly due to sufficient increase in exchangeable sodium causing more hydrolysis effect. Similar results were also reported by Girdhar (1996).

4.4.2 SAR of equilibrium solution

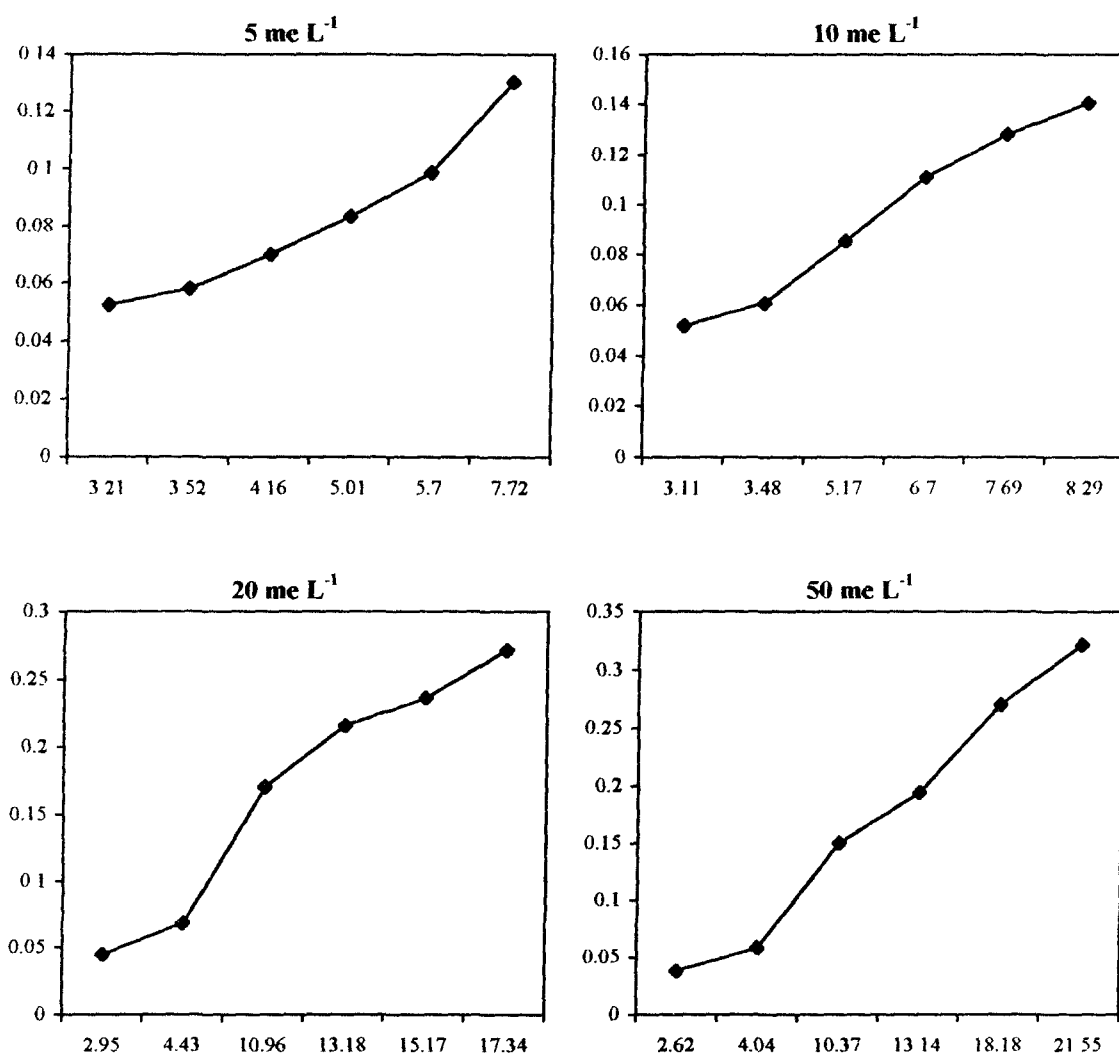
The data presented in Tables 54, 55 and 56 showed that the SAR of the equilibrium solution (SAR_{eq}) was decreased as compared to equilibrating solution (SAR_{iw}) and it was recorded more in waters of low salt concentration and high SAR, hence maximum difference was observed with maximum SAR of equilibrating water i.e. $30 \text{ mmol}^{1/2} \text{L}^{1/2}$ at all total electrolyte concentration levels at all the three depths. The SAR_{eq} was showed increasing trend with soil depth. This increasing SAR with depth indicated that sodification has started in deeper layer and it is continuing upward Sagare et al. (1991) also reported similar results.

The maximum difference in SAR_{eq} was observed with maximum SAR_{iw}, i.e. $30 \text{ mmol}^{1/2} \text{L}^{1/2}$ at all the TEC levels. Such a decrease was with maximum value of 74.2, 72.3, 42.2 and 28.1 per cent at 0-30 cm depth, 70.4, 67.7, 42.9 and 33.8 per cent at 30-60 cm depth and 69.8, 64.3, 41.1 and 33.6 per cent at 60-90 cm depth at the TEC levels of 5, 10, 20 and 50 meL^{-1} respectively.

At low electrolyte concentration, high SAR values were not attained in the equilibrium solution may be because of addition of calcium and magnesium from the mineral dissolution as well as exchange phase. The decline in SAR with TEC range as of the present study is also supported by Patil (1986).

Table 54. Effect of water quality on equilibrium SAR, ESR, ESP and K_g at 0-30 cm depth

TEC meL^{-1}	SAR $\text{mmol}^{1/2}\text{L}^{1/2}$	SAReq $\text{mmol}^{1/2}\text{L}^{1/2}$	ESR	ESP	K_g mmol L^{-1}
5	2.5	3.21	0.05235	4.97	0.01631
	5	3.52	0.05800	5.48	0.01647
	10	4.16	0.07005	6.54	0.01687
	15	5.01	0.08339	7.69	0.01664
	20	5.70	0.09858	8.97	0.01691
	30	7.72	0.13033	11.53	0.01693
10	2.5	3.11	0.05173	4.91	0.01638
	5	3.48	0.06078	5.72	0.01633
	10	5.17	0.08532	7.86	0.01647
	15	6.70	0.11089	9.98	0.01655
	20	7.69	0.1280	11.34	0.01664
	30	8.29	0.14060	12.32	0.01696
20	2.5	2.95	0.04485	4.29	0.01520
	5	4.43	0.06859	6.41	0.01544
	10	10.96	0.17026	14.54	0.01553
	15	13.18	0.2162	17.77	0.01554
	20	15.17	0.2368	19.12	0.01560
	30	17.34	0.2717	21.36	0.01567
50	2.5	2.62	0.03781	3.64	0.01437
	5	4.04	0.05837	5.51	0.01444
	10	10.37	0.15051	13.08	0.01451
	15	13.14	0.19438	16.27	0.01479
	20	18.18	0.27077	21.30	0.01489
	30	21.55	0.32167	24.33	0.01492

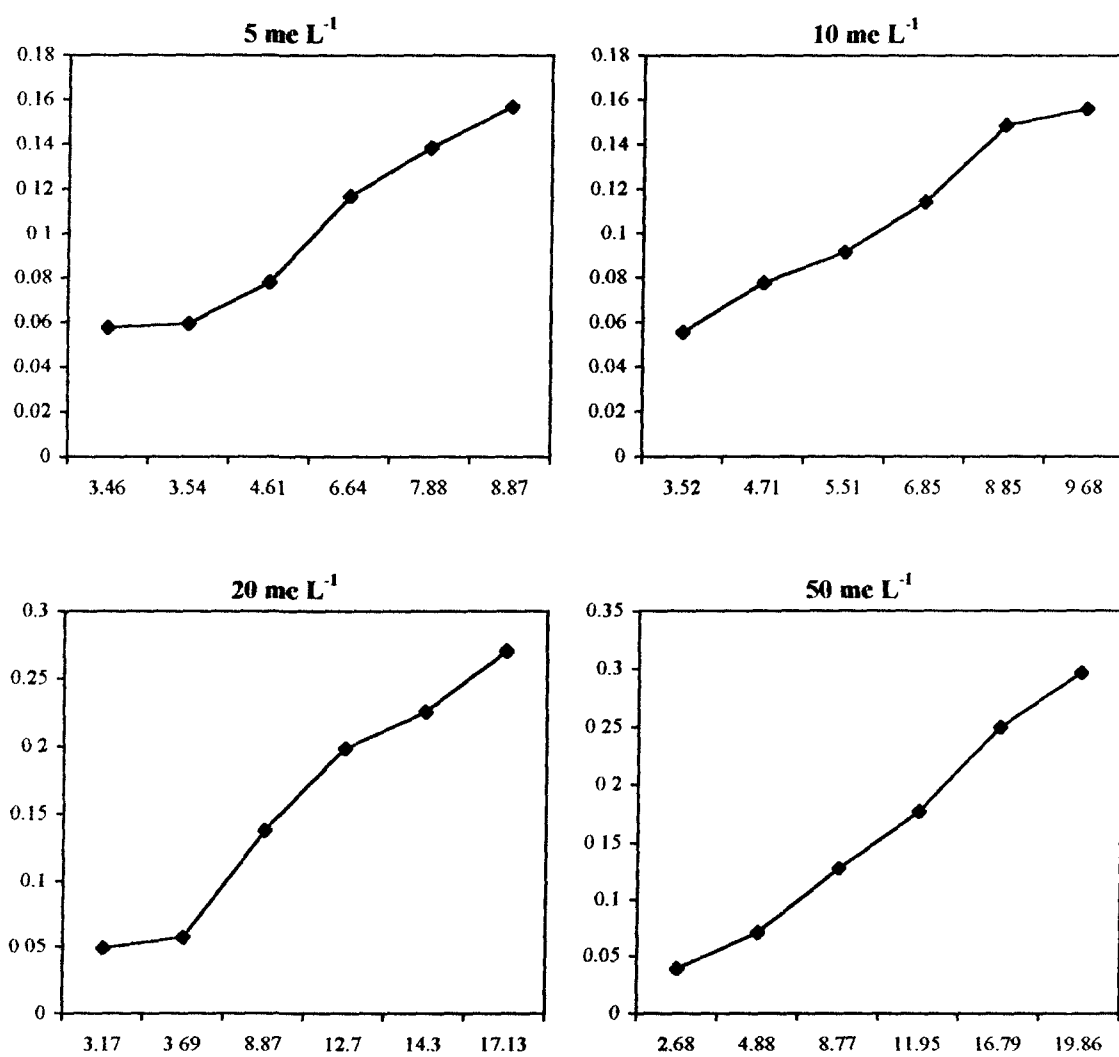


X = SAReq
Y = ESR

Fig. 16. ESR-SAR relationship (0-30 cm)

Table 55. Effect of water quality on equilibrium SAR, ESR, ESP and K_g at 30-60 cm depth

TEC meL^{-1}	SAR $\text{mmol}^{1/2}\text{L}^{1/2}$	SAReq $\text{mmol}^{1/2}\text{L}^{1/2}$	ESR	ESP	K_g mmol L^{-1}
5	2.5	3.46	0.05775	5.45	0.01669
	5	3.54	0.05944	5.61	0.01679
	10	4.61	0.07802	7.23	0.01692
	15	6.64	0.11681	10.45	0.01756
	20	7.88	0.1387	12.18	0.01760
	30	8.87	0.15683	13.55	0.01768
10	2.5	3.52	0.05576	5.28	0.01584
	5	4.71	0.07766	7.20	0.01647
	10	5.51	0.09148	8.38	0.01660
	15	6.85	0.11439	10.36	0.01669
	20	8.85	0.14844	12.92	0.01677
	30	9.68	0.15611	13.50	0.01682
20	2.5	3.17	0.04908	4.67	0.01548
	5	3.69	0.05721	5.41	0.01550
	10	8.87	0.13809	12.13	0.01556
	15	12.70	0.19836	16.55	0.01561
	20	14.30	0.22550	18.40	0.01576
	30	17.13	0.27042	21.28	0.01578
50	2.5	2.68	0.03871	3.72	0.01444
	5	4.88	0.07062	6.59	0.01447
	10	8.77	0.12799	11.34	0.01459
	15	11.95	0.17702	15.09	0.01481
	20	16.79	0.24983	19.48	0.01488
	30	19.86	0.29678	29.67	0.01494

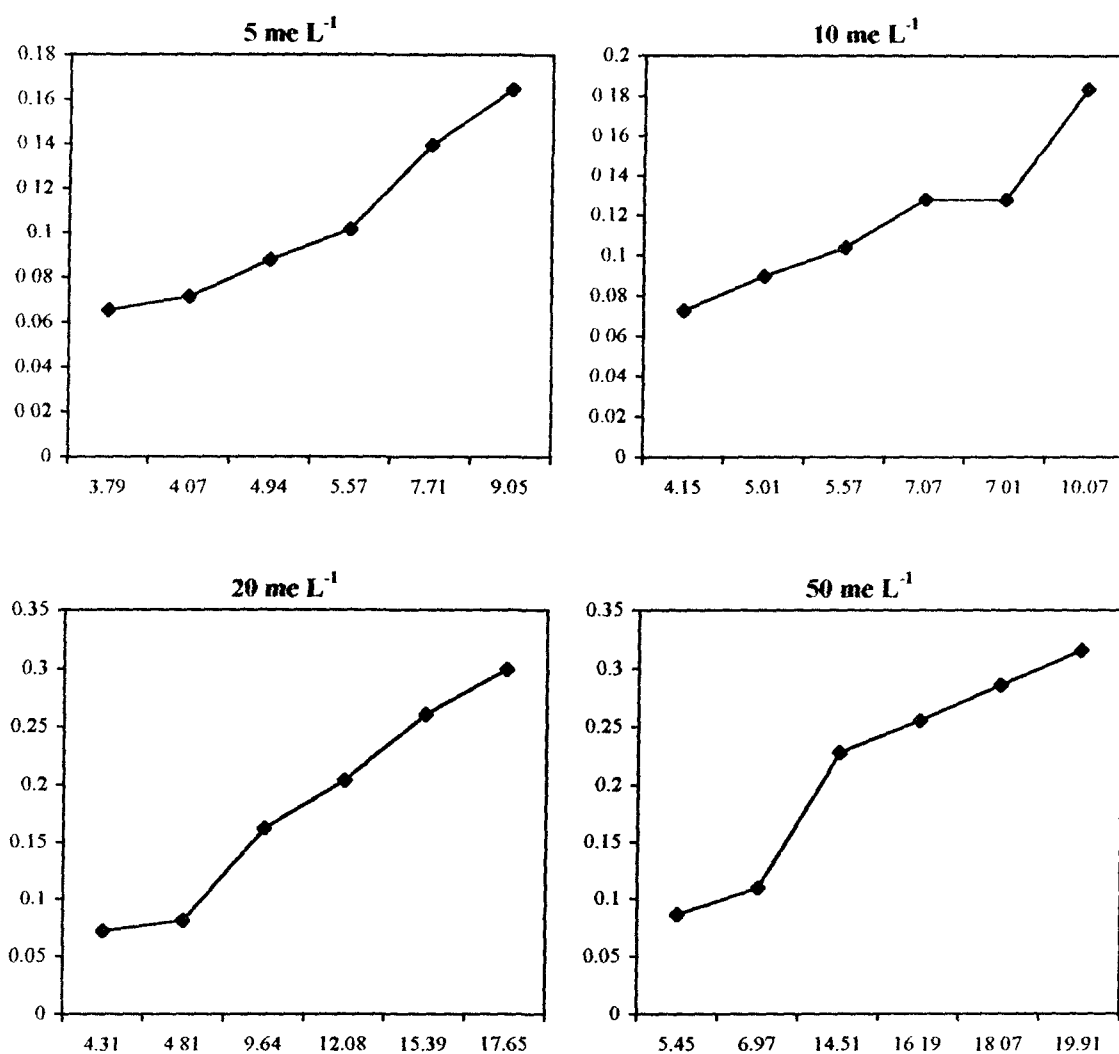


X = SAReq
Y = ESR

Fig. 17. ESR-SAR relationship (30-60 cm)

Table 56. Effect of water quality on equilibrium SAR, ESR, ESP and K_g at 60-90 cm depth

TEC meL^{-1}	SAR $\text{mmol}^{1/2}\text{L}^{1/2}$	SAReq $\text{mmol}^{1/2}\text{L}^{1/2}$	ESR	ESP	K_g mmol L^{-1}
5	2.5	3.79	0.0654	6.14	0.01725
	5	4.07	0.0715	6.67	0.01758
	10	4.94	0.0877	8.06	0.01773
	15	5.57	0.1015	9.88	0.01822
	20	7.71	0.1393	12.22	0.01815
	30	9.05	0.1646	14.13	0.01811
10	2.5	4.15	0.0728	6.79	0.01754
	5	5.01	0.0897	8.23	0.01790
	10	5.57	0.1038	9.40	0.01806
	15	7.07	0.1281	11.35	0.01812
	20	7.01	0.1277	11.32	0.01822
	30	10.07	0.1836	15.51	0.01824
20	2.5	4.31	0.0717	6.69	0.01663
	5	4.81	0.0807	7.46	0.01678
	10	9.64	0.0162	13.97	0.01685
	15	12.08	0.2039	16.93	0.01688
	20	15.39	0.2607	20.67	0.01694
	30	17.65	0.2995	23.04	0.01692
50	2.5	5.45	0.0861	7.92	0.01580
	5	6.97	0.1093	9.85	0.01568
	10	14.51	0.2277	18.54	0.01569
	15	16.19	0.2556	20.35	0.01578
	20	8.07	0.2863	22.25	0.01584
	30	19.91	0.3157	23.99	0.01586



X = SAReq
Y = ESR

Fig. 18. ESR-SAR relationship (60-90 cm)

4.4.3 Exchangeable sodium per cent

Data pertaining to the ESP of soil as a function of different qualities of water at three different depths (0-30, 30-60 and 60-90 cm) are presented in Tables 54, 55 and 56.

The presented data revealed that the ESP increased with increasing SAR_{iw} and TEC of equilibrating solution. The positive interaction of TEC and SAR influences ESP built up. The ESP values increased with soil depth. This might be due to high sodimized clay content and strong alkaline condition at lower depth. The mean ESP values irrespective of SAR_{iw} was 7.5, 8.6, 13.9 and 14.0 mmol^{1/2}L^{-1/2} at 0-30 cm depth, 9.0, 9.5, 13.0 and 14.3 mmol^{1/2}L^{-1/2} at 30-60 cm depth and 9.5, 10.4, 14.7 and 17.5 mmol^{1/2}L^{-1/2} at 60-90 cm depth with 5, 10, 20 and 50 meL⁻¹ TEC respectively.

4.4.4 ESR-SAR relationship in soils

Data obtained on Gapon's selectivity coefficient (K_g) and functional relationship between ESR and SAR_{eq} are presented in Table 54, 55 and 56. The data indicated that there was a linear relationship between ESR-SAR for different TEC and SAR_{iw} as shown in Fig. 16, 17 and 18. The values of Gapon's selectivity constant decreased with salinity and increased with SAR_{iw}. It showed increasing trend with soil depth.

The results revealed that the values of Gapon's constant were in the range of 0.0143 to 0.0169, 0.0144 to 0.01768 and 0.0158 to 0.0181 at 0-30, 30-60 and 60-90 cm soil depth respectively. Irrespective of the SAR levels, increase in TEC from 5 to 50 meL⁻¹ decreased K_g was not constant as proposed by Gapon, but

varied with variation in SAR. Similarly, when the data was compared irrespective of TEC levels, the K_g values increased when SAR increased from 2.5 to 3.0 $\text{mmol}^{1/2}\text{L}^{1/2}$. These observations indicated that the K_g values decreased with increasing TEC and increased with increasing SAR of equilibrating solution. The decrease in K_g with increasing TEC is in accordance with, Frenkel and Alperovith (1983).

4.4.5 Application of different cation exchange equations

From the data obtained on the equilibrium solution in chloride series with different salinity and SAR levels for all the three depths, the important ion exchange equations were tested and coefficient of variation for them are presented in Table 57. It was revealed that the Gapon selectivity coefficient decreased with the increase of electrolyte concentration and it increased with soil depth. The values of K_v and K_{KDO} were also decrease with salinity but the rate of decrease was much higher than Gapon constant.

In comparison study of different selectivity coefficients revealed that the equation of Gapon showed less coefficient of variation than K_v and K_{KDO} . For different soil depths, the selectivity coefficients on the basis of mean values of coefficient of variation, were in the order for different soils depths as

0-30 cm soil depth.

$$K_{KDO} > K_v > K_g$$

30-60 cm soil depth

$$K_{KDO} > K_v > K_g$$

60-90 cm soil depth

$$K_v > K_{KDO} > K_g$$

Table 57. The mean values with coefficient of variation (CV %) of different selectivity constants under various salinity levels at different depths of saline-sodic soil

Depth	TEC meL ⁻¹	Parameters	K _G mmol L ⁻¹	K _V mmol L ⁻¹	K _{KDO} mmol L ⁻¹
0-30	5	Mean	0.01668	0.07883	0.0501
		CV %	5.03	15.53	48.48
	10	Mean	0.01659	0.05332	0.04855
		CV %	11.59	33.54	32.56
	20	Mean	0.01549	0.02838	0.02435
		CV %	0.95	42.57	46.46
	50	Mean	0.01465	0.01590	0.0144
		CV %	4.72	19.40	15.68
30-60	5	Mean	0.01720	0.12168	0.11088
		CV %	2.39	9.72	8.41
	10	Mean	0.01663	0.08048	0.07059
		CV %	1.98	12.23	12.34
	20	Mean	0.015615	0.03943	0.03024
		CV %	0.73	40.89	60.97
	50	Mean	0.01468	0.01878	0.0481
		CV %	1.32	19.38	50.06
60-90	5	Mean	0.01784	0.1641	0.1479
		CV %	1.95	19.27	16.54
	10	Mean	0.01801	0.1154	0.10187
		CV %	1.32	10.92	10.97
	20	Mean	0.01684	0.06031	0.05583
		CV %	0.65	50.83	54.03
	50	Mean	0.1577	0.028	0.02469
		CV %	0.40	43.58	5.43

This suggests that K_g can give a fair idea of level of sodification than the other constants.

Frankel and Alperovitch (1983) also reported decrease in the values of selectivity coefficients with total electrolyte concentration. Paliwal and Maliwal (1970) and Patil (1986) compared the different selectivity coefficients and observed that the Gapon constant was superior to the others. These studies taken under equilibrium conditions indicated that Gapon equation is more satisfactory in predicting the degree of sodification on the basis of equilibrium SAR of the soil solution and K_g value obtained for a particular system using representative waters.

4.5 Reclamation measures and its effect on wheat

To study the performance of different amendments in these saline sodic soils from study area, a pot culture experiment was conducted with FYM (10 Mg ha⁻¹), FeS₂ (5 Mg ha⁻¹), PMC (5 Mg ha⁻¹), sulphur (400 kg ha⁻¹), FeS₂ (5 Mg ha⁻¹) + PMC (5 Mg ha⁻¹), sulphur (400 kg ha⁻¹) + PMC (5 Mg ha⁻¹) with wheat as a test crop and its performance was assessed periodically. The soil samples after harvest of crop were also analysed for different nutritional parameters and discussed in this chapter.

4.5.1 Physiological characters

4.5.1.1 Length of earhead

The data pertaining to the total length of earhead after harvest of the crop as influenced by FYM, FeS₂, PMC, sulphur and its combinations are presented in Table 58.

The presented data revealed that the length of wheat earhead significantly increased with application of FYM (10 Mg ha^{-1}) over control and it was recorded 6.42 cm which was 25.18 per cent more than that of control treatment. This increase in length of earhead might be due to the improvement in saline sodic soil by the application of FYM which created favourable congenial environment for length of growth.

The length was significantly increased with the application of FeS_2 , PMC, sulphur and their combinations. The length of earhead was maximum i.e. 6.31 cm with the application of PMC (5 Mg ha^{-1}) which was significantly superior over control and at par with T_2 (FYM). In the combination treatments it was found that the application of $\text{FeS}_2 + \text{PMC}$ increased the length of earhead significantly over control and it was 5.74 cm and with sulphur + PMC it was recorded 6.04 cm.

From this results it was observed that the length of earhead was increased significantly with the application of different amendments and the maximum length of plant was under the treatment T_2 (10 Mg ha^{-1} FYM) followed by T_4 (5 Mg ha^{-1} PMC).

4.5.1.2 Weight of 100 grains of wheat

From Table 58, it could be observed that the weight of 100 grains of wheat was significantly increased by the application of FYM, FeS_2 , PMC, sulphur and their combinations over control. The weight of 100 grains was significantly increased (2.97 g) with the application of FYM (10 Mg ha^{-1}) over control and on par with rest of the treatments.

Table 58. Effect of amendments on morphological characters of wheat

Treatment	Length of earhead (cm)	Weight of 100 grain (g)
T ₁	4.01	2.17
T ₂	6.420	2.97
T ₃	6.31	2.83
T ₄	6.10	2.87
T ₅	5.98	2.80
T ₆	5.74	2.77
T ₇	6.04	2.93
S.E. $\pm$	0.34	0.07
C.D. at 5 %	1.04	0.21

The increase in 100 grain weight by the application of different amendments was statistically significant. The maximum grain weight i.e. 2.87 g was recorded with the treatment T_4 (5 Mg ha^{-1} PMC), which was significantly superior over control with the application of FeS_2 and sulphur the 100 grain weight was recorded 2.83 and 2.80 g respectively.

In the combination treatments the 100 grain weight was significantly superior over control in both the combinations i.e. FeS_2 + PMC and sulphur + PMC but the maximum grain weight was observed in T_7 i.e. 2.93 g (sulphur + PMC) and in T_6 (FeS_2 + PMC) the 100 grain weight was 2.77 g.

In general, the 100 grain weight of wheat significantly increased with the application of FYM, FeS_2 , PMC, sulphur and their combinations in saline sodic soil. The maximum grain weight was recorded with T_2 (10 Mg ha^{-1} FYM).

4.5.1.3 Grain yield

The results regarding the average wheat grain yield presented in Table 59.

The yield of wheat grain significantly increased due to the application of FYM over control, which was recorded 39.16 g pot^{-1} and the increase was 51.07 per cent over control. These results were in conformity with those obtained by Singh et al. (1980a).

The application of FeS_2 , PMC, sulphur and their combinations resulted in significant increase in the yield of wheat grain over control treatment. The yield of grain under the treatment T_3 , T_4 and T_5 were 35.23, 35.63 and 36.77 g pot^{-1} , respectively.

However the yield of grain obtained under T_5 (sulphur) treatment was more (36.77 g pot^{-1}) than the rest of the treatment.

It would be seen from the Table 59 that the combination effects of FeS_2 + PMC and sulphur + PMC were also significantly superior over control and on par with other treatments. The maximum yield of grain obtained in the treatment T_7 (sulphur + PMC) i.e. 34.70 g pot^{-1} and the yield obtained in the treatment T_6 (FeS_2 + PMC) was 32.43 g pot^{-1} . This might be due to the improvement of soil conditions by adding of these amendments.

Thus, the yield of grain significantly increased by the application of FYM, FeS_2 , PMC, sulphur and its combinations. The highest yield was obtained under the treatment T_2 (FYM) followed by T_5 (sulphur).

4.5.1.4 Straw yield

The data pertaining to the average straw yield of wheat as influenced by FYM, FeS_2 , PMC, sulphur and their combinations are given in Table 59.

The average straw yield was increased by the application of PMC over control and the yield obtained in this treatment was 38.90 g pot^{-1} . Similar results were recorded by Singh *et al.* (1980a).

It would be seen from the data given in Table 59 that the average straw yield of wheat produced by the application of FYM, FeS_2 , sulphur and their combinations was statistically significant over control. The maximum straw production was 36.50 g pot^{-1} under the T_2 (10 Mg ha^{-1} FYM) treatment, which was superior over control. With

Table 59. Effect of amendments on grain and straw yield of wheat

Treatment	Grain yield (g pot ⁻¹)	Straw yield (g pot ⁻¹)
T ₁	19.16	26.16
T ₂	39.16	36.50
T ₃	35.23	36.16
T ₄	35.63	38.90
T ₅	36.77	31.66
T ₆	32.43	30.63
T ₇	34.70	34.2
S.E. $\pm$	1.15	1.11
C.D. at 5 %	3.55	3.39

the application of FeS_2 and sulphur the straw yield was 36.16 and 31.66 g pot⁻¹, respectively.

The combination effect of FeS_2 + PMC and sulphur + PMC also increased straw yield. The maximum straw yield was obtained with sulphur + PMC i.e. 34.2 g pot⁻¹ followed by FeS_2 + PMC i.e. 30.63 g pot⁻¹.

In general, it was observed that the straw yield of wheat was increased by the application of amendments and it was maximum at T_4 (5 Mg ha⁻¹ PMC) followed by T_2 (10 Mg ha⁻¹ FYM).

4.5.2 Reclamation measures and its effect on available nutrients after harvest of wheat

4.5.2.1 Available nitrogen

From the data presented in Table 60, it was revealed that the available nitrogen was significantly increased by the application of amendments over control.

The available nitrogen significantly increased with the application of FYM, Iron pyrite, sulphur, PMC and its combinations during reclamation of saline sodic soil. The maximum available nitrogen in soil was 47.4 mg kg⁻¹ under the treatment of FYM which was significantly more than control and on par with the rest of the treatment combinations of amendments. It indicated that the saline sodic soil amended with Iron pyrite, PMC, sulphur and their combinations increased available nitrogen in soil over control. This increase in available nitrogen might be due to stimulation of micro-organism and/or neutralization of toxic salts thereby creation of

favorable habitat for them and it increases N mineralization in soil. Similar results were reported by Rai and Prasad (1983).

4.5.2.2 Available phosphorus

It would be seen from the data presented in Table 60 that the available phosphorus significantly increased with the application of FYM over control.

Further, it was observed that the available phosphorus in the soil increased significantly when the soil amended with iron pyrite, PMC, sulphur and their combinations over control. The available phosphorus was maximum i.e. 2.37 mg kg^{-1} when the soil was amended with FYM which was significantly superior to the rest of the treatments. The maximum availability of phosphorus with the application of FYM might be due to the dissolution of native phosphorus. Similar results were reported by Raman and Goswami (1982).

In general, it was observed that the available phosphorus was significantly increased with the application of FYM, iron pyrite, PMC, sulphur, iron pyrite + PMC and sulphur + PMC. The maximum availability of phosphorus was under T_2 (FYM) followed by T_4 (PMC).

4.5.2.3 Available potassium

The data pertaining to the available potassium as a function of FYM, FeS_2 , PMC, sulphur and their combinations are presented in Table 60.

The available potassium in saline-sodic soil increased significantly with the amendments over control. The maximum availability of potassium was recorded with FYM (10 Mg ha^{-1}) and it

was 230 mg kg⁻¹. This might be due to the increase in available potassium in soil. Similar results were reported by Leather (1983).

In general, it was observed that the available potassium was significantly increase with the application of different amendments but FYM found better in improving available potassium status in soil followed by iron pyrite (5 Mg ha⁻¹)

4.5.2.4 DTPA extractable Fe

It would be observed from Table 60 that the available Fe content in soil was significantly increased by the application of different amendments over control.

The available Fe in soil was significantly increased by the application of FYM, FeS₂, PMC, sulphur and their combinations over that of control. The maximum increase in the available Fe (7.60 mg kg⁻¹) in soil was due to the application of only pyrites which was superior to that of all other treatments of amendments. This findings indicated that the available iron was increased by the addition of pyrites in soil which might be due to release of Fe during oxidation of iron pyrites. Similar results were also reported by Naik (1988), who recorded that the pyrite application in calcareous soil increased the available iron in soil.

The data presented in the same table showed that the interaction effects of FeS₂ + PMC and sulphur + PMC were significant in respect of available Fe. The maximum available Fe was 7.18 mg kg⁻¹ with the application of FeS₂ + PMC which was significantly more than the rest of the treatment combinations of amendments (sulphur + PMC). It might be due to the available iron was increased in iron

pyrites treatments when it added with PMC. This indicated that PMC might helped in oxidation process of iron pyrites to release iron.

In general, it was noted that the available iron significantly increased with the addition of FYM, FeS_2 , PMC and sulphur in saline-sodic soils.

4.5.2.5 DTPA extractable manganese

The data pertaining to the DTPA extractable Mn content in soil presented in Table 60, revealed that the increase in available manganese in soil by the application of FYM, FeS_2 , PMC, sulphur and their combinations was statistically significant. The maximum available Mn content in soil recorded under the treatment of sulphur (6.80 mg kg^{-1}) which was significantly superior to the rest of the treatments. This indicated that the available Mn increased due to reduction in soil pH by acidulating effect of sulphur.

The combination of sulphur + PMC were found to be significant over control. However, it was found higher than all the treatments i.e. FYM, FeS_2 , PMC, FeS_2 + PMC.

4.5.2.6 DTPA extractable zinc

The data pertaining to the available zinc in soil as influenced by the FYM, FeS_2 , PMC, sulphur and their combinations are given in Table 60.

The data revealed that the zinc content in soil was significantly increased by the application of FYM (0.72 mg kg^{-1}) over no amendments. Similar observations were reported by Raman and Goswami (1982) who studied the nutrient availability during

reclamation of salt affected soil and they observed that the application of FYM increased the DTPA extractable Zn in soil.

Similarly the available Zn content in soil by the application of FeS_2 , PMC, sulphur and their combination was significantly more than control. The maximum available Zn content in soil was 0.64 mg kg^{-1} under the PMC treatment which was significantly superior over control and on par with other treatments.

Among the combinations the available Zn content in soil was maximum with FeS_2 + PMC than sulphur + PMC.

From these observations it is concluded that the available Zn content was increased by the application of amendments than control treatment.

4.5.2.7 DTPA extractable Copper

The data regarding the DTPA extractable Cu content in soil are presented in Table 60.

The presented data indicates that the available Cu content in soil increased significantly with the application of FYM, PMC and sulphur + PMC over control and other treatments were found on par. The maximum availability of Cu was recorded when the soil was amended with FYM i.e. 0.96 mg kg^{-1} followed by PMC i.e. 0.90 mg kg^{-1} , which was significantly superior over control. This increase might be due to the Cu content in these organic sources.

Similarly the available Cu content in the combination treatments was highest with sulphur + PMC i.e. 0.86 mg kg^{-1} and FeS_2 + PMC i.e. 0.84 mg kg^{-1} this might be due to the effect PMC.

Table 60 Available nutrients in soil after harvest of wheat crop (mg kg⁻¹)

Treatment	N	P	K	Fe	Mn	Zn	Cu
T ₁	41.08	2.37	143.33	4.36	4.19	0.50	0.54
T ₂	47.41	3.73	230.00	6.12	6.74	0.72	0.96
T ₃	46.49	3.42	190.00	7.60	6.46	0.59	0.84
T ₄	47.27	3.62	171.66	6.35	6.37	0.64	0.90
T ₅	46.49	3.61	160.00	6.19	6.80	0.61	0.79
T ₆	47.04	3.16	185.00	7.18	7.08	0.64	0.84
T ₇	47.00	3.56	183.33	5.30	7.12	0.63	0.86
S.E. $\pm$	0.73	0.051	10.17	0.29	0.53	0.046	0.10
CD at 5 %	2.22	0.16	30.86	0.89	1.62	0.14	0.31



A) Effect of FYM on wheat (30DAS) in Saline-Sodic Soil



B) Effect of FYM on wheat (Flowering stage) in Saline-Sodic Soil



C) Effect of Iron pyrite on wheat (30DAS) in Saline-sodic soil



D) Effect of Iron pyrite on wheat (Flowering stage) in saline-sodic soil

In general from these results it was observed that the DTPA Cu content in soil was increased when the soil amended with different amendments.

4.5.3 Reclamation measures and its effect on uptake of nutrient by wheat grain and straw

4.5.3.1 Uptake of nitrogen

The uptake of N by wheat grain and straw as influenced by the application of FYM, FeS_2 , PMC, sulphur and their combination are presented in Table 61.

The uptake of nitrogen by grain and straw increased significantly by the application of FYM over control i.e. 36.40 and 8.02 mg kg^{-1} respectively. This might be due to the more availability of nutrients to the plant. These results are in accordance with the findings of Dahiya et al. (1980).

Similarly the N uptake by grain and straw increased significantly with the application of FeS_2 , PMC and sulphur and their combination over control. The maximum uptake by grain was 31.74 mg kg^{-1} at the treatment T_4 (PMC 5 Mg ha^{-1}) which was on par with other treatments. Similar results were reported by Patil and Kale (1983a).

Further, it was observed that the highest uptake of nitrogen by grain was under T_7 (sulphur + PMC) which was significantly superior over control and on par with other treatments.

On the whole it showed that the nitrogen uptake by grain and straw significantly increased by the application of FYM, FeS_2 ,

PMC, sulphur and their combination over control and the maximum uptake in grain and straw was recorded with T_2 i.e. FYM 10 Mg ha^{-1} .

4.5.3.2 Uptake of phosphorus

The data regarding the uptake of phosphorus by grain and straw of wheat are given in Table 61.

It was observed that the uptake of phosphorus by grain and straw of wheat significantly increased by the application of FYM, FeS_2 , PMC, sulphur and their combinations over control. The maximum uptake by grain i.e. 7.66 mg kg^{-1} and straw i.e. 10.09 mg kg^{-1} was recorded when the soil was amended with FYM and PMC respectively. This might be due to supply of phosphorus from these organic sources.

Further it was observed that the uptake of P by grain was maximum with sulphur which was significantly superior over control and on par with other treatments. This increase in phosphorus might be due to acidulating effects SO_4^{2-} released from sulphur which make native phosphorus available. Similar results were reported by Verma and Abrol (1980).

Among the combination treatments the uptake of P was significantly increased with sulphur + PMC i.e. 6.64 mg kg^{-1} , 9.65 mg kg^{-1} by grain and straw respectively. While in case of FeS_2 + PMC the uptake of phosphorus was 6.36 and 9.05 mg kg^{-1} respectively.

In a nutshell it was observed that the uptake of phosphorus significantly increased by the application of different amendments. The uptake of phosphorus was maximum under the treatment T_2 (FYM) followed by T_5 (sulphur).

4.5.3.3 Uptake of potassium

The data in respect of uptake of potassium by grain and straw of wheat as influenced by FYM, FeS_2 , PMC, sulphur and their combinations are presented in Table 61.

From the data, it was observed that the uptake of potassium by grain and straw significantly increased by the application of FYM over no FYM (control). The uptake of potassium was 7.93 and 22.62 mg kg^{-1} by grain and straw respectively, followed by PMC where the uptake of potassium by grain and straw was 7.86 and 22.21 mg kg^{-1} respectively. This increase in uptake of potassium indicates that the supply of potassium through these organic sources.

The uptake of potassium significantly increased with FeS_2 , sulphur and their combination over control. The potassium uptake by grain (7.48 mg kg^{-1}) and straw (21.06 mg kg^{-1}) was highest under the treatment T_3 (FeS_2). From the data of combination treatments, it was revealed that the maximum uptake of potassium by grain and straw i.e. 7.82 and 19.55 mg kg^{-1} respectively was under the T_7 treatment (sulphur + PMC), which was significantly superior over control and on par with T_6 (FeS_2 + PMC), where the uptake by grain and straw was 7.11 and 17.70 mg kg^{-1} respectively.

Overall results showed that the uptake of potassium by grain and straw significantly increased by the application of FYM, FeS_2 , PMC, sulphur and their combinations over control and it was maximum in grain and straw at T_2 i.e. FYM 10 Mg ha^{-1} .

Table 61. Effect of amendments on uptake of N, P, K (mg kg^{-1}) by wheat grain and straw

Treatment	Nitrogen		Phosphorus		Potassium	
	Grain	Straw	Grain	Straw	Grain	Straw
T ₁	7.91	1.25	4.19	6.81	4.40	13.14
T ₂	36.40	8.02	7.66	9.95	7.93	22.62
T ₃	30.40	5.52	6.33	9.45	7.48	21.06
T ₄	31.74	5.82	6.42	10.09	7.86	22.21
T ₅	31.72	5.53	6.98	9.25	6.40	13.48
T ₆	28.60	5.58	6.36	9.05	7.11	17.70
T ₇	29.39	6.77	6.64	9.65	7.82	19.55
S.E. $\pm$	1.06	0.87	0.36	0.57	0.42	2.34
C.D. at 5 %	3.21	2.63	1.10	1.73	1.26	7.08



A) Effect of PMC on wheat (30 DAS) in Saline-sodic soil



B) Effect of PMC on wheat (Flowering stage) in saline-sodic soil



C) Effect of Sulphur on wheat (30DAS) in Saline-sodic soil



D) Effect of Sulphur on wheat (Flowering stage) in Saline-sodic soil

4.5.3.4 Uptake of iron

The results regarding the uptake iron by grain and straw as influenced by the application of FYM, FeS_2 , PMC, sulphur and their combinations are given in Table 62.

The uptake of iron by grain and straw increased significantly by the application of iron pyrite. The uptake of iron was recorded in this treatment was 1.24 and 1.96 mg kg^{-1} by wheat grain and straw respectively which was significant over control and on par with other treatments. This increase in uptake of iron might be due to release of Fe from iron pyrites during oxidation process and release of native iron from the calcareous soil. These results were in agreement with the findings of Sharma and Yadav (1987).

FYM, PMC, sulphur and their combinations significantly increased uptake of Fe by grain and straw. The maximum uptake of Fe by grains (1.22 mg kg^{-1}) was under the treatment of T_2 (FYM) and T_5 (sulphur) and the uptake of iron by wheat straw was maximum (1.95 mg kg^{-1}) when the soil was amended with PMC (5 Mg kg^{-1}).

Further, from the table it would be seen that the combination effect of FeS_2 + PMC and sulphur + PMC were significant over control. The highest uptake of iron by wheat grain and straw was 1.31 and 2.02 mg kg^{-1} respectively under the treatment of T_6 (FeS_2 + PMC). Which was statistically significant over control and on par with T_7 (sulphur + PMC). The uptake of Fe in T_7 was 1.24 and 1.88 mg kg^{-1} by wheat grain and straw respectively.

On the whole, it was observed that the uptake of iron by grain and straw significantly increased by the application of different amendments and found maximum under T₃ (Iron pyrite) treatment.

4.5.3.5 Uptake of manganese

The results regarding the uptake of Mn by wheat grain and straw as a function of FYM, FeS₂, PMC, sulphur and its combinations are presented in Table 62.

The data revealed that the application of FYM (10 Mg ha⁻¹) significantly increased uptake of Mn by wheat grain and straw over control. The uptake of Mn by wheat grain and straw due to application of FYM was 0.17 and 0.22 mg kg⁻¹ respectively. This increased in Mn uptake with the application of FYM might be due to the decrease in pH and ESP of saline sodic soil which increased Mn uptake. The results were in agreement with the findings of Swarup (1992).

Iron pyrite, PMC, sulphur and their combinations significantly increased the uptake of Mn by wheat grain and straw over control. The uptake of Mn by wheat grain and straw was 0.17 and 0.24 mg kg⁻¹ respectively at the treatment T₄ (PMC) which was significantly superior over control and on par with rest of the treatments. There was no significant difference in uptake of Mn by grain and straw among the treatments.

Further it was observed from the Table that combine effects on the uptake of Mn by wheat grain and straw due to application of sulphur with PMC was significant in both grain (0.16 mg kg⁻¹) and straw (0.217 mg kg⁻¹) over control. Similar results were

reported by Gangadhara et al. (1990). While the uptake of Mn in the treatment T_6 (FeS_2 + PMC) was 0.14 and 0.20 mg kg^{-1} by grain and straw respectively. This might be due to release of native Mn by acidulating effects of PMC and iron pyrites during the oxidation process.

In general it was observed that the Mn uptake by wheat grain and straw significantly increased when the soil was amended with different amendments. The maximum uptake of Mn was recorded with T_2 (FYM).

4.5.3.6 Uptake of Zinc

It would be seen from the data presented in Table 62 that the uptake of Zn by wheat grain significantly increased by the application of FYM over control. The uptake of Zn by wheat grain was 0.13 mg kg^{-1} and the uptake by wheat straw was significantly superior with T_4 (PMC) i.e. 1.07 mg kg^{-1} over control. This increase in Zn uptake might be due to increased in the concentration of Zn because of decrease in pH and ESP of soil. This results are in support of findings coated by Swarup (1992).

It was revealed that the uptake of Zn by grain and straw was significantly increased by the application of FeS_2 , PMC, sulphur and their combinations. The uptake of wheat grain and straw was highest with T_4 (PMC) i.e. 0.12 and 1.07 mg kg^{-1} respectively. Which was statistically significant over control and on par with rest of the treatment combinations. The uptake of Zn by wheat grain and straw was 0.11 and 0.96 mg kg^{-1} respectively with T_5 (sulphur) and 0.11 and 0.90 mg kg^{-1} by wheat grain and straw respectively with T_3

(FeS₂). It indicated that the application of sulphur and iron pyrites increased the uptake of Zn by wheat plant.

The effects of combine application of sulphur with PMC found significantly superior over control in the uptake of Zn by wheat grain and straw and which was on par with FeS₂ + PMC and the uptake of Zn by wheat grain and straw was 0.11 and 1.07 mg kg⁻¹ respectively with T₇ treatment (sulphur + PMC) followed by T₆ (FeS₂ + PMC).

From these results it was revealed that the uptake of Zn by wheat grain and straw significantly increased by the application of different amendments and recorded maximum with FYM in case of grain and PMC in case of straw.

4.5.3.7 Uptake of copper

The data in respect of uptake of Cu by wheat grain and straw as influenced by FYM, FeS₂, PMC, sulphur and their combinations are given in Table 62.

From the data it was observed that the uptake of Cu by wheat grain and straw significantly increased with the application of FYM i.e. 0.046 and 0.072 mg kg⁻¹ respectively, over control. Similarly the uptake of Cu was 0.046 and 0.056 mg kg⁻¹ by wheat grain and straw respectively with treatment T₄ (PMC). This might be due to the supply of copper from FYM and PMC.

Further it was revealed that the uptake of Cu by straw of wheat significantly increased by the application of FeS₂, sulphur and their combinations. The uptake of Cu was maximum with FeS₂ i.e. 0.043 and 0.062 mg kg⁻¹ by wheat grain and straw respectively

Table 62. Effect of amendments on uptake of Fe, Mn, Zn, Cu (mg kg⁻¹) by wheat grain and straw

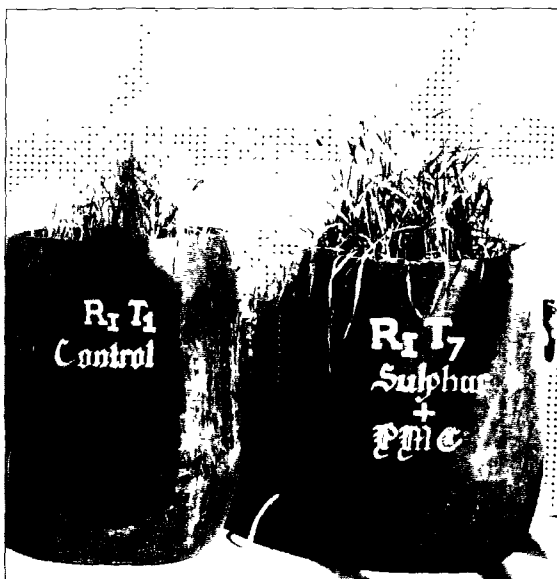
Treatment	Fe		Mn		Zn		Cu	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T ₁	0.53	1.32	0.057	0.164	0.040	0.44	0.014	0.034
T ₂	1.22	1.83	0.17	0.218	0.13	0.87	0.046	0.072
T ₃	1.24	1.96	0.12	0.215	0.11	0.90	0.043	0.052
T ₄	1.09	1.95	0.17	0.240	0.12	1.07	0.046	0.056
T ₅	1.22	1.86	0.16	0.213	0.11	0.96	0.041	0.047
T ₆	1.31	2.02	0.14	0.200	0.10	0.76	0.035	0.046
T ₇	1.24	1.88	0.16	0.217	0.11	1.07	0.045	0.048
S.E. $\pm$	0.035	0.14	0.011	0.014	0.0088	0.055	0.086	0.005
C.D. at 5 %	0.105	0.41	0.033	0.018	0.027	0.17	N.S.	0.016



A) Effect of FeS_2 + PMC on wheat (30DAS) in saline-sodic soil



B) Effect of FeS_2 + PMC on wheat (Flowering stage) in saline-sodic soil



C) Effect of Sulphur + PMC on wheat (30 DAS) in saline-sodic soil



D) Effect of Sulphur + PMC on wheat (Flowering stage) in saline-sodic soil

which was significantly superior over control and on par with T_5 (sulphur). The uptake of Cu by wheat grain and straw was 0.041 and 0.047 mg kg⁻¹ respectively with sulphur. These results are supported with the findings of Gangadhara et al. (1990) and Ghosh et al. (1990).

The data presented in Table 62 showed that the effects of FeS_2 + PMC and sulphur + PMC on the uptake of Cu by wheat grain and straw were significant over control, but the maximum uptake of Cu among these two treatments were recorded with T_7 (sulphur + PMC) where the uptake of Cu by wheat grain and straw were 0.045 and 0.048 mg kg⁻¹ respectively.

In general, it was observed that the uptake of Cu increased by the application of FYM, FeS_2 , PMC and sulphur and FYM found effective in increasing the uptake of Cu by wheat crop.

From the above presented results it was observed that, the study area was classified as saline-sodic having family Vertic Halaquept with poor drainage conditions. The clay complex was predominated with sodium which deteriorated the physical conditions of swell-shrink soil. Therefore, study of installation of sub-surface drainage were undertaken in order to replace Na^+ by Ca^{2+} . It was observed that the sub-surface drainage found effective in removing of salts from soil the drainage water.

In the study of leaching of soil column with FYM, PMC, FeS_2 , sulphur, FeS_2 + PMC and sulphur + PMC. Sulphur treated columns were leached more salts than other. In then study of predictive approaches for sodicity K_g showed less cv. than K_v and K_{KDo}

and it was suggested that the K_g can give fair idea of level of sodification than other constants.

In a pot culture experiment FYM treated pots gave superior yield over other amendments i.e. FeS_2 , PMC, sulphur, FeS_2 + PMC and sulphur + PMC.

Hence, there is need of reclamation of the study area with sub-surface drainage with amendments like FYM, FeS_2 , PMC and sulphur for next few years for better crop growth and soil conditions.

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**SUMMARY
AND
CONCLUSIONS**

5. SUMMARY AND CONCLUSIONS

The results obtained from field experiment conducted at college of Agricultural Engineering Farm, Central Research Farm of M.P.K.V., Rahuri and laboratory studies conducted at Department of Agricultural Chemistry and Soil Science, M.P.K.V., Rahuri under the head of "Assessment of saline-sodic soil during reclamation process" are summarised as under.

5.1 Assessment of saline-sodic soil

5.1.1 Properties of saline-sodic soil

5.1.2 Morphometric properties

Saline-sodic were developed on lower piedmont with basin shape topography. Degraded soil structure with salt efflorescences on soil surface and columnar to prismatic structure with vertic properties were observed. The water table was shallow i.e. 0.8 to 1.2 m and soil have aquic moisture regime.

5.1.1.2 Taxonomic classification

The saline-sodic soil pedons were classified as fine smectitic family of Vertic Halaquept and tentative soil series was Phule-3.

5.1.1.3 Physical and chemical properties of saline-sodic soil

The bulk density of saline-sodic pedon ranged from 1.26 to 1.76 Mg m⁻³, which were generally increased with depth indicating compactness in the subsurface horizon. The high COLE values ranged

from 0.18 to 0.29 in saline-sodic pedons were reported which showed very high swell-shrink potential.

The pH_e of saline-sodic pedons ranged from 8.27 to 8.85 and it increased with depth indicating mildly alkaline reaction.

The E_{ce} in saline-sodic pedons was high and it ranged from 5.25 to 8.69 dSm⁻¹. The E_{ce} in saline-sodic pedons decreased with depth.

In saline-sodic soil, sodium was the predominant cation followed by Ca²⁺, Mg²⁺ and K⁺ in that decreasing order. The Cl⁻ was the dominant ion followed by the SO₄²⁻ and HCO₃⁻ in saline-sodic soil and CO₃⁻ was absent in these soil.

The SAR of saline-sodic soil ranged from 13.62 to 27.89 mmol^{1/2}L^{-1/2} and it increases with depth indicating sodiumized clay content in lower layer.

The ESP values of saline-sodic soil ranged from 15.03 to 28.52. It showed increasing trend with depth.

5.1.2 Spatial variability

In spatial variability experiment, the large variability was recorded in E_{ce}, sodium content of saturation paste extract of soil, sodium adsorption ratio and exchangeable sodium per cent, where the C.V. per cent was more than 25 per cent indicating considerable high within site variability of the soil salinity. But it was recorded less than 10 in soil bulk density hence the variability in bulk density was minimum. The semi-variance in all properties explained above increased with time.

5.1.3 Effect of sub-surface drainage on soil properties

5.1.3.1 pH_s

The pH_s values of saline-sodic soil decreased with decreasing sub-surface drain spacing and 15 m drain spacing found optimum. The maximum reduction was recorded with 15 m drain spacing and at 60 cm depth i.e. 5.05 per cent followed by 90 cm depth i.e. 3.86 per cent over initial value.

5.1.3.2 ECe

The ECe values in saline-sodic soil decreased with time i.e. at an interval of four months upto one year. The maximum reduction in ECe was recorded with 15 m drain spacing and the reduction was 10, 24 and 28 per cent with 60, 90 and 120 cm drain depths over initial values, respectively.

5.1.3.3 Cationic concentration in saturation paste extract of saline-sodic soil

The $Ca^{2+}+Mg^{2+}$ content in saturation paste extract of saline sodic soil showed increasing trend at an interval of four months upto one year.

The reduction in sodium content was recorded 36.7 per cent with 15 m drain spacing and 120 cm drainage depth in one year, which indicated that there was large outflow of water in this treatment by which the removal of ions were more as compared to other treatments.

The potassium content in saturation paste extract of saline-sodic soil increased with the installation of sub-surface drainage in all the treatments but the trend was not specific.

5.1.3.4 Anionic concentration

The chloride sulphate and bicarbonate content in saturation paste extract of soil showed decreasing trend over initial value. The reduction in chloride content was maximum with 15 m drain spacing. The per cent decrease of chloride was 47.8, 53.8 and 45 at 60, 90 and 120 cm drainage depth, respectively. The maximum reduction in HCO_3^- content was with 15 m drain spacing and it was 37.5, 31.5 and 31.5 per cent at 60, 90, 120 cm depths, respectively.

Similarly, the reduction in sulphate content was 36.2, 31.8 and 20.8 per cent 60, 90 and 120 cm depth, respectively at 15 m drain spacing.

5.1.3.5 SAR and exchangeable sodium per cent

The reduction in SAR and ESP values was recorded highest with 15 m drains spacing and 120^{cm} drainage depth and it was 19.1 and 31.1 per cent, respectively.

5.2 Effect of sub-surface drainage on quality of drainage water

The maximum concentration of ions in leachate were recorded with 15 m drain spacing at all three depths i.e. 60, 90 and 120 cm. There was no much effect on pH of leachate but the EC of the leachate increased from July 2001 to January 2002 and again showed decreasing trend thereafter upto July 2002 in all the treatments.

The $\text{Ca}^{2+} + \text{Mg}^{2+}$ content was highest in first five leachates and decreased thereafter.

The removal of sodium potassium, chloride, bicarbonate and sulphate showed increasing trend from July 2001 to January 2002 and decreased thereafter.

5.3 Effect of leaching on quality of leachate and on soil properties (Column study)

5.3.1 pH

The pH values of leachate increased by the application of sulphur > sulphur + PMC > FYM > PMC > Iron pyrite > Iron pyrite + PMC > control. Q

5.3.2 Electrical conductivity of leachate

The removal of soluble salts was more by the addition of sulphur followed by sulphur + PMC and it was 45.15 dSm^{-1} within 120 days of leaching.

5.3.3 Ionic concentration

- i. The $\text{Ca}^{2+} + \text{Mg}^{2+}$ content in leachate was more under the soil treated with canal water only.
- ii. The removal of sodium through leachate was 174.47 meL^{-1} under sulphur treated columns, which was higher than other treatments.
- iii. The removal of Cl^{-} were also more (177.17 meL^{-1}) when the soil was treated with sulphur.
- iv. The removal of HCO_3^{-} was 123.7 meL^{-1} with FYM treatment column.
- v. The removal of SO_4^{2-} was 83.0 meL^{-1} with sulphur + PMC treated columns which was superior than other treatments.

5.3.4 Soil properties

- i. The pHe and ECe values were decreased with FYM, FeS_2 , PMC, sulphur and their combination but maximum decrease was recorded with sulphur treated columns which was 5.70 per cent for pHe and 86.19 per cent for ECe at 0-30 cm depth.
- ii. The Ca^{2+} content in saturation extract increased with PMC over initial values.
- iii. The Na^+ content in saturation paste extract decreased with all the amendments but 97.98 per cent decrease was recorded with sulphur.
- iv. The anion such as Cl^- , HCO_3^- and SO_4^{2-} content in saturation paste extract of soil decreased maximum with sulphur treated columns than other amendments and it was 96.66, 97.77 and 50 per cent, respective at 0-30 cm depth.

5.4 Predictive approaches for sodicity

5.4.1 pH of equilibrium solution

The pH of equilibrium solution showed regular increase with increasing SAR and a regular decrease with increasing TEC of equilibrating solution and it increased with soil depth.

5.4.2 SAR of equilibrium solution

The SAR of the equilibrium solution was decreased as compared to equilibrating solution and it was recorded more in water of low electrolyte concentration.

5.4.3 Exchangeable sodium per cent

The ESP values increased with increasing SAR and TEC of equilibrating solution. The positive interaction of TEC and SAR influences ESP built up. The ESP values increased with soil depth.

5.4.4 ESR-SAR relationship

The results showed that there was a linear relationship between ESR-SAR for different TEC and SAR_{iw}. The values of Gapon's selectivity constant decreased with salinity and increased with SAR_{iw}. It showed increasing trend with soil depth.

5.4.5 Application of different cation exchange equations

On comparison of different selectivity coefficients reveal that the equation of Gapon showed less coefficient of variation than K_v and K_{KDO} . It was suggested that the K_g can give fair idea of level of sodification than other constants.

5.5 Effect of reclamation measures on wheat

5.5.1 Length of earhead

The length of wheat earhead significantly increased with the application of FYM (10 Mg ha⁻¹) over control and it was 64.53 cm which was 25.28 per cent more than control.

5.5.2 Weight of 100 grains

The weight of 100 grains significantly increased by the application of FYM, FeS₂, PMC, sulphur, FeS₂ + PMC and sulphur + PMC over control and maximum grain weight was recorded with PMC (5 Mg ha⁻¹) i.e. 2.87 g.

5.5.3 Grain yield

The yield of wheat grain significantly increased due to the application of FYM over control which was recorded 39.16 g pot⁻¹ the increase was 51.07 per cent over control.

5.5.4 Straw yield

From the results, it was observed that average straw yield was significantly increased by the application of PMC over control and it was recorded 38.90 g pot⁻¹.

5.5.5 Available nutrient

The available N, P, K, Zn and Cu was maximum when the soil was amended with FYM (10 Mg ha⁻¹) which was significantly superior over control and on par with rest of the treatments. The available nutrients was 47.5, 2.37, 230, 0.72 and 0.96 mg kg⁻¹ N, P, K, Zn and Cu, respectively.

Whereas the Fe content was maximum with application of iron pyrites and it was 7.60 mg kg⁻¹ and the Mn content was maximum (6.80 mg kg⁻¹) with sulphur, which was significant over control.

5.5.6 Uptake of nutrients

The uptake of N, P, K, Mn, Zn and Cu by grain was maximum with FYM and it was 36.40, 7.66, 7.93, 0.17, 0.13 and 0.046 mg kg⁻¹, respectively and uptake of Fe was maximum with Iron pyrite + PMC.

Whereas the uptake of N, K and Cu by wheat straw was highest with FYM and it was 8.02, 22.62 and 0.072 mg kg⁻¹, respectively whereas uptake of P, Mn and Zn was highest with PMC

and it was recorded 10.09, 0.240 and 1.07 mg kg⁻¹, respectively and the uptake of iron by wheat straw was recorded highest with Iron pyrite + PMC. All these results are statistically significant over control.

Conclusions

1. The all 5 soil pedons were showing characteristics of saline-sodic soil and classified as fine smectitic family Vertic Halaquept and tentative soil series Phule-3.
2. In the spatial variability experiment large variation in salinity was observed from point to point i.e. 50 x 50 m. Hence, this spacing is not sufficient for variability study, the spacing must be reduce in order to get more precise results. For soil bulk density the distance were sufficient.
3. Installation of sub-surface drainage found effective in decreasing of surface soil salinity, the decrease in salinity was maximum with 15 m drain spacing and 120 cm drainage depth. The Ca²⁺ and Mg²⁺ increased with time where as other ions showed decreasing trend upto one year.
4. In a column study the leaching was maximum in first leachate and decreased thereafter. Maximum leachate were collected when the soil was amended with sulphur followed by sulphur + PMC, hence the removal of salts and ions were maximum with sulphur and it also found better in improvement of soil upto 120 days after leaching.
5. In the study of predictive approaches for sodicity SAR eq, ESR, ESP increased as the total electrolyte concentration and SAR of the synthetic water.

6. The K_g values decreased with salinity and increased with SAR_{iw} and soil depth.
7. Among K_g , K_r and K_{kdo} , K_g showed less c.v. per cent and hence K_g can give fair idea of level of sodification than other constants in these soils.
8. The application of FYM found better for improving the grain and straw yield and available N, P, K, Zn and Cu under saline-sodic condition whereas available Fe were improved with the application of FeS_2 . The available Mn was more when soil was amended with sulphur + PMC.
9. The uptake of N, P, K, Mn, Zn and Cu in grain and uptake of N, K and Cu by wheat straw was highest with FYM. Whereas the uptake of Fe by both grain and straw recorded highest with FeS_2 . The uptake of P, Mn and Zn by wheat straw recorded highest with PMC treated pots.
10. Thus the experiment proved that the sub-surface drainage is one of the best reclamation technology for saline-sodic soil and FYM, PMC, sulphur and Iron pyrites are the amendments which are useful in reclaiming such soils.
11. Hence, there is need of reclamation of the study area with sub-surface drainage with amendments like FYM, FeS_2 , PMC and sulphur for next few years for better crop growth and soil conditions.

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**LITERATURE
CITED**

6. LITERATURE CITED

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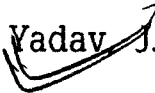
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* **Originals are not seen.**

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Chapter Opener Page



APPENDICES

7. APPENDICES

Appendix-I : Morphometric properties of saline-sodic pedons
(1 to 5)

Depth (cm)	Colour		Texture	Crack width (cm)	Depth of ground water (m)
	Dry	Moist			
0-30	10 YR 5/3	10 YR 3/3	Clay	1.0 – 4.0	0.8 – 1.2
30-60	10 YR 5/3	10 YR 3/3	Clay	0.5 – 1.0	Except pedon-1
60-90	10 YR 4/1	10 YR 3/3	Clay	-	-

Appendix-II : Spatial variation in electrical conductivity of saturation paste extract of soil (dSm⁻¹)

Grid No.	Grid point	June 2001 (Initial)	October 2001	February 2002	June 2002
1	1	6.6	6.3	6.1	5.7
1	2	4.90	4.16	4.50	4.40
1	3	2.09	1.91	1.60	1.02
1	4	7.91	7.76	7.70	7.56
1	5	3.79	3.14	3.05	2.80
2	1	5.80	5.20	5.00	4.60
2	2	3.79	3.40	3.07	2.88
2	3	8.76	6.70	6.50	6.10
2	4	5.00	4.87	4.45	4.17
2	5	7.06	6.62	6.25	5.30
3	1	5.99	5.38	5.05	4.85
3	2	3.90	3.16	3.07	2.80
3	3	7.65	7.40	6.65	6.30
3	4	9.30	8.85	8.65	8.30
3	5	4.66	3.90	3.55	2.85
4	1	13.65	18.90	19.40	19.46
4	2	4.20	5.10	6.18	7.20
4	3	9.90	8.72	7.80	8.00
4	4	8.19	7.69	8.10	7.98
4	5	7.80	7.45	6.85	6.50
5	1	8.80	9.50	8.56	9.99
5	2	7.00	7.61	6.70	8.00
5	3	13.50	12.30	10.20	9.20
5	4	9.60	9.20	9.03	8.88
5	5	7.13	7.09	6.70	6.00
6	1	6.90	6.55	6.60	6.70
6	2	3.05	6.10	6.75	7.20
6	3	19.40	18.20	18.10	17.70
6	4	8.83	8.39	8.07	7.90
6	5	23.00	22.84	22.60	22.10

Appendix-III : Spatial variation in sodium content of saturation paste extract of soil (me L^{-1})

Grid No.	Grid point	June 2001 (Initial)	October 2001	February 2002	June 2002
1	1	43.47	39.78	47.82	30.43
1	2	16.30	15.21	14.43	13.43
1	3	10.00	7.82	8.47	8.21
1	4	40.21	39.69	36.6	34.43
1	5	21.73	19.56	18.30	16.80
2	1	40.21	37.34	32.73	28.30
2	2	27.17	27.39	26.20	21.13
2	3	51.08	45.00	42.60	39.34
2	4	33.69	28.08	26.00	24.82
2	5	34.78	27.17	22.82	22.73
3	1	34.78	29.34	27.73	22.39
3	2	24.73	20.30	18.69	16.52
3	3	45.65	36.95	45.65	44.13
3	4	61.95	56.52	50.23	45.65
3	5	29.34	25.00	28.56	24.30
4	1	98.91	10.36	126.00	130.00
4	2	33.69	34.75	47.82	30.43
4	3	52.17	48.91	72.82	65.21
4	4	53.26	50.23	48.91	46.56
4	5	52.17	44.56	38.04	34.09
5	1	61.95	31.51	32.60	40.20
5	2	45.65	47.82	49.02	50.00
5	3	83.69	75.00	76.08	75.00
5	4	56.52	55.26	54.34	45.65
5	5	46.73	38.04	31.52	29.08
6	1	57.60	59.78	72.82	80.60
6	2	38.04	39.78	47.82	30.43
6	3	92.39	88.04	83.69	86.95
6	4	32.60	29.34	27.73	24.82
6	5	134.80	130.00	126.00	108.69

Appendix-IV : Spatial variation in SAR of saturation paste extract of soil

Grid no.	Grid point	June 2001 (Initial)	October 2001	February 2002	June 2002
1	1	14.93	10.35	10.07	9.54
1	2	6.52	6.13	6.64	5.61
1	3	5.00	5.21	6.43	4.79
1	4	10.40	8.51	9.45	9.38
1	5	8.55	7.16	8.20	5.60
2	1	15.23	13.67	11.14	9.86
2	2	13.58	12.91	12.71	10.94
2	3	15.97	12.74	13.83	13.95
2	4	13.80	12.59	11.65	9.22
2	5	13.69	9.21	5.70	5.39
3	1	13.69	13.19	12.11	8.20
3	2	12.36	10.51	9.99	10.01
3	3	13.04	10.15	12.78	14.14
3	4	14.04	13.14	11.93	10.35
3	5	10.51	10.46	12.80	9.20
4	1	22.73	24.01	30.14	21.13
4	2	12.57	13.16	16.43	14.50
4	3	12.95	1.63	16.93	14.49
4	4	11.43	10.91	10.00	8.88
4	5	15.95	12.87	10.77	10.17
5	1	17.20	11.54	11.72	15.22
5	2	16.18	17.19	22.59	16.16
5	3	18.85	15.82	16.61	13.39
5	4	15.52	13.12	13.00	11.41
5	5	14.78	12.51	10.39	9.44
6	1	19.20	20.19	22.76	22.38
6	2	15.91	13.93	15.94	10.14
6	3	17.46	15.89	16.34	13.67
6	4	6.80	6.65	6.88	6.31
6	5	20.11	20.56	19.11	16.82

Appendix-V : Spatial variation in Exchangeable sodium percentage of saturation paste extract of soil

Grid no.	Grid point	June 2001 (Initial)	October 2001	February 2002	June 2002
1	1	17.20	12.28	11.97	11.35
1	2	7.71	7.26	7.86	6.55
1	3	5.76	6.03	7.60	10.47
1	4	12.35	10.15	11.25	11.17
1	5	10.19	8.50	9.77	6.54
2	1	18.93	15.89	13.18	12.70
2	2	15.81	15.10	14.89	12.95
2	3	18.24	14.92	16.06	16.19
2	4	16.04	14.75	13.73	10.98
2	5	15.92	10.97	6.67	6.27
3	1	15.92	15.40	15.16	9.77
3	2	14.51	12.47	11.88	11.89
3	3	15.24	12.05	14.97	16.39
3	4	16.28	15.34	14.04	12.28
3	5	12.47	12.41	14.98	10.96
4	1	24.39	25.46	30.16	22.76
4	2	14.73	15.48	18.69	22.87
4	3	15.14	12.60	19.16	16.74
4	4	13.50	12.91	11.88	10.57
4	5	18.22	15.04	12.76	12.07
5	1	19.42	13.61	13.81	17.49
5	2	18.43	19.43	24.28	18.90
5	3	20.98	18.09	18.86	15.61
5	4	17.78	15.33	15.18	13.46
5	5	17.04	14.66	12.30	11.25
6	1	21.30	22.19	24.45	24.10
6	2	18.17	16.18	18.20	12.05
6	3	19.68	18.18	18.60	15.90
6	4	8.06	7.88	8.16	7.45
6	5	22.12	22.53	21.21	19.06

Appendix-VI : Spatial variation in bulk density of soil (mg m^{-3})

Grid No.	Grid point	June 2001 (Initial)	October 2001	February 2002	June 2002
1	1	1.41	1.29	1.29	1.26
1	2	1.38	1.36	1.28	1.20
1	3	1.61	1.56	1.50	1.43
1	4	1.24	1.22	1.19	1.24
1	5	1.41	1.33	1.32	1.30
2	1	1.61	1.48	1.37	1.32
2	2	1.61	1.34	1.21	1.18
2	3	1.45	1.41	1.37	1.30
2	4	1.40	1.35	1.17	1.34
2	5	1.50	1.42	1.36	1.32
3	1	1.28	1.28	1.18	1.10
3	2	1.42	1.38	1.36	1.19
3	3	1.17	1.33	1.19	1.17
3	4	1.44	1.35	1.26	1.33
3	5	1.61	1.60	1.45	1.40
4	1	1.43	1.48	1.50	1.49
4	2	1.54	1.57	1.58	1.62
4	3	1.50	1.46	1.41	1.35
4	4	1.55	1.26	1.19	1.35
4	5	1.16	1.21	1.17	1.17
5	1	1.49	1.50	1.48	1.52
5	2	1.56	1.49	1.50	1.52
5	3	1.61	1.54	1.52	1.37
5	4	1.51	1.48	1.43	1.40
5	5	1.69	1.61	1.44	1.40
6	1	1.60	1.56	1.58	1.60
6	2	1.42	1.44	1.48	1.47
6	3	1.59	1.52	1.51	1.31
6	4	1.36	1.26	1.20	1.18
6	5	1.56	1.49	1.35	1.28

Appendix-VII : Semi-variance for electrical conductivity of saturation paste extract of soil

Observation	Lag class	Number of pairs in class	Average lag distance	Semi-variance			
				Initial June-01	October-01	February-02	June-02
1	-1	30	-	-	-	-	-
2	0	0	-	-	-	-	-
3	1	0	-	-	-	-	-
4	2	0	-	-	-	-	-
5	3	49	1.00	10.78	15.37	15.58	15.08
6	4	0	-	-	-	-	-
7	5	40	1.41	9.34	13.23	12.62	11.83
8	6	0	-	-	-	-	-
9	7	100	2.15	10.85	16.09	16.14	16.26
10	8	0	-	-	-	-	-
11	9	24	2.83	11.44	15.80	15.42	15.44
12	10	27	3.00	17.18	22.92	22.48	23.25

Appendix-VIII : Semi-variance for sodium content in saturation paste extract of soil

Observation	Lag class	Number of pairs in class	Average lag distance	Semi-variance			
				Initial June-01	October-01	February-02	June-02
1	-1	30	-	-	-	-	-
2	0	0	-	-	-	-	-
3	1	0	-	-	-	-	-
4	2	0	-	-	-	-	-
5	3	49	1.00	492.08	538.50	623.06	622.25
6	4	0	-	-	-	-	-
7	5	40	1.41	439.47	387.70	507.55	525.41
8	6	0	-	-	-	-	-
9	7	100	2.15	436.04	451.05	560.85	570.50
10	8	0	-	-	-	-	-
11	9	24	2.83	477.98	471.57	582.57	583.78
12	10	27	3.00	685.22	709.31	802.51	830.21

Appendix-IX : Semi-variance for sodium adsorption ratio of saturation paste extract of soil

Observation	Lag class	Number of pairs in class	Average lag distance	Semi-variance			
				Initial June-01	October-01	February-02	June-02
1	-1	30	-	-	-	-	-
2	0	0	-	-	-	-	-
3	1	0	-	-	-	-	-
4	2	0	-	-	-	-	-
5	3	49	1.00	11.64	12.63	20.39	32.30
6	4	0	-	-	-	-	-
7	5	40	1.41	12.30	10.61	14.60	33.61
8	6	0	-	-	-	-	-
9	7	100	2.15	11.23	11.62	20.61	43.02
10	8	0	-	-	-	-	-
11	9	24	2.83	11.50	14.14	23.87	51.71
12	10	27	3.00	14.67	19.03	34.87	63.07

Appendix-X : Semi-variance for exchangeable sodium per cent in soil

Observation	Lag class	Number of pairs in class	Average lag distance	Semi-variance			
				Initial June-01	October-01	February-02	June-02
1	-1	30	-	-	-	-	-
2	0	0	-	-	-	-	-
3	1	0	-	-	-	-	-
4	2	0	-	-	-	-	-
5	3	49	1.00	12.87	12.55	19.26	26.19
6	4	0	-	-	-	-	-
7	5	40	1.41	14.93	12.69	14.78	27.46
8	6	0	-	-	-	-	-
9	7	100	2.15	13.42	13.52	19.80	34.68
10	8	0	-	-	-	-	-
11	9	24	2.83	14.36	13.45	23.44	41.98
12	10	27	3.00	15.73	16.10	33.44	53.09

Appendix-XI : Semi-variance for bulk density of soil

Observation	Lag class	Number of pairs in class	Average lag distance	Semi-variance			
				Initial June-01	October-01	February-02	June-02
1	-1	30	-	-	-	-	-
2	0	0	-	-	-	-	-
3	1	0	-	-	-	-	-
4	2	0	-	-	-	-	-
5	3	49	1.00	0.0197	0.0124	0.0128	0.0107
6	4	0	-	-	-	-	-
7	5	40	1.41	0.0191	0.0135	0.0159	0.0145
8	6	0	-	-	-	-	-
9	7	100	2.15	0.0175	0.0114	0.0154	0.0161
10	8	0	-	-	-	-	-
11	9	24	2.83	0.0241	0.0136	0.0228	0.0202
12	10	27	3.00	0.0180	0.0130	0.0216	0.0261

Appendix-XII : Reduced concentration of chloride for break through curve

No. of pore volumes	Control	FYM	Iron pyrite	PMC	Sulphur	Iron pyrite + PMC	Sulphur + PMC
1.	0.411	0.079	0.080	0.130	0.069	0.095	0.130
2.	0.423	0.105	0.082	0.176	0.112	0.105	0.135
3.	0.426	0.124	0.084	0.213	0.115	0.105	0.178
4.	0.779	0.133	0.181	0.213	0.119	0.133	0.225
5.	0.823	0.142	0.221	0.230	0.127	0.142	0.250
6.	0.880	0.166	0.285	0.427	0.127	0.166	0.250
7.	1.000	0.181	0.443	0.460	0.136	0.199	0.260
8.		1.000	0.677	0.544	0.166	0.210	0.307
9.			1.000	0.598	0.212	0.234	0.338
10.				1.000	0.239	0.249	0.423
11.					0.254	0.332	0.676
12.					0.424	0.443	0.847
13.					0.638	0.666	1.000
14.					0.957	1.00	
15.					1.000		

Appendix-XIII : Effect of water quality on physico-chemical characteristics of equilibrium and exchangeable phases (0-30 cm depth)

TEC meL ⁻¹	SAR mmol ^{1/2} L ^{1/2}	pH	EC dSm ⁻¹	Ca ²⁺ meL ⁻¹	Mg ²⁺ meL ⁻¹	Na ⁺ meL ⁻¹	Cl ⁻ meL ⁻¹	Density of solution	Moisture content	NaX me/ 100 g	Yan me/ 100 g
5	2.5	8.25	1.48	1.8	1.7	4.25	5.0	0.980	68.87	2.91	0.104
	5	8.28	1.44	1.6	1.5	4.37	6.4	0.998	70.14	3.20	0.228
	10	8.32	1.46	1.5	1.4	5.00	6.4	0.990	65.65	3.81	0.182
	15	8.32	1.94	1.4	0.9	5.37	6.6	0.992	73.08	4.50	0.138
	20	8.40	1.62	1.0	0.7	5.25	6.8	0.994	65.39	5.24	0.207
	30	8.56	1.42	1.1	1.0	7.88	6.8	0.996	65.26	6.75	0.214
10	2.5	8.09	1.70	3.0	2.8	5.30	10.0	0.920	65.21	2.86	0.452
	5	8.10	1.64	2.8	2.0	5.37	10.8	0.986	58.31	3.34	0.310
	10	8.12	1.72	2.6	2.0	7.82	10.8	0.888	76.7	4.57	0.471
	15	8.28	2.10	2.4	1.9	9.78	10.6	0.892	78.47	5.76	0.891
	20	8.42	2.00	2.0	1.4	10.0	10.8	0.902	80.37	6.6	0.467
	30	8.50	1.62	2.0	1.3	10.62	17.2	0.910	74.17	7.12	0.835
20	2.5	8.00	2.36	6.0	5.1	6.95	17.0	0.882	76.53	2.47	1.06
	5	8.10	2.50	5.8	4.8	10.21	17.2	0.982	56.00	3.73	0.483
	10	8.10	2.58	5.9	4.7	25.21	18.4	0.988	60.72	8.43	0.657
	15	8.10	2.97	6.1	4.9	30.86	18.8	0.937	74.70	10.26	0.884
	20	8.24	2.86	4.1	3.1	28.69	19.2	0.993	73.01	11.05	0.903
	30	8.46	2.53	3.2	3.9	32.60	19.6	0.976	69.15	12.35	0.795
50	2.5	7.92	5.26	18.0	16.0	10.82	28.0	0.988	75.91	2.08	1.52
	5	8.02	5.42	16.4	12.0	15.21	28.2	0.983	68.66	3.16	1.31
	10	8.06	5.30	11.3	8.0	32.17	28.8	0.986	73.52	7.50	1.27
	15	8.10	5.90	11.0	6.0	38.26	29.6	0.990	70.70	9.34	1.21
	20	8.18	5.72	8.0	5.9	47.82	21.0	0.992	68.04	12.38	0.50
	30	8.22	5.10	8.0	3.4	51.30	31.0	0.991	70.63	13.98	1.16

Appendix-XIII contd.....

(30-60 cm depth)

TEC meL ⁻¹	SAR mmol ^{1/2} L ^{1/2}	pH	EC dSm ⁻¹	Ca ²⁺ meL ⁻¹	Mg ²⁺ meL ⁻¹	Na ⁺ meL ⁻¹	Cl ⁻ meL ⁻¹	Density of solution	Moisture content (%)	NaX me/ 100 g	Yan me/ 100 g
5	2.5	8.40	1.15	0.8	1.0	3.26	6.8	0.992	57.88	3.19	0.173
	5	8.46	1.16	1.2	1.0	3.69	6.7	0.982	53.08	3.28	0.138
	10	8.60	1.07	1.0	0.8	4.34	6.4	0.989	65.00	4.23	0.156
	15	8.75	1.17	1.1	0.7	6.25	6.7	0.980	66.32	6.10	0.184
	20	8.80	1.18	1.0	1.0	8.75	6.9	0.980	68.67	7.17	0.233
	30	8.86	1.37	0.8	1.0	8.34	6.8	0.980	58.67	7.92	0.178
10	2.5	8.60	1.59	2.6	2.0	5.32	9.6	0.99	65.06	3.08	0.284
	5	8.72	1.30	2.1	1.6	6.41	9.8	0.923	65.00	4.21	0.177
	10	8.64	1.32	1.9	1.2	6.84	9.6	0.966	64.34	4.90	0.137
	15	8.67	1.33	1.6	1.0	7.82	9.4	0.995	67.78	6.00	0.137
	20	8.46	1.48	1.0	0.7	8.15	9.4	0.943	68.92	7.55	0.187
	30	8.34	1.42	0.9	0.7	8.26	9.2	0.988	60.00	7.89	0.168
20	2.5	8.64	2.52	7.0	5.2	7.82	17.3	0.986	72.50	2.70	0.884
	5	8.88	2.20	6.9	4.2	8.69	1.8	0.988	70.00	3.17	0.542
	10	8.88	2.31	3.7	1.7	14.56	17.8	0.990	65.65	7.05	0.498
	15	9.01	2.40	2.3	1.1	16.52	18.0	0.992	63.00	9.68	0.120
	20	9.01	2.36	1.9	1.0	17.17	18.2	0.996	60.24	10.75	0.171
	30	9.10	2.28	1.6	0.6	17.82	20.2	0.998	62.62	12.38	0.432
50	2.5	8.37	5.48	20.4	17.81	17.81	32.2	0.986	73.75	2.11	1.99
	5	8.38	5.22	18.9	11.9	19.13	34.4	0.984	66.05	3.73	1.45
	10	8.50	5.40	14.1	7.4	28.69	36.2	0.988	70.85	6.47	1.58
	15	8.53	5.38	11.1	5.9	34.78	32.6	0.987	68.38	8.63	0.12
	20	8.58	5.52	7.0	3.9	39.13	38.4	0.988	58.19	11.52	0.97
	30	8.54	5.52	5.2	3.4	41.30	40.0	0.953	62.95	13.21	0.888

Appendix-XIII contd.....

(60-90 cm depth)

TEC meL ⁻¹	SAR mmol ^{1/2} L ^{1/2}	pH	EC dSm ⁻¹	Ca ²⁺ + Mg ²⁺ meL ⁻¹	Na ⁺ meL ⁻¹	Cl ⁻ meL ⁻¹	Density of solution	Moisture content (%)	NaX me/ 100 g	Yan me/ 100 g
5	2.5	8.60	1.10	3.8	5.2	4.6	0.980	70.14	3.59	0.132
	5	8.62	1.14	3.4	5.3	6.0	0.998	70.14	3.90	0.20
	10	8.80	1.12	3.4	6.43	6.6	0.992	73.08	4.71	0.198
	15	8.80	1.15	3.0	7.0	7.0	0.888	76.70	5.38	0.256
	20	8.60	1.18	2.8	7.16	7.2	0.892	78.47	5.81	0.284
	30	8.92	1.20	2.6	7.82	7.6	0.902	80.37	6.47	0.328
10	2.5	8.80	1.60	6.0	7.18	10.2	0.988	60.72	3.96	0.299
	5	8.72	1.64	5.8	7.26	10.6	0.976	69.15	4.21	0.352
	10	8.92	1.62	5.6	8.38	10.8	0.983	68.66	4.80	0.281
	15	9.06	1.56	5.4	9.44	10.8	0.900	68.87	5.49	0.263
	20	9.40	1.90	5.0	11.18	10.9	0.991	70.63	6.63	0.249
	30	9.40	1.96	4.8	11.88	14.6	0.990	70.70	7.13	0.513
20	2.5	8.64	2.10	11.0	10.10	18.0	0.992	57.88	3.88	0.680
	5	8.90	2.12	10.8	11.18	18.8	0.988	60.72	4.33	0.641
	10	9.00	2.16	10.6	22.18	18.8	0.989	65.0	8.10	0.642
	15	9.20	2.18	10.2	27.18	19.2	0.980	66.32	9.8	0.753
	20	9.28	2.20	8.8	32.18	19.4	0.980	68.67	11.96	0.772
	30	8.80	2.28	8.6	32.40	19.6	0.943	68.92	12.15	0.710
50	2.5	8.60	5.60	30.0	21.10	28.0	0.982	53.08	4.56	1.10
	5	8.72	5.62	28.0	26.10	28.8	0.992	57.88	5.68	0.97
	10	8.92	5.40	20.2	46.0	29.2	0.988	60.72	10.67	1.08
	15	9.18	5.30	16.8	46.80	29.6	0.980	68.67	11.68	1.23
	20	9.30	5.34	13.6	47.0	29.6	0.998	70.14	12.81	1.05
	30	9.32	5.68	12.8	49.43	31.2	0.992	73.08	13.65	1.06

Chapter Opener Page



VITA

8. VITA

Satishchandra Maroti Jadhao

A candidate for the degree

of

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