

INVESTIGATION ON THE EFFECT OF SOIL AMENDMENTS AND
LAND TREATMENTS ON SOIL CHARACTERISTICS AND
PRODUCTIVITY OF COTTON GROWN IN
SALT AFFECTED VERTISOLS

THESIS

*Submitted to the
Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola
in fulfilment of the requirements for the
Degree of*

DOCTOR OF PHILOSOPHY
IN
AGRICULTURE
(AGRICULTURAL CHEMISTRY AND SOIL SCIENCE)

BY

SHRIDHAR SHANKARRAO REWATKAR



DEPARTMENT OF AGRICULTURAL CHEMISTRY AND SOIL SCIENCE
POST GRADUATE INSTITUTE,

**Dr. PANJABRAO DESHMUKH
KRISHI VIDYAPEETH, AKOLA (M. S.)
INDIA**

YEAR

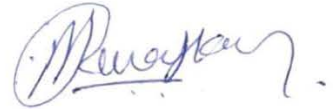
1998

DECLARATION OF STUDENT

I hereby declare that the experimental work and its interpretation of the thesis entitled **“Investigation on the Effect of Soil Amendments and Land Treatments on Soil Characteristics and Productivity of Cotton Grown in Salt Affected Vertisols”** or part thereof has not been submitted for any other degree or diploma of any University, nor the data have been derived from any thesis / publication of any University or Scientific organisation. The sources of materials used and all assistance received during the course of investigation have been duly acknowledged.

Akola

Dated: 14 December, 1998



(S.S.Rewatkar)
Signature of the student

Dr.B.N.Sagare,

M.Sc. (Agri.), Ph.D.

Associate Professor,
University Department of Agril.Chemistry
and Soil Science,
Dr.P.D.K.V., Akola (M.S.)

CERTIFICATE

This is to certify that **Shri Shridhar Shankarrao Rewatkar** has satisfactorily prosecuted his course of research for a period of not less than two years and the thesis entitled "**Investigation on the Effect of Soil Amendments and Land Treatments on Soil Characteristics and Productivity of Cotton Grown in Salt Affected Vertisols**" submitted by Shri Shridhar Shankarrao Rewatkar is the result of his original work and is of a sufficiently high standard to warrant its presentation for evaluation and adjudication for award of **Ph.D.** degree.

Akola

Date : 14 December 1998



(B.N.Sagare)
Research Guide

Countersigned



(K.B.Gahukar)

Associate Dean,
Post Graduate Institute,
Dr.Panjabrao Deshmukh Krishi Vidyapeeth,
Akola

ACKNOWLEDGEMENT

I feel immense pleasure in expressing my gratitude and indebtedness to my Hon'ble Guide **Dr.B.N.Sagare**, M.Sc.(Agri.), Ph.D., FAO Fellow (USA), Recipient of World Bank Washington (USA) Award; Associate Professor, University Department of Agricultural Chemistry and Soil Science, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola for suggesting the research topic, valuable guidance, keen interest, constructive criticism and constant encouragement throughout the period of investigation.

I am hereby indebted to **Dr. R.B.Puranik**, Head, University Department of Agricultural Chemistry and Soil Science, Dr.Panjabrao Deshmukh Krishi Vidyapeeth, Akola for his generosity and moral support for providing necessary facilities to complete the research work.

I am deeply indebted to **Dr. G.M.Bharad**, M.Sc. (Agri.), Ph.D., Hon'ble Vice-Chancellor, Dr.PDKV, Akola for his generosity, moral support for completing the present study.

My deep seated gratitude and devoted thanks to **Dr. K.B.Gahukar**, Dean (Agri) and Associate Dean, Post Graduate Institute, Dr.Panjabrao Deshmukh Krishi Vidyapeeth, Akola for providing necessary facilities during the course of investigation.

I am specially thankful to **Shri S.G.Thote**, Associate Professor for his guidance in statistical analysis, **Shri S.D.Deshmukh** and **Shri.V.P.Babhulkar** for their help in the laboratory work and support.

I acknowledge my sincere thanks to **Dr. Y.S.Guhe**, Professor and Ex-Head and **Dr.R.C.Dakhore**, Ex-Professor, **Dr.V.N.Deshmukh**, Professor, University Department of Agricultural Chemistry and Soil Science, for providing necessary facilities.

I am highly thankful to **Dr. V.B.Shekar**, Director of Research and Associate Dean, College of Agriculture, Akola, **Dr.P.A.Varade**, Ex-Dean (Agri.) and Ex-Head, University Department of Agril. Chemistry and Soil Science, **Dr.P.D.K.V.**, Akola.

I am grateful to Dr. Sheshrao Thakare, Dr.S.R.Umale, Dr.P.Ratnakar, Prof. R.P.Joshi, Dr. R.L.Kalane, Dr.D.Zadode, Dr.H.N.Ravankar, Dr. V.R.Padole, Dr. M.N.Patil, Dr.S.N.Ingle, Dr.D.B.Patil, Dr.V.V.Gabhane, Dr.S.G.Wankhade, Shri S.N.Ingle, Dr.D.B.Patil, Dr.P.V.Sarode, Shri ^{G.S.}Lahariya, Dr.R.T.Patil, ShriS.S.Wanjari, Shri S.M.Bhoyar, Shri ^{R.T.}P.H.Vaidya, Shri B.M.Solanke, Shri.P.W.Deshmukh, Shri [^]Nikesar, Shri R.C.Deshmukh, Shri Samadhan Wakode for their help in completing the thesis work.

I am also thankful to Shri Nitin Kharche, for the help provided in display of various graphs encountered in this thesis.

I express my heartiest thanks to Sau.Nalini B. Sagare and family.

I will be failing in my duty if I do not record my love, affection and gratitude to my father, mother, wife Sau. Kalindi S.Rewatkar, brothers, sister, my son and daughter for their constant encouragement and kind blessings without which I would not have been able to see the light of present days.

Place : Akola

Dated : 14 December, 1998



(S.S.Rewatkar)

TABLE OF CONTENTS

	CHAPTER	Page
I.	INTRODUCTION	1
II.	REVIEW OF LITERATURE	6
III.	MATERIALS AND METHODS	45
IV.	RESULTS AND DISCUSSION	62
V.	SUMMARY AND CONCLUSIONS	130
	BIBLIOGRAPHY	136
	APPENDICES	
	Appendix - I	155
	Appendix - II	156
	VITA	157
	THESIS ABSTRACT	

LIST OF TABLES

Table No.	Title	Page No.
1.	Physiochemical characteristics of pedon excavated in experimental field	53
2.	Initial physio-chemical characteristics of surface soil	55
3.	Seed cotton yield ($q\ ha^{-1}$) as influenced by land treatments and gypsum levels.	64
3(a)	Interaction effect in respect of seed cotton yield	64
4	Stalk yield ($q\ ha^{-1}$) as influenced by land treatments and gypsum levels	69
4(a)	Interaction effect in respect of stalk yield	69
5	Economics of cotton as influenced by land treatments and gypsum levels.	73
6	Bulk density ($Mg\ m^{-3}$) as influenced by various treatments.	77
6(a)	Interaction effect in respect of bulk density	77
7	Hydraulic conductivity ($cm\ hr^{-1}$) as influenced by land treatments and gypsum levels.	81
7(a)	Interaction effect in respect of hydraulic conductivity	81
8	Soil moisture percentage (gravimetric) as influenced by land treatments and gypsum levels.	86
8(a)	Interaction effect in respect of soil moisture percentage (gravimetric)	86
9	Available soil moisture storage (mm) as influenced by land treatments and gypsum levels.	89
9(a)	Interaction effect in respect of available soil moisture storage.	89
10	pHs as influenced by land treatments and gypsum levels	93
10(a)	Interaction effect in respect of pHs.	93

11	ECe (dSm ⁻¹) as influenced by land treatments and gypsum levels.	97
11(a)	Interaction effect in respect of ECe.	97
12	SAR _e as influenced by land treatments and gypsum levels.	101
12(a)	Interaction effect in respect of SAR _e	101
13	Ionic Na ⁺ (Cmol L ⁻¹) as influenced by land treatments and gypsum levels.	106
13(a)	Interaction effect in respect of ionic composition of Na ⁺	106
14	Ionic composition of Ca ⁺⁺ (Cmol L ⁻¹) as influenced by land treatments and gypsum levels.	109
14(a)	Interaction effect in respect of ionic composition of Ca ⁺⁺	109
15	Ionic composition of Mg ⁺⁺ (Cmol L ⁻¹) as influenced by land treatments and gypsum levels.	114
15(a)	Interaction effect in respect of ionic composition of Mg ⁺⁺	114
16	ESP as influenced by land treatments and gypsum levels	118
16(a)	Interaction effect in respect of ESP	118
17.	Correlation matrix of soil parameters and seed cotton yield	122
18.	Multiple linear regression coefficients of soil parameters on seed cotton yield in different models.	128

LIST OF FIGURES

Fig. No.	Title	Page No.
1	Map of purna valley showing experimental site	46
2	Lay out of field experiment conducted at Gopalkheda	56
3	Seed cotton yield ($q\ ha^{-1}$) as influenced by land treatments and gypsum levels.	65
4	Stalk yield ($q\ ha\ hr^{-1}$) as influenced by land treatments and gypsum levels.	70
5	B:C ratios of cotton cultivation as influenced by land treatments and gypsum levels.	74
6	Bulk density ($Mg\ m^{-3}$) as influenced by land treatments and gypsum levels.	78
7	Hydraulic conductivity as influenced by land treatments and gypsum levels.	82
8	Available soil moisture storage (mm) as influenced by land treatments and gypsum levels.	90
9	pHs as influenced by land treatments and gypsum levels.	94
10	Ece (dSm^{-1}) as influenced by land treatments and gypsum levels.	98
11	SARe as influenced by land treatments and gypsum levels.	102
12	Ionic Na^{-1} ($Cmol\ L^{-1}$) as influenced by land treatments and gypsum levels.	107
13	Ionic Ca^{++} ($Cmol\ L^{-1}$) as influenced by land treatments and gypsum levels.	110
14	Ionic Mg^{++} ($Cmol\ L^{-1}$) as influenced by land treatments and gypsum levels.	115
15	ESP as influenced by land treatments and gypsum levels.	119

LIST OF PLATES

Plate No.	Title	After page
1	Showing the effect of land treatments on growth of cotton	63
2a	Showing the effect of gypsum on growth of cotton	67
2b	Showing the effect of gypsum on growth of cotton	67
3	Showing the interaction effect on growth of cotton	67

ABBREVIATIONS

MM	Millimeter
cm	Centimeter
m	Meter
$^{\circ}\text{C}$	Degree centigrates
%	Per cent
mg	Milligram
g	Gram
kg	Kilogram
q	Quintal
ha	Hectare
-1	Per
EC	Electrical conductivity
d Sm^{-1}	Deci Simens per meter
CEC	Cation exchange capacity
$\text{C mol (P}^{+}) \text{ kg}^{-1}$	Centimole proton donar per kilogram
$\text{SE(m)} \pm$	Standard error of means
C.D.	Critical difference
R^2	Coefficient of determinant
δ	Sigma
>	Greater than
<	Less than
viz.	Namely
<i>et al.</i>	Et alia (and others)
GR	Gypsum requirement
HC	Hydraulic conductivity
AWC	Available water storage capacity
BD	Bulk density
B:C ratio	Benefit cost ratio
SAR	Sodium adsorption ratio
Na	Sodium
Ca	Calcium
Mg	Magnesium
ha-1	Per hectare
m	Meter
km^2	Killometers square

CHAPTER I

INTRODUCTION

Soils are a vital natural resource whose sustainable use greatly determines the capability of life support system and the socioeconomic development of a people. History records the rise and fall of civilizations in accordance with the wise use or abuse of the soil resources. Major issues of soil resources include degradation by displacement of soil material (water and wind erosion) and internal soil deterioration resulting from chemical degradation (salinization/sodification and loss of nutrients). Aridity of climate, unscientific irrigation, topographical situations, groundwater rise, continue seepage, and poor drainability of soil are some of causes of formation of salt affected Vertisols (Varade *et al.*, 1985).

In India, an area of about 12 million ha is affected due to salinity/sodicity (Yadav and Gupta, 1984). The problem is being increasing gradually with the expansion of irrigation facilities, illdrained nature of black soil and faulty irrigation water use. According to one estimate, about 50 per cent of canal irrigated areas are degraded with salt problem to varying degrees due to lack of proper drainage system, inefficient use of irrigation water, and poor water quality. Next to the Indo-Gangetic alluvial plain, this problem is appearing at a fast rate in medium to deep black soils of central peninsular India. In Maharashtra, black soils (Vertisols and its intergrades) occupy an area of about 30

million ha of which 0.54 million ha is reported to be salt affected (Bhumbla, 1981; Abhange *et al.*, 1986).

Accumulation of salts in the soil solum limits the supply of essential nutrients and thereby inhibits the physiological functions of the plants to some extent (Sarin, 1961; Strogonov, 1964; Narayanan, 1966).

The influence of soil salinity/sodicity may act in three ways on plants:

- i) The physical effect of salts in increasing the osmotic pressure of the soil solution, thereby decreasing the availability of water to the plants (Hayward and Wadleigh, 1949 and Bernstein, 1961), which is known as physiological drought.
- ii) Toxic effect of various ions like Na^+ , Mg^{++} , HCO_3^- and CO_3^- (Kelley, 1951) on plant, termed as specific ion effect.
- iii) Unfavourable soil physical conditions especially in saline/sodic Vertisols due to high smectitic clay content.

Although initially, the salt problem is in soil itself, the same may be aggravated due to other factors like improper drainage, arid and semiarid climatic conditions, irrigation with poor quality water and high ground water table etc.

The Maharashtra state occupies a pride place amongst the cotton growing states of the country. It accounts for ^{the} largest area, of about 28.0 lakh ha and cotton production in Maharashtra in 1994-1995 was estimated to 26 lakh bales of lint (Anonymous, 1995). In Vidarbha, the area occupied by cotton is about 16 lakh ha (57 % of Maharashtra) having productivity of lint hardly $155 \frac{\text{kg}}{\text{ha}}^{-1}$ as against Indian and Israel

averages of 261 and 1900 Kg lint ha⁻¹, respectively (Anonymous, 1998); indicating wide scope to enhance cotton productivity per unit area and per unit time.

Cotton is the most important industrial crop playing a vital role in the history of mankind and civilization by providing basic fibre of typical nature for clothing. Today, cotton cultivation and textile industry have occupied vital position in the agricultural economy of the country. In India, it is one of the most important fibre crop and continues to be "King of Fibre". It is also one of the main cash crops in our country especially in Vidarbha region of Maharashtra and popularised as "White Gold". Cotton has been selected for the study, as it is one of the main fibre crop of the region, which was classified as salt tolerant by U.S. Soil Salinity Laboratory Staff (Richards, 1954).

The soils of Purna basin are the alluvial deposits which vary in depth and it may be upto 421 m; underlain by Deccan trap. The unique feature of vally soils is that out of 7500 km² area nearly 3000 km² is having brackish ground water. Recent studies indicated that the soils of Purna vally of Vidarbha region are neither saline nor sodic in upper layer as per the criteria laid down by U.S. Salinity Laboratory Staff (Richards, 1954) but have sever drainage problem even at low salinity/sodicity. However, some areas of the basin do have salinity/sodicity problem even at surface layer and it's intensity increased with the depth of soil. Poor drainability, and high intensity rain storms in area; water stagnation takes place in the *kharif* season, whearas in *rabi* season, deep and wide cracks

are developed in soil which intensify evapotranspiration and disturb the sustainability in the productivity of *Kharif* and *rabi* crops.

The intensification of salinity/sodicity parameters of these soils due to irrigation with well water even for few years was reported by Nimkar *et al.* (1992) and this problem was also experienced by valley farmers. Thus, the major problems by valley soils are poor drainage due to presence of high content of montmorillonite clay and native salinity/sodicity. However, installation of effective drainage system is practically and economically not feasible.

In Purna valley (Vidarbha region) Vertisols; development of salinity/sodicity is the natural and geological phenomenon, where the intensity of salinity/sodicity is comparatively less in surface layer and it enhanced with the depth of soils. However, in most of the Vertisols (other than Purna valley of Vidarbha region), the major cause of salt accumulation is excess and unscientific irrigation; where the intensity of salinity/sodicity is more in surface layer and it decreased with the depth of soils.

Reclamation technologies so far developed is for alluvial soils (well drained), and irrigated black soils, may not be useful as such for the improvement of saline/sodic Vertisols of Purna Valley in Vidarbha region. Moreover, almost all the work so far done is pertaining to genesis, characterization and classification of soils; however reclaimative/management part is lacking, which is the burning issue of these soils.

In view of this, the present research work pertaining to "Investigation on the effect of soil amendments and land treatments on soil characteristics and productivity of cotton grown in salt affected Vertisols" was initiated during 1994-95 and 95-96 with the following specific objectives:

- 1) To study the morphometric, physicochemical and hydrological characteristics of representative site of Purna valley.
- 2) To evaluate the effect of land treatments and gypsum levels on seed cotton yield and physicochemical and hydrological characteristics of soils,
- 3) To estimate the economics of land treatments and gypsum levels applied to hybrid cotton grown in this valley soils,
- 4) To determine the relationship amongst the various soil attributes and between soil attributes and yield of seed cotton and
- 5) To decide the yield variation factors of hybrid cotton grown in sodic Vertisols of Purna valley in Vidarbha region.

CHAPTER II

REVIEW OF LITERATURE

Salt affected soils are mainly confined to arid and semiarid areas in different agroecological zones of country as a consequence of hydro-geochemical conditions and land relief (Bhargava *et al.*, 1976). In India, an area of about 12 million ha is salt affected (Yadav and Gupta, 1984); out of which 1.42 million ha are medium deep and deep black soils (Bhumbla, 1981). In Maharashtra, black soils (Vertisols and its intergrades) occupy an area of about 30 million ha, of which 0.54 million ha are reported to be salt affected (Abhange *et al.*, 1986). In dryland situations, problem of salinity/sodicity in black soils is mainly due to lower topographical situations of various river valleys and illdrained nature of black soils. Salt affected soils present diverse problems and differ greatly from normal soils in respect of morphological features, physical, chemical and biological characteristics. They show wide variations from place to place and distinguished into certain categories, the important ones being the saline and sodic soils. Available literature on characterization and improvement/reclamative measures of salt affected Vertisols have been reviewed in this chapter under the following heads.

- 2.1 Genesis and characterization of salt affected Vertisols.
- 2.2 Effect of amendments on productivity of crops
- 2.3 Effect of amendments on physico-chemical characteristics of salt affected Vertisols

2.4 Effect of land configurations on productivity of crops

2.5 Effect of land configurations on physico-chemical characteristics of Vertisols.

2.1 Genesis and Characterization of Salt Affected Vertisols

The causes of salt accumulation in Vertisols are aridity of the climate, topographic situation leading to the deposition of salts by runoff water in low lying areas affecting the A-horizon, high water table with saline nature and impervious subsoil conditions leading to imperfect drainage and salt bearing sub-strata (Basu, 1950). According to Abrol and Fireman (1977), the possible causes of salt accumulation are high salt deposits inherited by the soil from the original parent material during soil forming processes, salt content in the irrigation water applied or water lost in conveyance through irrigation distribution system, more salts in seepage water from higher elevation coming through upward movement (capillary action from shallow ground water table), aridity of climate, poor drainage and coasted soils adjacent to sea water.

Dubey *et al.* (1983) noticed that flat to basin type topography, restricted drainage, high temperature and low permeability of deposited material enhance process of salinization and sodification. Development of salinity/sodicity may be resulted in change of morphology, clay translocation, increase in lime and exchangeable Na content of soil. Unscientific irrigations, topographical situations, aridity of climate, ground water rise, continue seepage, poor drainability and chocking of natural drains are some of the causes of formation of salt affected Vertisols in

command areas of Maharashtra. (Varade *et al.* 1985). Apart from genetic factors some secondary factors viz. high clay content, poor hydraulic conductivity, illdrained nature of soil are found responsible for development of saline/sodic soil (Dubey and Sharma, 1987; Sharma *et al.* 1987).

Yadav and Girdhar (1981) reported that the degree of dispersion increases and hydraulic conductivity decreases with an increase in the Mg:Ca ratio in the leaching water at a given SAR, in both calcareous and noncalcareous soils. However, the effect of increasing Mg:Ca ratios on the said properties was found to be more pronounced at higher than at lower SAR values. Further, Tiwari *et al.* (1983) inferred that nature and causes of alkalinity vary from place to place. Accumulation of salts through runoff water from the adjoining area, impeded drainage due to poor hydraulic conductivity, very high sodium content, fluctuating water table caused by canals flowing near the fields and consequently capillary rise of water resulting in accumulation of alkali salts on the surface during summer are some of the contributory factors to the development of salt affected Vertisols.

Presence of cracks at the initiation of wet season (Virmani *et al.*, 1982), Vertisols have high infiltration rates which decrease drastically with increasing wetting of soil. Poor drainability is an inherent physical constraint for crop production of these soils during rainy season. High pH of Vertisols and its intergrades is mainly associated with

presence of CaCO_3 and high contents of bases, especially calcium and magnesium.

Challa (1995) observed that microknolls of alkaline phase are larger and the interval between the knolls is more than that of the knolls of normal phase, depressions or slick spots of alkaline phase are also bigger than the microbasins of normal phase. Mechanical separates of the soils of alkaline phase have relatively higher amount of fine clay as compared to the normal soils. Exchangeable Na^+ , $\text{Ca}^{2+} + \text{Mg}^{2+}$ cations on the exchange complex might be responsible for the bigger microknolls and micro basins in alkaline phase of the soils as compared to the soils of normal phase. Balpande *et al.* (1997) pointed out that weak plasma separation in soils of south-west part of Purna valley of Vidarbha region as compared to north-east part is related to decrease in swelling of fine smectite in pedons. Further, they stated that lack of adequate soil water during wetting cycles due to sodicity in subsoils is thought to be the most likely reason for weak swelling of smectite and also for deepening of cracks. Malewar and More (1988) pointed out that there was no remarkable variation in clay mineral assemblage in normal and salt affected Vertisols of Maharashtra. Either montmorillonite or chlorite is dominant clay mineral detected in these soils. They, further, noticed that pH, E_{Ce}, bulk density, porosity, hydraulic conductivity and drainability of Vertisols are greatly affected due to salt-accumulation.

Bharambe and Ghonshikar (1985) noticed that Vertisols of Jayakwadi command area (Maharashtra) are moderately deep to very

deep with normal pH and EC, clayey in texture having slow to moderate drainability. While characterizing the salt affecting soils of Purna command area of Marathwada (Maharashtra), More *et al.* (1988) reported that pH, E_c and CEC of these soils ranged between 8 to 10.7, 0.8 to 19 dSm⁻¹ and 8 to 45 Cmol (p+) kg⁻¹ ^{respectively.} They, further reported that calcium is dominant cation in the saline soils, whereas sodium is dominant in sodic Vertisols. Soluble cations, CEC and E_c are higher in surface layer which decreased with depth. Chlorides and sulphates are dominant in saturation extract of saline and saline-sodic profiles, whereas, bicarbonates are relatively higher in the saturation extract of sodic profiles. In Purna command of Marathwada (Maharashtra) (More *et al.*, 1987), about 65% of the soils (Black soil region) were affected due to salinity/sodicity. Respective percentages of saline, saline-sodic, sodic and normal soils in this command area have been reported as 22.92, 14.58, 33.33 and 29.17. Chlorides and sulphates are dominant in saturation extract of saline soils, whereas, in sodic soils, bicarbonate content is relatively higher as compared to carbonate.

Alkali black clay soils are deep, clay loam to clay, calcareous and low in organic carbon content (Dubey *et al.*, 1983 and Sharma *et al.*, 1987). The structure on the surface is weak, fine, subangular to angular blocky. These soils swell on wetting and crack on drying due to predominance of smectite (Dubey, *et al.*, 1981). Alkali levels beyond ESP 10, leads to severe structural degradation due to high degree of clay dispersion. With increasing ESP, the rate of penetration of

drying front declines and moisture changes in lower layers are much slower (Gupta and Verma, 1983). Thus, higher amount of water in lower layers do not allow and therefore deeper cracks develop in alkali Vertisols. These physico-chemical characteristics of sodic Vertisols render salt leaching rather difficult (Verma *et al.*, 1989), unless these are suitably amended to improve the physical conditions.

While studying the salt affected Vertisols of Purna valley of Vidarbha region (Maharashtra), Nimkar (1990), Sagare *et al.* (1991), Magar (1990), Kadu (1991) and Balpande (1993) indicated that Vertisols of Purna valley are deep (> 150 cm), dark to very dark grayish brown in colour, having slickensides in subsoils and developed on alluvium of basaltic origin. These soils are strongly to very strongly alkaline (pH 8 to 9), calcareous (5 to 17 per cent CaCO_3) ECe value ranged from 0.5 to 6.00 dSm^{-1} , fine textured with clay, silt and sand ranging from 50 to 70, 20 to 40 and 1 to 12 per cent, respectively. Clay, CaCO_3 and ECe values are found to be increased with depth and exhibit intersecting slickensides forming parallelepiped tilting at an angle between 35° to 45° and taxonomically classified as Aridic Haplusterts, Sodic Haplusterts and Sodic Calcicusterts (Padole and Ravankar, 1996). Bulk density (BD), saturated hydraulic conductivity (HC) and available water capacity (AWC) varied from 1.60 to 2.06 Mg m^{-3} , 0.2 to 7 mm hr^{-1} and 7.0 to 27.0 per cent, respectively. BD and AWC increased, whereas HC decreased with the depth of pedons; cole values ranged from 0.09 to 0.28 cm cm^{-1} . Low HC is mainly related to higher clay content and that is 2:1 type and high

ESP and low organic carbon content of these soils. Organic carbon content of these soils ranged between 0.10 to 0.44%, (low in organic carbon content), whereas, CEC 43 to 81 cmol (P⁺) kg⁻¹. Exchangeable cations present in these soils are in the order of Ca>Mg>Na>K in most of the pedons, with Ca:Mg ratio from 0.4 to 3.5. Respective values of ESP, EMP and SAR varied from 0.6 to 26.2 and 18.6 to 60.1 and 0.5 to 28.0, with increasing trend alongwith depth of soil solum. In the saturation extract, the SSP varied from 18.9 to 90.5 per cent. In general, soils of Purna basin are neither saline nor sodic in the surface horizon (0 to 40 cm), however, in subsoil horizon mild salinity and sodicity have been reported by most of the workers.

As regards ground water, Tanpure *et al.* (1977) pointed out that only 11.4% well water samples were free from all hazards and majority of well water samples are not suitable for irrigation in these problematic soils. Sagare (199f) and Nimkar *et al.* (1992) also noticed that continuous use of such well water hastens sodification process in these soils. Among anions, chlorides, whereas among cations sodium ions are dominant in well water and as per USDA classification the well water could be classified under C₄S₂, C₄S₃ and C₄S₄ classes; indicating higher salinity and sodicity hazard, when used for irrigation purpose. Balpande (1993) pointed out that ground water of Purna valley tract of Vidarbha region have high to very high salinity and low to medium sodicity hazard. Residual sodium carbonate of these waters was high indicating unsuitability of water for irrigation in these soils.

Abhange (1986) proposed the criteria for categorization of salt affected Vertisols of Maharashtra based on electrical conductivity (1:2 soil-water suspension) as EC 0-1, 1-3 and >3 for non-saline, slightly saline and highly saline soils, respectively. Saturation extract is an equipotential soil moisture content for various soils, the electrical conductance of the saturation extract linearly relates to the osmotic pressure as well as concentration of salts in the solution, it's EC has been interpreted directly in terms of plant growth. The dividing line between the saline and non-saline soils was established at 4 dSm^{-1} for water extracts from saturated soil paste (USDA, 1960). Salt sensitive plants, however, can be adversely affected in soils having $\text{ECe } 2 \text{ to } 4 \text{ dSm}^{-1}$ (Basu, 1950).

An exchangeable sodium percentage (ESP) of 15 has been used at the United States Soil Salinity Laboratory as boundary limit between non-sodic and sodic soils. However, Balpande *et al.* (1996) suggested that ESP 5 should be used as the lower limit for sodic subgroups of Vertisols, rather than ESP 15 as given in keys to Soil Taxonomy (USDA, 1994). This is because of severe limitations to the use of such soils owing to the development of adverse physical conditions in terms of very poor drainage even at such a low ESP. On the other hand Vertisols of western India with an ESP around 15 have very poor physical condition causing extreme difficulty in tillage operations (Bhattacharya *et al.*, 1994). Current lower limit of 15 ESP of USSS for all soils is arbitrary and tentative and thus, it would be prudent to evaluate the lower limit of

ESP in view of loss of productivity in different groups of soils (Balpande *et al.*, 1997).

2.2 Effect of Amendments on Productivity and Content of Crops

Crop yield is governed by a number of factors among which photosynthetic efficiency and rate of translocation of photosynthates are of prime importance. Under saline conditions, the rate of photosynthesis and translocation and further utilization of photosynthates are dependent on the salt tolerance capacity of the plant which is reported to vary with the plant genotype as well as the type of salt (Rathert *et al.*, 1982; Strogonov, 1973).

When gypsum and pyrite were applied on equivalent basis, either pyrite was observed to be inferior or at par with gypsum in increasing the grain yields (Pathak *et al.*, 1978; Tiwari and Sharma, 1989), whereas gypsum proved to be superior to pyrite on alkali black soils. Pyrite had 92 % effectiveness as compared with gypsum (Sharma and Gupta, 1986) and the gypsum induced higher dissolution of native CaCO_3 . It is further reported that application of gypsum @ 50 % GR gave optimal returns (Tiwari and Sharma, 1989) and proved better than applied in two splits (25 % in first year + 25 % in second year) in alkali loam soil (pH 9.9 - 10.3, ESP 73). However, sole application of gypsum @ 75 % GR in the first year to an alkali black clay soil produced maximum cumulative yields of rice and wheat over a period of three years and this was followed by the treatment where gypsum was applied @ 50 % GR in first year + 25

% GR in second year. Gupta *et al.* (1988) observed that gypsum use efficiency was maximum during first year when gypsum was applied @ 25 % GR, whereas its application @ 50 and 75 % GR had maximum efficiency after third and fourth cropping season.

Shivakant and Rajkumar (1992) noticed that onward gypsum application @ 40,60,80 and 100% GR enhanced grain yield of rice, grown on salt affected soils significantly over control followed by pyrite, pressmud and FYM. Further, they observed a sharp decline in rice yield at pH 9.22 and ESP 75.86. Germination percentage, growth and crop yield and nutrient uptake by wheat were significantly enhanced with increasing levels of nitrogen (through urea) alongwith gypsum (Prakas and Verma, 1994). Increase in ESP has strongly detrimental effect on plant growth and finally on biological yield of crops. Yield reduction to the extent of 25 and 41 per cent was recorded at ESP 23.5 and 44.4, respectively and at ESP 60 seedlings failed to grow. Application of gypsum helped the plants to grow at all ESP levels (Arora and Nayyar, 1983). Although salt affected soils are potentially productive, without suitable technologies for their reclamation with organic and inorganic amendments, these soils can not be put under cultivation (Rajkumar *et al.*, 1991).

Swarup (1991) recorded a significant response on rice to zinc plus gypsum, green manure and FYM plus gypsum. This indicated that zinc requirement of the rice which invariably suffers from Zn deficiency in sodic soils could be met through organic sources like green manure and FYM, which contained about 20 and 24 ppm of Zn on dry

weight basis, respectively. Khandelwal and Lal (1991) while studying the different qualities of irrigation water applied to various soils; observed that grain and straw yields of rice decreased with an increase in EC and SAR of irrigation water, however effect was less on permeable light textured soils. Increase in grain and straw yields was observed with low boron content in irrigation water; but a decrease at higher level was recorded. Effect of application of gypsum, pressmud, and pyrites on leachate composition, soil properties and yield of rice under percolated and unpercolated conditions was studied by Patel and Singh (1991) and noticed that increasing levels of amendments increased significantly the yield of rice and wheat and maximum yield of rice was recorded with pressmud, followed by gypsum, and pyrites. Data further, indicated that pyrite was found to be as effective as one third of gypsum quantity when applied on total S content basis. Percolation did not affect yield of rice but significantly increased wheat yield. Potculture studies (Singh *et al.*, 1990) indicated that gypsum was more effective in reducing the pH, conductivity and sodium content of the soil as compared to pyrite.

A pot culture study, conducted by Mohite and Shingte (1981) to evolve a suitable techniques for reclamation of a sodic soil by using high salt water dilution method in conjunction with usual amendments (FYM and gypsum), recorded the highest dry matter production of maize in sodic soil reclaimed in this manner; besides higher reclamation efficiency. While studying the effect of three levels of gypsum (5, 10 and 20 t ha⁻¹ equivalent to 25, 50 and 100% of GR), Chauhan and

Tripathi (1983) observed that application of gypsum @ 20 t ha⁻¹ gave maximum and significantly higher yield of barley and paddy over control and gypsum @ 5 and 10 t ha⁻¹.

Maximum values of pH, ECe and ESP recorded for salt affected Vertisols were 9.3, 106 dSm⁻¹ and 90 per cent respectively, (Varade *et al.*, 1985). Further, they pointed out that reclamation of these problematic Vertisols can be done by an integrated approach of chemical, biological and hydro-techniques. Application of gypsum @1/6th of GR was sufficient to get satisfactory crop yields. Pyrite application to saline-sodic and sodic Vertisols was also found beneficial. However, combination of chemical amendments alongwith FYM was found more effective than their individual application. Among the various green manures, dhaincha is good green manuring crop to improve salt affected Vertisols.

Rajkumar *et al.* (1991) conducted the field experiment at Faizabad on soil having pH 9.56, ECe 4.58 dSm⁻¹ and GR 16.13 t ha⁻¹ with various amendments viz. gypsum, pyrite (@ 40, 60, 80 and 100% GR) PMC and FYM (10, 20, 30 t ha⁻¹) and reported that amendments significantly increased the grain and straw yields of rice over control. Gypsum at 100% GR gave significantly higher grain and straw yield than other treatments. Effect of amendments on yield of rice might be mainly due to reduction in soil sodicity. This agrees with the finding of Shukla and Pandey (1987), who also obtained higher yield with gypsum and pyrite application. However, gypsum was found superior to pyrite.

Sodicity deteriorates the physical conditions of the soil. As a result, the plants are unable to utilize the soil moisture which affects their growth adversely. Gypsum application was found most effective for reclamation of such soils.

In a pot culture experiment conducted by Swamy *et al.* (1991) on sandy loam soil having pH 7.4, ECe 0.95 dSm⁻¹ and low organic carbon content (0.27 %), with three levels of residual Na₂CO₃ in irrigation water (2.5, 5 and 10 meq litre⁻¹) and three gypsum treatments viz. control, water passed through gypsum bag and gypsum mixed with soil @ 3 t ha⁻¹. A maximum and significant increase in grain yield of green gram was recorded due to soil application of gypsum @ 3 t ha⁻¹ and then applied irrigation water was found better than water passed through gypsum bag. Talati (1960) also found that soil application of gypsum was more effective than gypsum treatment of water. Data further, indicated a significant decrease in yield of green gram, when residual Na₂CO₃ of irrigation water applied was equivalent to 10 meq litre⁻¹. However, decrease in yield was not significant when the residual Na₂CO₃ of water was equivalent to 5.0 meq litre⁻¹. Application of sodic water to soil mixed with gypsum resulted in higher N content in grain and straw as compared to control. Higher organic carbon content of the soil in these treatments might have helped in greater availability of N to the plants, resulting in higher yield. Effect of amendments on the P and K content in general was at par, indicating that amendments did not increase their content in the plant significantly. Increased levels of residual sodium carbonate depressed the N and P

percentage in seed and straw significantly. Paliwal (1972) pointed out that the ionic imbalance and physiological disorder play vital role in the nutrition of plants, when irrigated with poor quality waters. In a field trial (highly sodic soil having pH 10.5 and ESP 96) conducted on wheat and rice (Dubey and Mondal, 1994) at CSSRI, Karnal with treatments of gypsum (@ 12.5 t ha⁻¹ equivalent to 50% GR), pyrite (@ 10.2 t ha⁻¹ equivalent to gypsum on sulphur basis), FYM (30 t ha⁻¹), gypsum + FYM and pyrite + FYM and control (no amendment); followed by nonsaline (EC_w 0.4 dS m⁻¹) and saline (EC_w 4 dS m⁻¹) irrigation water. application of amendments enhanced the yield of both crops significantly, irrespective of the quality of the irrigation water used. Soil properties and crop yields were improved in the following order: control < FYM < pyrite < gypsum < pyrite + FYM < gypsum + FYM. Irrigation with saline water resulted in significantly higher yields of both crops than irrigation with nonsaline water. Increase in the yield of wheat due to the application of amendments was less than that for rice, which could be due to its low tolerance to exchangeable sodium. Similar results were also reported by several workers (Yadav and Agrawal, 1961; Swarup, 1985; Dubey *et al.*, 1987). Salt treatments exerted a negative influence on the translocation of photosynthetic assimilates and NaCl was more detrimental than that of Na₂SO₄. Transport of radioactivity from the source to pod and other plant parts such as leaves, stem and roots was adversely affected by both salinity regimes (Bhivare and Chavan, 1987).

More *et al.* (1994) observed that the equimolar mixture of NaCl and Na₂SO₄ decreased the reducing and non reducing sugars, chlorophyll and potassium content, but increased the proline content of sugarcane. The increase in accumulation of proline in leaves and retention of chlorophyll content, the cultivar, CO-419 appeared to be more salt tolerant than the other cultivars of sugarcane. CEC, ECe and CaCO₃ content of soil after crop harvest were influenced by different soil amendments and application of urea @ 90 kg N ha⁻¹ alongwith gypsum @ 50% GR was found to be more effective. Application of gypsum to sodic soil (pH 10.2, ESP 86) markedly decreased pH and ESP of the soil and increased significantly the yield and Zn, Fe and Mn concentration of the rice (Swarup, 1991).

Kumar *et al.* (1997) pointed out that relative yield of sunflower (taking it as 100 % in the case of good quality water used throughout) was 97, 80, 69 and 57%, when waters of 3, 6, 9 and 12 dSm⁻¹ were used throughout. However, even with waters of higher salinity, the yield remained more than 90% provided the presowing irrigation was applied with good quality water; indicating that sunflower is more sensitive to salinity at germination and early seedling stage. Sorghum and mungbean were also found to be comparatively more tolerant at later stages as compared to the seedling and early establishment stage (Minhas *et al.*, 1989a & b). Electrical conductivity of soil was higher when waters of increasing salinity were used throughout, as compared to the treatments, where in the presowing irrigation was applied with good

quality water. Thus, presowing irrigation with good quality water can help in the utilization of water of much higher salinity subsequently, which otherwise when used alone may cause a substantial lowering of the yield.

A study conducted by Girdhar (1988) to evaluate the effect of saline irrigation water on the performance of rice grown in a saline soil indicated that salinity delayed the germination and did not affect the final germination upto EC of 8 dSm^{-1} . However, at higher salinity level ($> 8 \text{ dSm}^{-1}$), the germination was significantly reduced as compared to control. Normal straw yield but significantly lesser grain yield of rice was recorded with irrigation water of $\text{ECe } 8.3 \text{ dSm}^{-1}$ and delayed maturity by about one week. Reduction in effective number of tillers and plant height, due to different salinity levels were nonsignificant. But the average grain weight per panicle and 1000 grain weight were significantly reduced as the soil salinity increased from 3.6 to 8.3 dSm^{-1} . Sodium accumulation in rice plant increased and K/Na ratio decreased with increasing soil salinity. Na content^{was} found higher at maturity than at tillering or flowering stage but percent increase in the Na content was significantly higher at flowering than at tillering or at maturity stage. Data, further indicated that salinity increased the N content of the rice plant but the content of P in different plant parts was not affected by salinity. Sharma *et al.* (1997) indicated that 65% of crop yield variation was due to soil salinity and the number of irrigations. The remaining unexplained variation is due to other factors. The information on extent of salinity problem and expected yield increase in very useful for optimizing the reclamation cost.

Sagare *et al.* (1996) conducted field trials on saline-sodic soils of Purna valley during 1993-94 to 95-96 to evaluate the effect of gypsum and reported that broadcasting of gypsum @ 50% GR enhanced seed cotton and grain yield of green gram and sorghum to the extent of 20 to 40% over no gypsum. Drastic reduction in chlorophyll content of rice at salinity level of 8.00 dSm^{-1} , irrespective of cultivar was recorded by Patil *et al.*, 1996). In a field trial conducted by Kalane *et al.* (1996) on deep Vertisols, with FYM 10 t ha^{-1} , safflower stalk 5 t ha^{-1} , gypsum 5 t ha^{-1} and sand 20 t ha^{-1} and observed a maximum increase in grain yield of soybean due to gypsum application.

High residual sodium carbonate in irrigation water significantly decreased the herb yield and oil production of lemon grass and increased pH and ECe of the sandy loam soil. However, increase in ECe was observed only in surface layer (Singh and Singh, 1997). Thus, increasing levels of residual sodium carbonate in irrigation water adversely affected the herb and oil production of lemon grass in sandy loam soil. Use of irrigation water of the varying residual sodium carbonate also increased the soil ECe and pH.

Studies conducted (More *et al.*, 1987) in Purna command area of Marathwada (Maharashtra) revealed that application of gypsum @ 50% GR and FYM @ 25 t ha^{-1} enhanced paddy and wheat yield grown on sodic Vertisols. These amendments also improved the physicochemical characteristics of soil. Data, further indicated that when gypsum was

applied alongwith FYM and farm residues, the dose of gypsum can be reduced to some extent.

2.3 Effect of Amendments on Physicochemical Characteristics of Salt Affected Vertisols

The replacement of exchangeable Na in sodic Vertisols with Ca requires the application of amendments which can either supply soluble calcium ions directly or induce its solubility from the soil constituents. Acid and acid farming materials have been evaluated in alkali black clay soil (Verma and Gupta, 1985; Sharma and Gupta, 1986). The results indicated that for reducing soil ESP, different amendments followed the order as $Al_2(SO_4)_3 > H_2SO_4 > \text{gypsum} > \text{pyrites}$. The dissolution of native $CaCO_3$ was much higher with acid and acidulants. The native $CaCO_3$ dissolved with gypsum applied @ 100 % GR was about 0.28 per cent. When all the amendments applied on equivalent basis, these had variable effect on physical properties. Gypsum followed by aluminium sulphate was more effective in increasing saturated and decreasing clay dispersion than other amendments (Verma and Gupta, 1985). The overall results obviously favoured the use of acids and acidulants in terms of effectiveness to reduce ESP, but the handling hazards and exorbitant prices restrict the practical use of these amendments. Pathak *et al.* (1981) further observed that application of amendments @ 60 % GR proved better than smaller doses in reducing boron toxicity.

Sodium leaching efficiencies (Moles of Na removed per unit leachate volume) were measured and compared (Robbin, 1986) from four non-cropped and four cropped treatments applied to 1.0 m deep sodic calcareous silt loam in lysimeters. Treatments were check, gypsum, chopped alfalfa (*Medicago sativa* L.), fresh manure, alfalfa, sorghum (sorghum bicolor), sudan grass (sorghum sudanese) hybrid. If Na-removal efficiency is defined as moles of Na removed per unit volume of leachate, then Na removal efficiency is shown as the slope of the curves at any given point. The check was the least efficient, whereas, the gypsum was most efficient treatment in terms of Na removal for noncropped treatments, chopped alfalfa was slightly less efficient than gypsum and manure was between the check and chopped alfalfa in both the cropped and noncropped treatments. He further, stated that three different reaction mechanisms could be acting individually or in combination to produce increased soil atmosphere CO₂ concentrations and increased Na-reclamation efficiency. In the first mechanism, respirating crop roots and decomposit organic matter could produce CO₂, which dissolves in water to produce carbonic acid. This acid would increase the solubility of calcium carbonate minerals by lowering the pH and dissolving the lime minerals and forming a host of complex calcium ion pairs, thus increasing Ca concentration in soil solution (Nakayama, 1970, Robbins, 1985). A second mechanism could act as a source of CO₂ in soil solution by producing CO₂ from the oxidation of plant root exudates (Vancura and Hanzlikova, 1972). Soil organisms oxidizing these polysaccharides,

proteins, and peptides could produce CO_2 as a byproduct and likewise, carbonic acid would be produced to dissolve soil lime minerals. By means of a third mechanism, soil organisms could produce organic acids (Chandrasekaram, 1969) which in turn would dissolve calcareous soil minerals, releasing CO_2 as the CaCO_3 dissolves, and Ca salts of the organic acids would be produced.

A field experiment conducted (Tiwari *et al.*, 1993) on salt affected Vertisols with thirteen varieties of cotton and four levels of gypsum (0, 11, 22 and 33 t ha⁻¹) and reported a linear decrease in pHs, ECe and ESP due to gypsum application. The results confirm the findings of Gupta *et al.* (1988). Gypsum applied @ 11, 22 and 33 t ha⁻¹ decreased ESP by about 45, 32 and 24 meq 100g⁻¹ soil, respectively. Leaf water potential was higher (negative) at first boll bursting stage than at square formation indicating that the crop faced greater stress of moisture at first boll-bursting stage; perhaps owing to higher evaporative demand of the crop. In a pot culture experiment (Singh and Sinha, 1987), it was noticed that gypsum application increased the leaf water potential at both the stages of crop growth. Acharya and Abrol (1978) showed that gypsum application greatly increased the water retention at a given tension as compared to control. Data, further indicated that dry matter and seed cotton yield were increased significantly with increasing gypsum levels and this may be attributed to favourable soil water conditions due to reduction in ESP. Thus, application of gypsum in alkali soil favours growth and yield of cotton significantly.

Dubey and Mondal (1994) while conducting the experiment on rice and wheat in highly sodic soils (pH 10.5 and ESP 96) of Karnal, observed a decrease in soil pH, ESP and increase in Exch. Ca + Mg and infiltration rate. They further, reported that gypsum + FYM reduced the soil pH substantially after the rice harvest as compared to other amendments with nonsaline water but with saline water, the effect of gypsum + FYM and pyrite + FYM in reducing the pH was similar. After harvest of both crops, EC was higher with the use of saline than with nonsaline water. Gypsum + FYM always gave the highest EC after rice irrespective of the quality of the water. After wheat, the gypsum treatment gave the maximum soil EC. There was an increase in EC after wheat as a result of an upward movement of salts under high evaporative demand during the wheat season. Decrease in ESP due to amendments was in the order of gypsum + FYM > gypsum > pyrite + FYM > pyrite > FYM > control. Application of saline water alongwith amendments significantly decreased ESP and increased exchangeable Ca + Mg of surface soil (0-15 cm) after the harvest of the rice and wheat crops especially gypsum + FYM treatment in both the saline and nonsaline water treatments. Data, further indicated that gypsum is more effective in ameliorating the sodic soil than pyrite. Infiltration rate was improved with the use of amendments as compared to control in both saline and nonsaline water. The initial infiltration rate recorded was very low (0.15 mm ha^{-1}) and maximum infiltration rate measured was 2.3 mm hr^{-1} due to treatment of gypsum + FYM in respect of saline water. Similar observations were also noticed by

Oster (1982) and Sharma (1986). Application of saline water increased the infiltration rate more than nonsaline water. Reeve and Bower (1960), Mohite and Shingte (1981) and Misopolinos (1985) also reported similar results.

Dahiya *et al.* (1980) showed that precipitation of soluble carbonates in the soil increased with increasing flow velocity, initial soil moisture content and concentration of calcium in the leaching solution. The results further showed that the calcium exchange capacity of the soil was reduced significantly and nearly proportionally with decrease in the degree of water saturation as a consequence of decreased water application rate and initial soil moisture content. In the leachate collected from amended soils, sodium, potassium, calcium, carbonate, bicarbonate and sulphate increased with the increasing levels of applied gypsum and pyrite (Singh *et al.*, 1980). Effect of leaching of artificially prepared sodic soils, rich in chloride and the other in bicarbonate ions with gypsum solution was evaluated in the laboratory by Singh *et al.* (1980). Soils were packed in acrylic columns and leached with gypsum solutions of three different concentrations, keeping the total amount of gypsum same in all the treatments. A greater decline in ESP and pH was observed with decrease in Ca concentrations in leaching solution. Leaching with 20 cm solution of 30 me L⁻¹ Ca concentration followed by 40 cm distilled water proved better than any other treatment in bicarbonate treated soil but in chloride treated one its effect was equivalent to leaching with 20 cm solution of 30 me L⁻¹ concentration. Decrease in EC was a function of total

amount of solution water passing through the columns in both the soils. In a pot culture experiment Mohite and Shingte (1981), evolved a suitable technique for reclamation of a sodic soil by using high-salt water dilution method in conjunction with usual amendments (FYM and gypsum). Removal of sodium was more with the treatment of FYM + gypsum and leaching with high salt water, as sufficient amount of Ca^{2+} was released (from gypsum) to replace Na^+ from the soil complex. A significant positive relationship of gypsum requirement with $\text{CO}_3 + \text{HCO}_3$, pH, exchangeable Na and CEC of soil was reported by Masih and Chauhan (1983). They further, observed a significant positive correlation for exchangeable Na with pH and $\text{CO}_3 + \text{HCO}_3$, pH with $\text{CO}_3 + \text{HCO}_3$ and SP with CEC.

Chauhan and Tripathi (1983) observed that gypsum application (25, 50, 100% GR) followed by leaching markedly reduced the soluble salt content, ESP, pH and water soluble boron and increased the HC of sodic soil. Increase in the dose of gypsum (5 to 20 t ha⁻¹) brought about progressive improvement in HC and decreased in ESP, pH and boron content of soil. Bhatti and Bakhsh (1995) showed that electrolytic conductivity and gypsum requirement had a very high correlation, indicating GR was found as best criterion for dividing the sodic soil in to different management zones.

A pot culture studies on four types of soils i.e. loamy sand, sandy loam, sandy clay loam and clay loam with different qualities of irrigation water was conducted by Khandelwal and Lal (1991). ECe of soil

was found to be increased with increasing EC of irrigation water, whereas, ESP and pH of the soils with increasing SAR of irrigation water. Boron content of soil increased with an increase in EC, SAR and B content of irrigation water but decreased with an increase in clay percentage of the soil. Patel and Singh (1991) studied the effect of various amendments on leachate composition under percolated and unpercolated conditions in pot culture using rice-wheat in sequence and reported that gypsum was found more effective in removing Na and Ca + Mg, whereas the cumulative removal of $\text{CO}_3 + \text{HCO}_3$ was higher with pressmud treatments than that of gypsum and pyrites under percolated conditions. Gypsum was more effective in reducing the pH, ESP and increasing exchangeable Ca and Mg in the soil than the pressmud and pyrites. Results further, indicated that soil properties were improved more under percolated than unpercolated conditions.

A potculture study on loam soil (pH 10.3, ECe 18.8 dSm^{-1} , ESP 83, SAR 148, RSC 148 mmol L^{-1}) with various levels of gypsum (0,25,50,75 and 100% GR) was conducted by Shrivastava and Shrivastava (1994). The gypsum was uniformly mixed in soil and waterlogged for 4 weeks with 5L water (having EC 150 micro-mho's cm^{-1} , SAR 1.2 and RSC 0.9 meq L^{-1}) on the basis of maximum water holding capacity of soil as 0.4 kg^{-1} . In linear correlation analyses, the GR values of soil leached with gypsum was more significantly correlated with pH, ESP, SAR and RSC than GR values of soils without leaching, indicating that better correlation coefficients are obtained by removing the soluble salts.

The results of multiple correlation and regression analyses showed that GR values of unleached soils are governed by both soluble and exchangeable phase sodicity indices, whereas GR values as obtained from leached soils are governed by soluble phase indices only.

Laboratory column study was conducted by Swarup *et al.* (1994) to evaluate the effect of gypsum (@ 0, 20, 50 and 100% GR) on the behaviour of native phosphate during reclamation of a highly sodic soil (pH 10.4, ESP 83.5). The soil was leached with good quality water (EC 0.3 dSm⁻¹) under a constant water head for ten weeks and phosphate concentration in the leachate was measured at weekly intervals. Results showed that increasing levels of gypsum drastically reduced the P losses and at the 6th week of the experiment, no phosphorus was detected in the leachates. Increasing rate of gypsum decreased the water soluble P(H₂O-P) substantially but it had little influence on the more strongly adsorbed P fraction (NaOH-P) or Ca-bound P(HCl-P). The main effect of gypsum was to transform the adsorbed P fraction to (NaHCO₃-P), more labile form.

Shivakant and Rajkumar (1992) pointed out that gypsum improved the soil properties more than pyrite, followed by pressmud and FYM at all the levels. Application of gypsum not only directly supplied soluble calcium, but also resulted in greater solubilization of the soil calcium carbonate, as shown by a greater build up of divalent cations but reduction of monovalent once. The effect of pyrite on soil improvement was nearly at par with that of gypsum. Application of pressmud and FYM slightly improved the soil properties.

Gill and Sinha (1981) reported that exchangeable and DTPA extractable forms of Mn increased with increasing periods of submergence of sodic soil at all levels of gypsum application. The aqueous pH of the soil suspension and fluctuations of partial pressure of CO₂ and redox-reactions exert a profound influence on solubility of Mn in soils. Increase in ESP caused increase in N, P and Na contents while K, Ca, Mg decreased. The plants in sodic soil suffer from the lack of Ca and physiological unavailability of P, which can be corrected by monocalcium-phosphate upto 45 ESP, beyond which the addition of gypsum is indispensable (Arora and Nayyar, 1983).

Swarup (1986), studied the effect of gypsum, pyrites, FYM and rice husk on the availability of native P and applied Zn and their uptake by rice on a highly sodic soil (pH 10.6, ESP 94) under submerged conditions. Application of Zn @ 9 kg ha⁻¹, increased DTPA extractable Zn status of the soil, when added with gypsum, FYM, pyrites and rice husk. Olsen's extractable P decreased with application of amendments and submergence in the following order with crop growth gypsum > pyrites > rice husk > FYM > control. He has further, reported that FYM with 30 days submergence prior to planting of rice proved effective in enhancing the absorption of P and Zn by the crop.

Unique feature of Purna basin of Vidarbha region is that salinity/sodicity of these soils increased with increasing soil depth and addition of gypsum @ 50% GR to cotton, sorghum and green gram reduced the pH of soil from 9.1 to 7.9, ECe from 4.58 to 3.17 dSm⁻¹ and

SAR from 18.07 to 7.59 (Sagare *et al.*, 1996). Raut *et al.* (1996) studied the performance of vermicompost alongwith agricultural wastes like sugarcane trash and sunflower straw in pot culture and maximum improvement in sodic Vertisols in terms of reducing ESP, soil pH and bicarbonate of sodic Vertisols due to vermicompost (20 t ha^{-1}) followed by 50% gypsum + 10 t ha^{-1} vermicompost. This has further facilitated to increase the availability of nutrients.

A laboratory experiment was conducted by Narkhede and Surve (1996) to assess the efficiency of different methods of gypsum application in advancement of wetting front and reducing time required for wetting sodic soil. Columns of sodic soils were prepared and three methods of gypsum application was tried viz. gypsum mixing with soil @ 1%, saturated solution of gypsum and gypsum layer of 3 mm thickness on soil surface and reported that saturated solution and layer methods of gypsum application were found more effective in enhancing the initial rate of advancement of wetting front, increasing depth of wetting and ultimately reducing time required for wetting the soil columns than that gypsum mixing with soil columns. Oxygen diffusion rate (ODR) in gypsum (5 t ha^{-1}) treated Vertisols at 1.0 cm depth was found highest and it was at par with FYM (10 t ha^{-1}) incorporation treatment which reflected higher yield. ODR values was found lowest under control than other treatments and it was decreased with increasing depth (Kalane *et al.*, 1996).

2.4 Effect of Land Configurations on Productivity of Crops

The Vertisols in India are being used below their maximum potential and there is much scope for increasing potential by intensification. In India, where almost all soils are already in use, current annual production is 2 billion tonnes of grain equivalent, but the potential of Indian soils is more than 4 billion tonnes (Swindale, 1989). Vertisols of India have high WHC (in first meter of the fully charged soil, 165 mm of water is available to crops; at a soil depth of 1.8 m, over 300 mm of water available), ^{however} lack of full root penetration below 40 cm depth reduces water use by about 30% (ICRISAT, 1978). Infiltration rate of dry Vertisols is very high (70 mm hr⁻¹) because of deep and wide and many cracks, however permeability drops to very low values (0.2 mm hr⁻¹) when they are saturated (ICRISAT, 1978). Vertisols are interactable when dry and poorly aired and sticky when saturated and frequently erodible when occur on slopy land and low infiltration when wet. Good land and water management of Vertisols is the key for sustainable yield under both limited and adequate rainfall conditions. High intensity storms and low infiltration rate, when surface soil is wet resulted in large amount of storm water runoff in most of the Vertisols. The alternating expansion and contraction of Vertisols on wetting and drying also contributes to the so called "self-mulching" characteristic of many Vertisols. During swelling of clayey soils, a vigorous disruptive action is associated with swelling as water is absorbed, the volume increases, cohesion is diminished, and any unconfined mass of the soil exhibits warping, cracking, exfoliation, and various degrees of disruption (Smith, 1959).

Soil acts as a reservoir for moisture storage and this characteristic of soil needs to be utilized to the maximum extent by adopting various cultural and mechanical methods i.e. contour cultivation, vertical mulch, ridges and furrow and farm ponds (Chittaranjan, 1982). Increase in soil moisture by 6.25 per cent was recorded due to contour ridging at Jobner in Rajasthan (Ram and Mohan, 1973). Contour and graded ridges recorded more moisture retention in soil and also reduced runoff and thereby increased the crop yield over across slope cultivation (Patil and Bangal, 1987). Moisture in soil enhanced fertilizer use efficiency which resulted in increasing the crop yields at a given fertility level (Parihar and Gajari, 1988).

Management practices to reduce erosion while maintaining crop yields have been developed under various climatic conditions; such practices are terracing, crop rotations, fertility management, graded furrows, narrow rows, wide-bed systems, conservation tillage, and runoff water management (Burnett, 1989).

The term "conservation tillage" has been defined in various ways but generally, it is the tillage system that reduces wind and water erosion and conserve moisture. Wide-bed, narrow-row systems have been developed to utilise the maximum potential of Vertisols and also provide the required surface drainage for storm runoff as in the graded furrow system (Arkin *et al.*, 1978, Morrison and Gerik, 1983). The wide beds consist of slightly raised cropping strips between widely spaced furrows. The width of the beds is determined by the farm equipment

available and the required water-carrying capacity of the furrows, so that effective drainage is provided but the beds are not overtopped. Cultivation along contour is a fundamental soil conservation practice for the prevention of soil and water losses on slopy land. Contour lines are used for tree planting, for laying out contour hedgerows, terraces, contour bunds and hillside ditches (Douglas, 1992). Contour furrows opened after three rows of bidi tobacco, enhanced its yield by 36 per cent over control (Bonde, *et al.*, 1978).

On class IV lands, development of agri. horticultural systems on CCT layout was found to be significantly better option followed by contour cultivation of crop along vegetation and in situ water conservation (Bharad *et al.*, 1991). Increase in cane yield for about 27 per cent was recorded due to cultivation of cane on contour trenches (Agrawal and Singh, 1970).

Sowing in paired rows in combination with normal interrow cultivation, ridging with tide ridge system or opening furrows between pairs of rows at different intervals in uniform row, increased seed cotton yield and also reduced surface runoff. Paired row planting and opening of furrows between two paired rows of cotton grown on medium deep soil, gave increase in yield of seed cotton over control (Patel *et al.*, 1989). Data further, indicated a higher moisture conservation in soil during fruiting period of cotton. Ridging across the slope in both bidi tobacco and cotton considerably reduced the runoff by 52.2 and 44.3 per cent, soil loss by 52.0 and 52.8 per cent and nitrogen losses by 50.9 and 45.8 per

cent over traditional method of planting which resulted in increasing their yields.

Dhruva Narayana (1983) stated that the soil and water conservation practices and broad bed and furrow system on the soil having slope upto 3 per cent, reduced runoff and soil loss considerably and also conserved soil moisture and nutrients; which resulted in increase in the yield. Similar results were also reported by Bansal and Shrivastava (1981).

Ghatol and Karale (1996) while studying the degraded soils of Amravati district of Vidarbha region proposed the restorative and conservation measures for Sodic Haplusterts which comprised of graded bunding, broad channel terracing, reclamation of small gullies and addition of amendments including gypsum and organic matter. On the basis of severity of degradation problems and reclamability criteria, various land use changes have been suggested for degradation control and optimization of production. Sagare *et al.* (1996) evaluated the effect of land treatments on Aridic Haplusterts of Vidarbha region and recorded a maximum increase in the yield of sorghum due to contour cultivation along leucaena hedgerows followed by opening of furrows after three rows of sorghum at 30 DAS. In addition, these treatments also reduced surface runoff and losses of soil and nutrients to the extent of 50 to 70% over across the slope cultivation (without furrow opening). Opening of furrows after three rows of green gram enhanced grains yield of green gram and also residual crop of safflower grown after green gram, in deep

Vertisols (Sagare *et al.*, 1996). Sowing of cotton on BBF of 1.8 m width gave significantly higher seed cotton yield over across slope cultivation (Sagare and Bhongale, 1993).

Thakare *et al.* (1989) reported that sowing on contour ridges and furrows with 0.2% grade gave significant increase in the yield of seed cotton over normal sowing on flat bed. While managing the sodic Vertisols of Madhya Pradesh, Verma *et al.* (1987) observed that ridge planting (planting on flat beds and ridges made along the slope during rainy season) enhanced the yield of sorghum and cotton considerably. Amongst the slopes used, 0.65% slope gradient provided the suitable drainage under the existing climatic conditions in moderately sodic clay soils for both crops as indicated by their yield performance. Bhamodkar and Hiwase (1996) conducted drainage studies on salt affected Vertisols of Vidarbha region and reported a higher yield of black gram and also improvement in drainability of soil due to deep ploughing as compared to shallow ploughing.

2.5 Effect of Land Configurations on Physico-chemical Characteristics of Vertisols

The behaviour of soil water has the greatest effect on agricultural use of Vertisols. Such behaviour depends on climatic and site factors, infiltration rate, and hydraulic conductivity of soil. The physical soil factors are difficult to measure in the laboratory and in the field and this makes estimates of the available water-holding capacity less reliable. These factors are also affected by the nature and concentration of the soil

solution and by the composition of the exchange complex. The relative saturation with Na, as compared with that of Ca and Mg influences strongly on shear strength, swelling pressure, plasticity index, and hydraulic conductivity. On the basis of the differences between Ca-saturated and Na-saturated smectites in hydrological and mechanical properties, we would expect self-mulching, Carbonate rich Vertisols which have relatively fine structural aggregates and strongly intersecting slickensides have the most favourable fabric for optimum infiltration and movement of water down the profile. Smith (1959) and Sleeman (1963) found that carbonate free Na-dominated clays developed a high intensity of fine cracks, whereas, Ca-dominated clays have fewer and wider cracks.

The management practices being used on deep Vertisols in India have been described and discussed by several authors (Michaels, 1982, Ryan *et al.*, 1982, Kanwar *et al.*, 1982). In traditional management, deep Vertisols are usually fallowed during the rainy season and cropped only in the post rainy season on stored soil moisture. Frequent cultivation by a blade harrow is done during the fallow period, primarily to control weeds. Improved cultivars and chemical fertilizers are generally not used. Annual yields from farmers field on Vertisols in selected villages of Peninsular India have been reported (Kanwar *et al.*, 1982) to be quite low. Water balance studies on traditional Vertisols management systems at ICRISAT (1978) center indicated that out of total rainfall 24 per cent was lost as runoff, whereas 46 per cent lost as evaporation and deep percolation. Improved land and water management practices for

alleviating the physical constraints of Vertisols should promote intake of water, improve aeration and workability, reduce erosion and runoff, and facilitate safe disposal of excess water. In India, differences in their management are primarily due to their location in a toposequence and prevailing agroclimatological regimes, which determine the choice of cropping systems. The improved technologies for management of deep Vertisols were developed and provides a framework for increasing crop yields on a sustained basis, while improving the land resource.

It is widely known that a permanent cover of grasses and trees is highly effective for controlling erosion and conserving water, but such cover dose not allow crop production, hence, tillage and support practices are relied upon to control soil and water erosion (Unger and Jones, 1989). Conservation tillage, which retains residues of crops on the soil surface , is more effective than clean tillage for conservingg soil and water. However, soil and water can also be conserved through proper use of clean tillage alone or by tillage in conjunction with suitable support practices, such as contouring, terracing, strip cropping, furrow diking and so on.

Sodicity of Vertisols and its effect on soil physical characteristics and plant growth is controversial. In several countries, good yields have been reported from Vertisols having $ESP > 40$. If sodicity is accompanied by salinity, the effect of the Na ion on the surface characteristics of the clay is counteracted viz. hydraulic conductivity and degree of structural stability increase with increasing electrolyte

concentration in the soil solution (Mukhtar *et al.*, 1974, Pandey *et al.*, 1974). Soil structure and water properties of Ca and Mg saturated smectites are only slightly modified by salt concentration, but a strong effect of salt concentration is found with Na smectite (Halitim *et al.*, 1984)

Reclamation of alkali soils requires assured water supplies for leaching/flushing after incorporation of chemical amendments and in many situations in alkali Vertisols, such water supplies are available. In alkali Vertisols having high clay contents, effectiveness of gypsum is limited to 15-20 cm due to poor water transmission properties. Under such conditions upland crop suffer heavily on account of poor drainage, root penetration and low moisture intake. In view of physical constraints of alkali soils, the raised and sunken bed system (1:1 configuration with bed widths of 4.5, 6.0 and 7.5 m) was recommended for areas of modest annual rainfall (<800 mm) and devoid of irrigation facility (Verma and Sharma, 1998). Alkali tolerant varieties of cotton and paddy were planted on raised and sunken beds, after a safe disposal of 40-50 mm stored water collected just after onset of monsoon to avoid any salt injury to rice crop. It was further, observed that 62-70 % of rain water could be conserved and that 25-40 q ha⁻¹ paddy yields and 2.4-4.9 q ha⁻¹ cotton yields could be obtained from the area under both crops without any supplemental irrigation.

Mkrtchyan (1991) revealed that the chemical amelioration of saline-sodic soils is rather a complicated process, which involves complex chemical reactions and displacement and translocation of the original and

newly formed soluble salts. It is important that the whole set of land reclamation processes be subdivided into stages and substages, with their priority and sequence clearly stated.

In ridge planting planter units are operated on ridges made by cultivation of the previous crop or after crop harvest. Conservation benefits resulted from the soil being covered with residues or growing crop during most of the year. Additional runoff-control benefits occur, if the ridges are on the contour. Ridge planting benefits poorly drained soils, such as Vertisols, because ridges are usually drier and better aerated than furrow bottoms or land that is managed in a flat condition (Griffith *et al.*, 1977).

Contouring involves performing tillage and cultural operations so that elevations along rows are as level as practical. When lister tillage or ridge planting is done on the contour, the potential for erosion by surface water flow is greatly decreased (Stewart *et al.*, 1975). Contouring provides almost complete protection against erosion from low to moderate intensity storms, but little or none against intense storms that overtop and break the contoured ridges. In contrast to contour furrows, which minimize runoff and erosion, graded furrows convey runoff water from fields at nonerosive velocities. Each furrow functions as a small graded terrace, although designed to remove excess water, graded furrows also conserve water. Runoff was less with graded furrows because the excess water was more uniformly distributed over the entire field, which provided more time and area for infiltration (Richardson,

1973). Furrows dikes (tied ridges) can effectively conserve water by retaining potential runoff on field areas until it infiltrates with this practice, small earthen dams are constructed between cropped ridges that are formed with a lister (bedder).The dikes are built across the furrow at intervals of 1-4 m, depending on slope and available equipment (Clark and Jones, 1981).

Terraces are constructed across the slope to manage runoff from fields at nonerosive velocities. They also retain water on fields until infiltration occurs, thus making more water available to plants. Terraces are generally combined with waterways or underground outlets that safely dispose excess water (ASAE, 1981). The effectiveness of terraces for conserving soil and water can be enhanced by complementary practices such as contouring stripcropping, diking and stripcropping and conservation tillage.

Singh and Pandey (1986) observed that for levelling the saline soils, the harrow could be most efficiently used for loosening the soil and the terracing-blade for transporting and spreading the soil when the soil moisture was 12 to 14%.

Study was undertaken on Vertisols at Bijapur Karnatak to find out effective conservation structure to minimise, runoff, soil loss and observed that ridges and furrows system minimised the runoff by 66% and increased the yield of rabi sorghum by about 50% over no land treatment (Belgami and Radder, 1994). On class IV land development of agro horticultural systems on CCT layout, was found to be significantly better

option for in situ rain water conservation. With CCT layout around 97 per cent of rain water was conserved in situ over the entire toposequence (Bharad, 1994).

In BBF system, a separate raised bed cropping zone and traffic zone on the furrow portion are created and therefore cropping zones remain loose and friable in montmorillonitic soil (Miranda, 1983). Sowing of cotton on BBF of 1.8 m width (furrow filled with sorghum stubbles) gave maximum increase in soil moisture storage, available water and productivity by 17.9, 19.0 and 31.4 per cent over across the slope sowing (Sagare and Bhongale, 1993).

Higher soil moisture content in cotton grown on deep black soils was recorded in contour ridges and furrows with 0.2% grade as compared to flat bed. Paired row planting and opening of furrows between two paired rows of cotton grown in deep black soils of Vidarbha region enhanced soil moisture percentage during fruiting period of cotton (Thakare *et al.*, 1989).

Kampen (1979) observed that runoff occurred earlier in Alfisols and later on vertisols. This contrasting nature of soil is attributed primarily to differences in type and amount of clay and other associated characteristics. He has further, noticed that there was less runoff in broad base and furrow system in Vertisols, the reverse was true for Alfisols with traditional flat cultivation with contour bunds. Furrow has a prominent feature in ridges and furrow system for the safe disposal of surplus water

Mkrtchyan (1991) stated that the drainage is widely applied in the areas of waterlogged, swamped or saline soils. The experience of land amelioration and reclamation showed that drainage is one of the indispensable measures for controlling soil salinization. There is a lack of knowledge on drainage design criteria for Vertisols. Most of the design theory developed considering water flow in soil to follow Darcy's law. Acharya and Varade (1980) showed that the general drainage theory does not work well for Vertisols. The problems experienced on drainage in black soils have been summarized by Varade (1982). The major ones are i) fine textured soils have poor drainage characteristics and hence subsurface drainage requirements are intensive and costly; ii) the soils may be non-darcy as for as soil water flow relations, affecting thereby drainage design calculations, iii) swelling and shrinkage leads to dislocation of drainlines iv) swelling affects drainage characteristics and hence drainage design criteria needs modification and v) choking of subsurface drains is very common due to deposition of clays.

Holsambre *et al.* (1982) studied drainage characteristics for saline-sodic Vertisols of Purna command (Marathwada) and reported typical peak co-efficient as 9.8 mm day^{-1} , mean effective field drainable porosity as 14.4 per cent and hydraulic conductivity as 1.55 m day^{-1} to be considered for the design of drainage system in this region. Subsurface brick drainage system is cheaper than tile drains and has maximum outflow and life.

CHAPTER III

MATERIALS AND METHODS

The field experimentation pertaining to the research problem entitled "Investigation on the effect of soil amendments and land treatments on soil characteristics and productivity of cotton grown in salt affected Vertisols" was carried out at Gopalkheda, the village situated near the bank of Purna river (Fig. 1). The soil selected for field investigation is the representative site of saline sodic soils of Purna valley. General features pertaining to the Purna basin, methods adopted for soil analysis and morphometric and physico-chemical characteristics of soil selected for investigation are encountered in this chapter under the following subheads.

3.1 General features of Purna valley,

3.2 Morphometric and physico-chemical characteristics of soil site selected for investigation,

3.3 Details of experimentation, and

3.4 Methods adopted for soil analysis

3.1 General Features of Purna Valley

3.1.1 Geomorphology and geology

Purna river basin is an east west elongated valley with slight convexity to the south; covering the part of Amravati, Akola and Buldana districts of Vidharbha region and extends from $20^{\circ}40'$ to $21^{\circ}90'$ N latitude and $76^{\circ}15'$ to $77^{\circ}45'$ E longitude with east west length of an about 150 km having width of about 10 to 60 km. Purna river originates at an

elevation of 900 m in Gawilgarh hills of Satpura in Betul district of Madhya Pradesh and drains for about 240 km before meeting Tapi. The total catchment area is about 18,929 km². The important tributaries of Purna are Pedhi, Chandrabhaga, Shahnur, Wan, Katepurna Nalganga, Gyanganga, Morna and Man. The Purna basin, a part of Payanghat plains bounded on the north by the scarp of Melghat and on the south by the scarp of Ajanta and is essentially a faulted valley of late cretaceous to early eocene age with a basement of the Deccan trap, filled with material comprising of boulders, pebbles, gravels, sand and clay derived entirely from the basalt, surrounding the valley. The geological succession as reported by Blanford (1869) is as follows:

Geological succession	Age
River alluvia, Kankar and sand	Recent
Conglomerates	Sub - recent
Trap dykes	Cretaceous
Deccan basalt flour with Intertrappen and ash belts	to Eocene
-----Erosional unconformity-----	
Upper Gondwana sandstone-----	lower Cretaceous

Palaeogeography based on latest bore hole information, the following is the geologic succession (Adyalkar, 1963) of Purna valley.

Name of the formation	Age
Purna Alluvium	Late pleistocene to Recent
Laterites	Paleocene
-----unconformity-----	
Deccan Trap	Late Cretaceous to Paleocene
-----unconformity-----	
Lametas	Cretaceans
Gondwanas (upper)	Carboniferous

Three geomorphic zones are identified on the basis of land form assemblage, nature of drainage, slope characters and sediment generation and deposition (Tiwari *et al.*, 1996). Those are i) Zone of high land relief, deep dissection and short interfluves, ii) Zone of alluvial plain and iii) Zone of moderate relief and gentle slope. Southern limit of the zone of high land relief marked by scarp faces coincides with east-west trending regional fault. Six sets of land forms related to three geomorphic episodes are recognized in the alluvial plain. Two episodes are related to reactivation of the east-west fault. Six morphostratigraphic units are present in the alluvial plain. Upper Gondwana sandstone, infratrappean siliceous limestone and Deccan trap make the Pre-Quaternary rock types. Quaternary sediments are classified in - to four lithostratigraphic formations. The Brown Silt formation is correlated with the Baneta Formation (of Narmada valley) of Upper Pleistocene age by the volcanic ash association. Lower Pleistocene in the Purna valley is represented by the Red silt formation.

3.1.2 Aquifer geometry and ground water quality

Inland salinity of ground water in parts of Purna alluvial tract is a historical phenomenon, as the highly saline groundwater was being used for manufacturing common salt in the past. In the Purna alluvial tract, the quality of ground water is saline in pockets, mainly in the north and central parts. The alluvial tract of Purna is elongated in the east west direction with an area of about 7,500 km². This alluvial tract covers the part of Amravati, Akola and Buldana districts and districtwise area is 3460, 2650 and 1390 km², respectively. The ground water is saline in about 2760 km² with an electrical conductivity of > 2000 micromhos cm⁻¹ at 25^oC, and mainly confined to northern bank of the Purna.

In the saline tract highly saline water with a maximum E.C. of 17,000 micromhos cm⁻¹ at 25^oC is observed within the younger alluvium (Gusanwadi, district Akola). In general, in the alluvial tract Ca/Na-HCO₃ type of ground water occurs. However, in saline tract at times Cl-type of ground water is also encountered. Further, in general, the type of water from north to south i.e. in the direction of ground water flow changes from HCO₃-Cl type which is a natural phenomenon. The absence of SO₄ type of ground water further suggests that the salinity of ground water is a natural phenomenon. Based on the available data and it's detailed analysis, it is observed that the salinity of ground water is a natural phenomenon and is mainly dependent on aquifer geometry, sluggish movement of ground water in the central part and can be termed as "Inland Salinity". The vertical movement of ground water is retarded due

to presence of clay and encourage more mineralisation (Dev Burman and Mehta, 1996).

3.1.3 Climatic conditions and surface flows

This region is one of the hottest in India with mean maximum temperature at Akola is being 41.1°C and 42.3°C during month of May and mean minimum temperature is being 8.2 and 10.5°C during the month of December with an annual rainfall of 1010 and 562.4 mm during 1994-95 and 95-96, respectively, (Appendix I and II). Purna river basin gets fairly good rainfall every year and are recorded at the rain gauge stations maintained by the CWC, IMD and the state Government. From the general trend of the rainfall, it is observed that the higher reaches of the basin receives more rainfall viz. Chikhalda, which is at an elevation 1103 m receives an average annual rainfall of 1708 mm, whereas, Yerli at an elevation of 228 m receives an annual mean rainfall of 727 mm. Average rainfall of Buldana is 875 mm (El. 650 m), Amravati 876 mm (El. 370 m), Akola 800 mm (El. 282 m), Lakhpuri 755 mm (El. 274 m), Gopalkheda 750 mm (El. 251 m) and Yerli -727 mm (El. 228 m). About 90% of the rainfall is received during the monsoon months i.e. June to October, however, 60% of the total rainfall received during July and August.

A good amount of runoff is generated in the basin and is measured at Gopalkheda, Lakhpuri and Yerli. The catchment areas are 3560, 9500 and 16517 km², respectively. The relationship between annual rainfall and runoff as well as dependability have been calculated for Gopalkheda and in general, the surface flows are negligible upto and

annual rainfall of about 500 mm. The rainfall in excess of this gives on an average 35 per cent as runoff.

3.1.4 Vegetation

The perennial vegetation in this area is very sparse. The density of tree is $<0.5 \text{ ha}^{-1}$ which consists of dry deciduous, mixed type; the common tree species are Babhul (*Acacia arabica*), *Prosopis juliflora* and (neem) (*Azadirachta indica*), occurring in scattered patches and in areas adjoining the village.

As regards grasses, very few patches of *Dicanthium spp* (Marvel), *Ischimum pylosum* (Kunda) are seen in the cultivated fields and along the road. Considering the soil and rainfall characteristics, cropping systems include cotton, sorghum, pigeonpea and greengram as major crops in *kharif* season; gram, wheat and safflower are taken as sequence crops after greengram in *rabi* season on residual moisture. The area under *kharif* fallow for retaining rainfall and growing wheat in *rabi* season decreased considerably because of low productivity of wheat crop and uncertainty of rainfall in October and November.

3.2 Morphometric and Physico-Chemical Characteristics of Soil Site Selected for Investigation

3.2.1 Morphometric characteristics of soil profile

The pedon of experimental site under study situated on moderately sloping topography (2.5 per cent slope gradient) is very deep, clayey, dark brown to very dark grayish brown in colour having subangular to angular blocky in structure, slightly hard to very hard,

friable to very firm (moist), sticky and plastic to very sticky and very plastic (wet), soil cracks upto 1 meter or more, 2 to 4 cm wide at surface horizon which narrow down with depth, Well developed slickensides are observed below 40 cm which appeared intersecting at the depth of about 90 cm and slight to strong effervescences with dilute HCl (10%) which increase with depth. Calcium carbonate and ferruginous concretions are observed throughout the depth of pedon. The dominant clay mineral is montmorillonite as indicated by higher values of CEC which makes the soil; a good source of plant nutrients. Few to common, medium to coarse, prominent mottles are observed. This indicates the illdrained nature of soil and incomplete leaching of salts in subsoil due to severe drainage impairment caused by increased clay content, high values of BD and dispersion of clay.

3.2.2 Physico-chemical characteristics of soil profile

Data (Table 1) pertaining to initial physico-chemical characteristics of profile samples of experimental field show that horizonwise pHs of soil ranged from 8.2 to 8.9, ECe 2.42 to 5.50 dSm^{-1} , ESP 14.06 to 27.85; SARe 11.94 to 25.80, whereas BD and HC varied in the range of 1.55 to 1.70 Mg m^{-3} and HC 0.30 to 0.85 Cm hr^{-1} , indicating illdrained nature of soil. As per criteria proposed by Richards (1954), for salinity/sodicity, the pedon of experimental soil, can be categorised as "Saline-Sodic" in nature. Efforts were also made to classify the pedon taxonomically as per Key to Soil Taxonomy (USDA 1992), and accordingly

Table 1. Physicochemical characteristics of Pedon excavated in experimental field

Depth of pedon (cm)	pHs	ECe (dSm ⁻¹)	ESP (%)	Ionic composition (Cmol L ⁻¹)			SAR	CEC (Cmol Kg ⁻¹)	BD (Mg m ⁻³)	HC (cm hr ⁻¹)	Soil category
				Ca ⁺⁺	Mg ⁺⁺	Na ⁺					
0-26	8.20	2.42	14.06	3.25	1.69	18.75	11.94	42.30	1.55	0.85	Saline sodic in
26-45	8.40	3.85	19.15	4.05	1.43	28.30	17.15	47.80	1.60	0.80	nature,
45-72	8.50	4.15	26.43	3.09	1.22	30.60	20.82	46.10	1.64	0.70	Taxonomically Sodic
72-103	8.60	5.00	27.34	2.70	1.88	34.40	24.75	47.90	1.67	0.40	Haplusterts
103+	8.90	5.50	27.85	2.25	1.55	35.60	25.80	48.30	1.70	0.30	
Profile mean	8.50	4.18	22.97	3.07	1.55	29.53	20.09	46.48	1.63	0.61	

the experimental soil is a member of very fine, montmorillonitic, hyperthermic family of Sodic Haplusterts.

3.2.3 Initial physico-chemical characteristics of surface soil:

Initial composite surface soil sample before the start of experimental field was collected and analysed for its physico-chemical characteristics and data are presented in Table 2. Data reveal that the experimental soil is clayey, illdrained (HC 0.82 cm hr⁻¹) water retentative, having AWC 13.80 per cent (by volume). Chemically this soil is strongly alkaline (pH 9.1), calcareous, moderate in N, low in available P₂O₅ and very high in available K₂O.

3.3 Details of Experiment

A field trial on Hybrid cotton (CV-AHH 468) was planned in split plot design during 1994-95 and 1995-96 at Gopalkheda, the village situated near the bank of Purna river.

3.3.1 Treatment details

Treatments (each replicated four times) applied to cotton are presented below (Fig. 2).

Main

A] Land treatments

- i) Control - No land treatment L₀
- ii) Opening of deep furrows after each row: 30 cm deep furrows were opened after each row of cotton by harrow (tide ridge system) immediately after first hoeing and maintained thereafter throughout the season. L₁

Table 2. Initial physico-chemical characteristics of surface soil sample

Soil property	Value	Methods adopted
a) Physical analysis		
Partical size distribution analysis		International pipette method (Jackson, 1979)
Sand (%)	6.4	
Silt (%)	32.2	
Clay (%)	61.4	
Bulk density (Mg m^{-3})	1.5 Mg m^{-3} ✓	Clod method (Black <i>et al.</i> , 1965).
Hydraulic conductivity (cm hr^{-1})	0.82	Constant Head method (Richards, 1954).
Water retention characteristics		
Field capacity (% by volumetric)		Pressure plate membrane apparatus (Black <i>et al.</i> , 1965).
0-30cm	29.9	
30-60cm	31.8	
PWP		Pressure plate membrane apparatus (Black <i>et al.</i> , 1965).
0-30cm	16.1	
30-60cm	20.7	
Available moisture (% by volume)		Pressure plate membrane apparatus (Black <i>et al.</i> , 1965).
0-30cm	13.8	
30-60cm	11.14	
b> Chemical analysis		
pH (1:2)	9.1	Glass electrod pH meter (Jackson, 1967).
ECe (dSm^{-1})	2.45	Electrical conductivity meter (Richards, 1954).
Organic carbon (%)	0.59	Walkley and Black's (wet oxidation) method (Jackson, 1967).
CaCO_3 (%)	11.4	Rapid titration method (Piper, 1966).
Available nitrogen (Kg ha^{-1})	280 ✓	Alkaline permanganate method (Subbiah and Asija, 1956).
Available P_2O_5 (Kg ha^{-1})	22 ✓	Olson's method (Jackson, 1967).
Available K_2O (Kg ha^{-1})	470 ✓	Flame emission spectrophotometer method (Jackson, 1967).
CEC ($\text{Cmol (P}^-\text{)Kg}^{-1}$)	42.5 ✓	Sodium acetate method (Richards, 1954)
SAR	12	Versenate method (Richards, 1954).
ESP (%)	14.5	(Richards, 1954).

SPLIT PLOT DESIGN

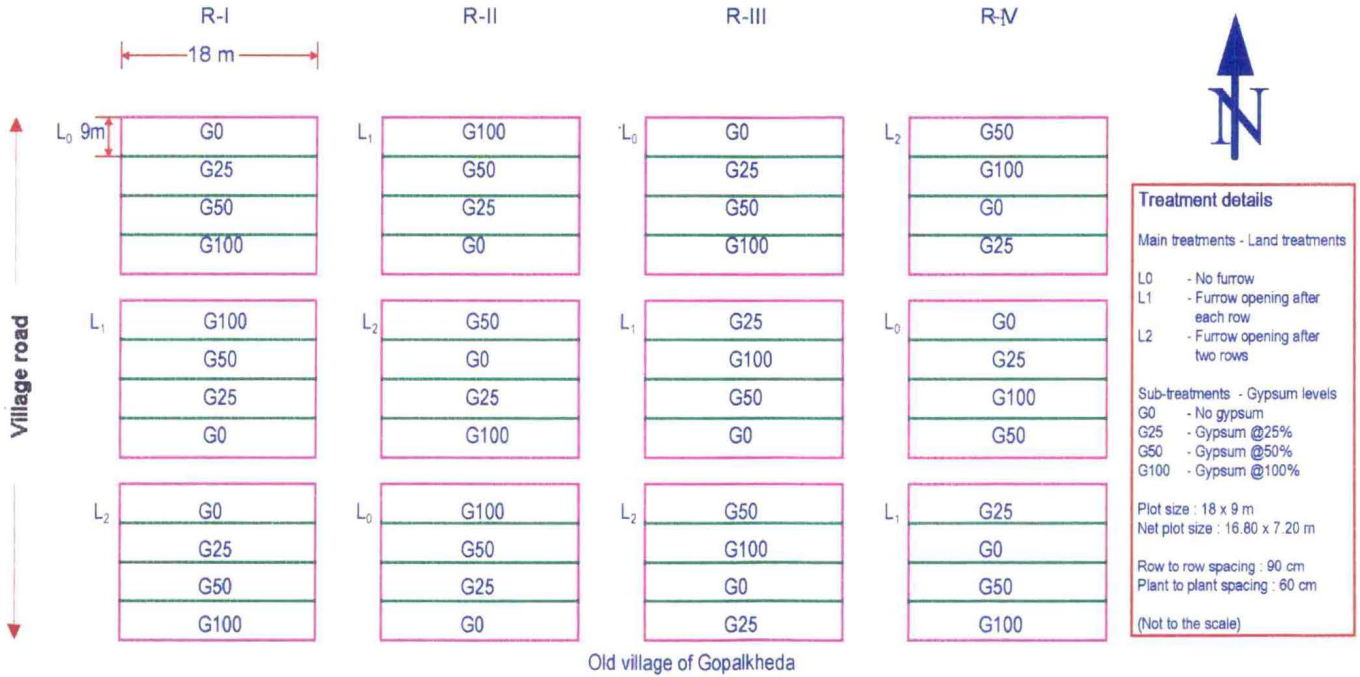


Fig. 2 : Layout of field experiment conducted at Gopalkheda

- iii) Opening of deep furrows after two rows of cotton: 30 cm deep furrows were opened immediately after first hoeing by harrow (tide ridge system) and maintain thereafter throughout the season.

L₂

Sub-treatments

B] Gypsum Levels

- i. Control G 0 (No Gypsum incorporation)
- ii. Gypsum @ 25% GR G 25 (Gypsum @ 1.25 t ha⁻¹)
- iii. Gypsum @ 50% GR G 50 (Gypsum @ 2.5 t ha⁻¹)
- iv. Gypsum @ 100% GR G 100 (Gypsum @ 5 t ha⁻¹)

Gypsum requirement was determined by Schooner's method (Richards, 1954) and it was incorporated in upper 15 cm layer of soil in summer (May) before last harrowing and mixed with soil by harrowing. Recommended levels of NPK (50 Kg N + 25 Kg P₂O₅ + 25 Kg K₂O) was applied to all cotton plots through urea, single superphosphate and muriate of potash, respectively.

Gross and net plot sizes were 18 x 9 and 16.80 x 7.20 m and row to row spacing and plant to plant spacing were 90 and 60 cm, respectively. The insecticidal and fungicidal sprayings were given as per the incident of pest and diseases. Dates of sowing and harvesting of cotton plant during both the years are -

	1994-95	1995-96
Dates of sowing	3.7.94	2.7.95
Period of picking	Nov. 94 to Jan. 95	Nov. 95 to Jan. 96
Date of harvesting of cotton plant	12, Jan.95	5, Jan. 96

3.4. Methods Adopted for Soil and Plant Analysis

3.4.1 Collection of soil and plant samples

a) Presowing soil sampling

To study the morphometric and physico-chemical characteristics of soil site before experimentation, profile pit (1 m long, 1 m wide and 1.5 m deep) was excavated in the centre of the experimental field and characteristics of Pedon excavated were studied morphometrically as per the procedure given in Soil Survey Manual (USDA, 1951). Special features of the soil Pedon pertaining to depth and width of the cracks, slickensids, pressure faces etc. were also recorded. About 1 kg representative samples from each horizon were collected in cloth bags for laboratory study. Composite surface soil sample (0-20 cm deep) was also collected to determine physico-chemical and nutrient status of soil.

The bulk soil samples collected were allowed to air dry and then weighed and crushed with wooden mortar and pestal and passed through 2 mm sieve. A small part of 2 mm sample was again grind to pass

through 100 mesh sieve for organic carbon and free calcium carbonate estimation.

b) Post harvest soil sampling

Post harvest soil samples (0-20 cm depth) from each experimental plot were collected after the last picking of cotton, then dried, processed and analysed to evaluate the changes in physico-chemical characteristics of soil as influenced by various land treatments and gypsum levels.

c) Soil sampling during investigation

Plotwise soil samples from 0-30 and 30-60 cm depth were collected during experimentation for moisture determination at various growth stages of cotton. It was collected from the fixed site of sampling and immediately estimated for moisture content (gravimetric).

3.4.2 Methods of Analysis

a) Physical Properties

Particles size analysis was carried out as per International Pipette Method after the removal of organic matter, CaCO_3 and free iron oxides. Sand (2000-50 μm), silt (50-2 μm) and clay fractions (<2 μm) were separated using the procedure of Jackson (1979).

Bulk density was determined by Wax Coating Clod Method (Black *et al.*, 1965).

Saturated hydraulic conductivity was determined by Constant Head Method as outlined by Richards (1954).

The moisture retention and release behaviour at 33 KPa and 1500 KPa was determined by Pressure Plate Membrane Apparatus (Black *et al.*, 1965).

Soil samples were dried at 105°C to a constant weight and moisture content was determined on dry weight basis (Jackson, 1967). Available soil moisture storage upto a depth of 60 cm of soil solum was calculated from per cent soil moisture (gravimetric).

b) Chemical Analysis

pH of 1:2 soil water suspension and of saturated paste was determined electrometrically using a pH meter as described by Jackson (1967).

The method as described by Richards (1954) was followed for the saturation extract preparation. The saturation extract of the soil samples were analysed for electrical conductivity (EC_e) and composition of soluble salts by methods outlined by Richards (1954).

Organic carbon was estimated as described by Walkley and Black's method (wet oxidation method) as described by Jackson (1967).

Calcium carbonate was determined by Rapid Titration Method as described by Piper (1966).

Available nitrogen was determined by Alkaline Permanganate Method as described by Subbiah and Asija (1956).

Available phosphorus was determined by Olsen's Method (Olsen, 1954).

Available potassium was determined in 1N ammonium acetate (pH 7.0) leachate by Flame Photometer (Jackson, 1967).

Cation exchange capacity was determined by saturated 1N sodium acetate method (pH 8.2). The washing with sodium acetate was given to remove salts followed by washing with alcohol to remove excess of sodium acetate. The adsorbed sodium was extracted by washing with 1N ammonium acetate (pH 7.0) and leachate was made upto known volume. Na^+ present in the leachate was determined with a Flame Emission Spectrophotometer (Richards, 1954).

The exchangeable calcium and magnesium were determined by leaching twice with 1N NaCl solution (Piper, 1950) and titrating the leachate with standard EDTA solution as per the method of Richards (1954). Exchangeable sodium and potassium were determined by leaching with 1N ammonium acetate (pH 8.2) solution. Na and K from the leachates were estimated by Flame Emission Spectrophotometer (Jackson, 1958).

c) Statistical Analysis

The pooled analysis, coefficient of correlation between dependent and independent soil variables and the regression equations were worked out as per procedure described by Panse and Sukhatme (1985).

CHAPTER IV

RESULTS AND DISCUSSION

Results obtained from the field experimentation entitled "Investigation on the effect of soil amendments and land treatments on soil characteristics and productivity of cotton grown in salt affected Vertisols" planned during 1994-95 and 1995-96 and related laboratory analysis are presented and discussed in this chapter under the following heads :

Effect of land treatments and gypsum levels on

- 4.1 Biological yield and economics of cotton,
- 4.2 Physical parameters of soil,
- 4.3 Chemical parameters of soil, and ✓
- 4.4 Correlation and regression studies

4.1 Biological Yield and Economics of Cotton

4.1.1 Seed cotton yield

a) Land treatments

Effectiveness of gypsum incorporation is limited to 15 to 20 cm depth of sodic Vertisols due to poor water transmission characteristics, high bulk density and high runoff potential. Under such conditions crops grown in these soils suffer mainly on account of poor drainage, root penetration and low moisture intake. Moreover, providing of subsurface and surface drainage systems are not feasible looking to the cost of drainage systems especially in deep sodic Vertisols. In view of these

physical constraints of sodic Vertisols, furrows were opened in cotton (grown in Sodic Haplustert) after each row and after every two rows for effective management of rain water and to improve the efficiency of applied gypsum and data pertaining to seed cotton yield are tabulated in Table 3 and graphically depicted in Fig. 3 and Plate 1.

Data reveal that both land treatments significantly enhanced seed cotton yield over control (no furrow opening) during 1994-95, however, a maximum and significant yield increase over control and opening of furrows after each row was recorded due to furrow opening after every two rows of cotton. During 1995-96, numerical enhancement in seed cotton yield was noticed with the opening of furrows after each row, over control, however, results were at par. Data further, indicated that furrow opening after every two rows of cotton gave a significantly higher increase in the seed cotton yield over control and furrow opening after each row.

Pooled results of 1994-95 and 1995-96, also recorded a significant augmentation in the seed cotton yield due to furrow opening after each row and after two rows of cotton and respective increases were 13.1 and 39.6 per cent as compared to control (no furrow opening). However, within the land treatments studied, opening of furrow after two rows gave a significantly higher yield over opening of furrows after each row. ~~Superiority of opening of furrows after two rows over each row in respect of enhancement of seed cotton yield may possibly be due to~~ More exposure of soil surface in each row treatment, ~~might have~~ resulted in,



Plate 1 : Showing the effect of land treatments on growth of cotton

Table 3. Seed cotton yield (q ha⁻¹) as influenced by land treatments and gypsum levels

Treatments	Year		Pooled	
	94-95	95-96	Means	% increase
Land treatments				
No furrow	7.93	7.24	7.58	-
Furrow each row	8.65	8.49	8.57	13.1
Furrow two rows	9.17	11.99	10.58	39.6
SE (m)±	0.15	0.42	0.22	-
CD (p=0.05)	0.51	1.47	0.76	-
Gypsum levels (% GR)				
G 0	7.34	7.92	7.63	-
G 25	8.42	8.78	8.60	12.7
G 50	9.11	9.61	9.35	22.5
G 100	9.47	10.65	10.06	31.8
SE(m)±	0.11	0.23	0.13	-
CD (p=0.05)	0.32	0.68	0.39	-
Interaction				
SE (m)±	0.19	0.40	0.23	-
CD (p=0.05)	0.56	1.17	NS	-

Table 3 (a). Interaction effect in respect of seed cotton yield

Land treatments	Gypsum Levels			
	G 0	G 25	G 50	G 100
No furrow	6.62	7.29	8.01	8.41
Furrow each row	7.02	8.48	9.27	9.5
Furrow two rows	9.24	10.02	10.78	12.27
SE (m)±			0.23	
CD (P=0.05)			NS	

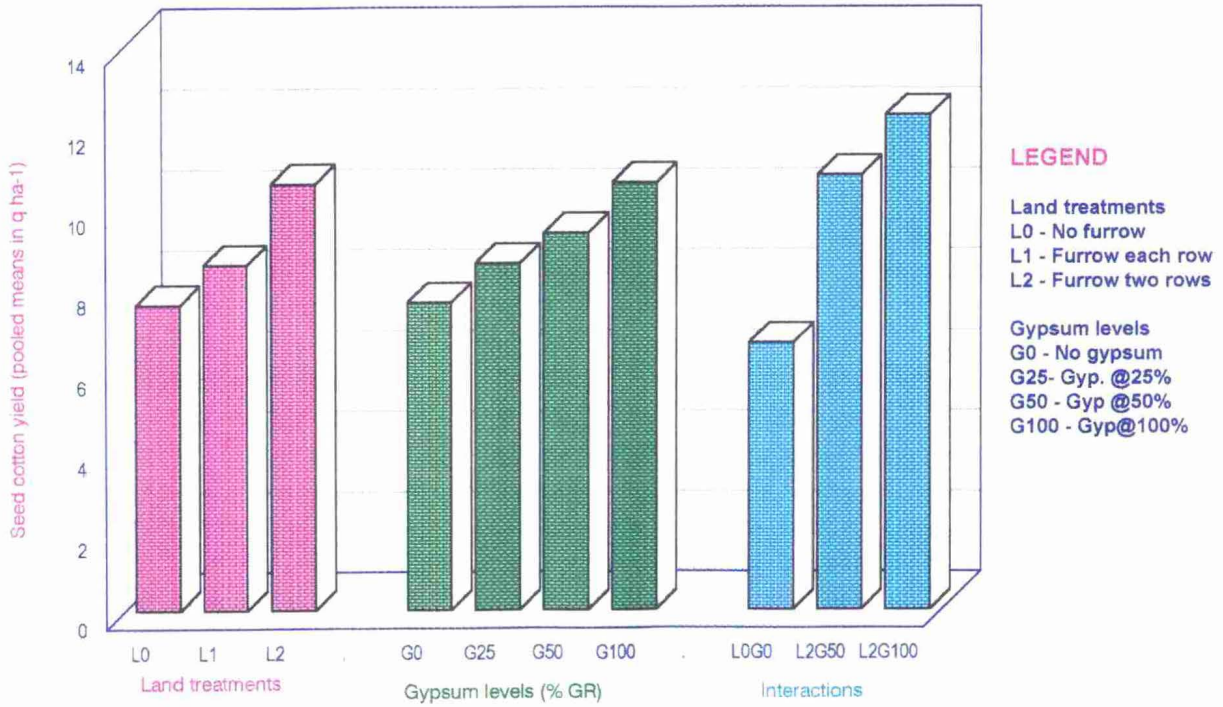


Fig. 3 : Seed cotton yield (q ha-1) as influenced by land treatments and gypsum levels

increasing losses of soil, nutrients and amendments through surface runoff and thus, recording a lesser ^{cotton} yield in the treatment of furrow opening after each row as compared to opening of furrow after two rows.

Similar increase in the productivity of greengram and residual crop of safflower grown after greengram due to opening of furrows in greengram grown in deep Vertisols reported by Sagare *et al.* (1996). Enhancement in seed cotton yield with sowing on contour ridges and furrows in sodic Vertisols was also reported by Thakare *et al.* (1989) and Verma *et al.* (1987). Enhancement in the productivity of seed cotton might be attributed to increment in available soil moisture storage and reduction in the salinity and sodicity parameters of these soils due to land treatments applied, as observed in further studies reported in this investigation. Increase in soil moisture storage improved fertilizer use efficiency which ^{have} might resulted in enhancement in the crop yields at a given fertility level (Parihar and Gajari, 1988). While studying the sodic Vertisols of Purna valley, Ghatol and Karale (1996) suggested the moisture restorative and conservative practices for these soils in addition to amendment incorporation. From the pooled data, it can be inferred that furrow opening after two rows of cotton ^{was} found better than control and opening of furrows after each row and it increased the seed cotton yield significantly to the extent of 39 and 23 per cent, ^{over control} respectively in Sodic Haplusterts.

b) Gypsum levels

The replacement of exchangeable Na^+ which is the dominant characteristics of sodic Vertisols with Ca^{++} ; requires the incorporation of amendments, which can either supply soluble calcium ions directly or induced its solubility in the soil constituents. In this investigation, the various levels of gypsum incorporation were tried as a reclamative measures and data pertaining to seed cotton yield as influenced by various gypsum levels are recorded in Table 3 (Fig. 3 and Plate 2).

A significant and progressive increase in seed cotton yield was noticed with increasing levels of gypsum application (@ 25, 50 and 100% GR) and a highest enhancement in the yield of seed cotton was observed with an incorporation of gypsum @ 100% GR during both the years of investigation. Pooled results also exhibit a similar impact of gypsum addition in respect of seed cotton yield and resulted in a significantly maximum increase due to incorporation of gypsum @ 100% GR over G 0 and gypsum applied @ 25 and 50% GR. The respective increases in seed cotton yield due to gypsum application @ 25, 50 and 100% GR were 12.7, 22.5 and 31.8 over control. These results are in agreement with those reported by sagare *et al.*(1996). Further, yield enhancement due to incorporation of gypsum in sodic soil could be attributed to a decrease in ECe and ESP/SAR of soil (Swarup, 1991).

Salt affected soils are potentially productive, ~~however~~ suitable technologies for their improvement like incorporation of organic and inorganic amendments ~~during cultivation~~ need to be used.



Plate 2(a) : Showing the effect of gypsum on growth of cotton



Plate 2(b) : Showing the effect of gypsum on growth of cotton



Plate 3 : Showing the interaction effect on growth of cotton

(Rajkumar *et al*; 1991). Sodicty deteriorates the physical conditions of soils, as a result, plants can not utilize the soil moisture effectively (which is termed as physiological drought). An addition of gypsum^{is} found most effective in reclamation of such soils (Shukla and Pandey, 1987). Crop yield is a function of number of factors, among which photosynthetic efficiency and rate of translocation of photosynthate are of prime importance; which may be affected due to salinity/sodicty parameters of soil.

Interaction effect of land treatment and gypsum levels was non-significant in pooled analysis (Table 3a, Plate 3). However, highest seed cotton yield was recorded due to interaction of opening of furrows after two rows amending with gypsum @ 100% GR.

To summarize, a significantly maximum increase in seed cotton yield by about 30% over G0 could be obtained with the application of gypsum @100% GR followed by gypsum @50% GR (22.5% increase over G0) applied to Sodic Haplusterts.

4.1.2 Stalk yield

a) Land treatments

A significant enhancement in the stalk yield of cotton (Table 4, Fig. 4) over control was found due to furrow opening after each row and after two rows of cotton during both the years of experimentation and both land treatments were at par with each other. Pooled analysis also indicates a similar trend in respect of stalk yield and furrow opening after each row and after two rows enhanced the stalk yield by about 73 and 80 per cent

Table 4: Stalk yield (q ha⁻¹) as influenced by land treatments and gypsum levels

Treatments	Year		Pooled	
	1994-95	1995-96	Means	% Increase
Land treatments				
No furrow	26.04	34.02	30.03	-
Furrow each row	45.10	59.24	52.17	73.70
Furrow two rows	47.05	61.14	54.10	80.10
SE, (m)±	1.737	2.369	2.050	
CD (p=0.05)	6.012	8.200	7.094	
Gypsum levels				
G 0	31.19	41.05	36.12	-
G 25	36.63	47.81	42.22	16.90
G 50	42.95	55.54	49.24	36.30
G 100	46.81	61.48	54.14	49.90
SE(m)±	0.91	1.34	1.11	
CD (p=0.05)	2.63	3.90	3.23	
Interaction				
SE(m)±	1.57	2.33	1.93	
CD(p=0.05)	4.55	6.76	NS	

Table 4(a). Interaction Effect in respect of stalk yield

Land treatments	Gypsum levels			
	G 0	G 25	G 50	G 100
No furrow	16.61	26.52	36.10	40.88
Furrow each row	42.35	47.05	55.31	63.96
Furrow two rows	49.39	53.08	56.32	57.59
SE(m)±			1.93	
CD(p=0.05)			NS	

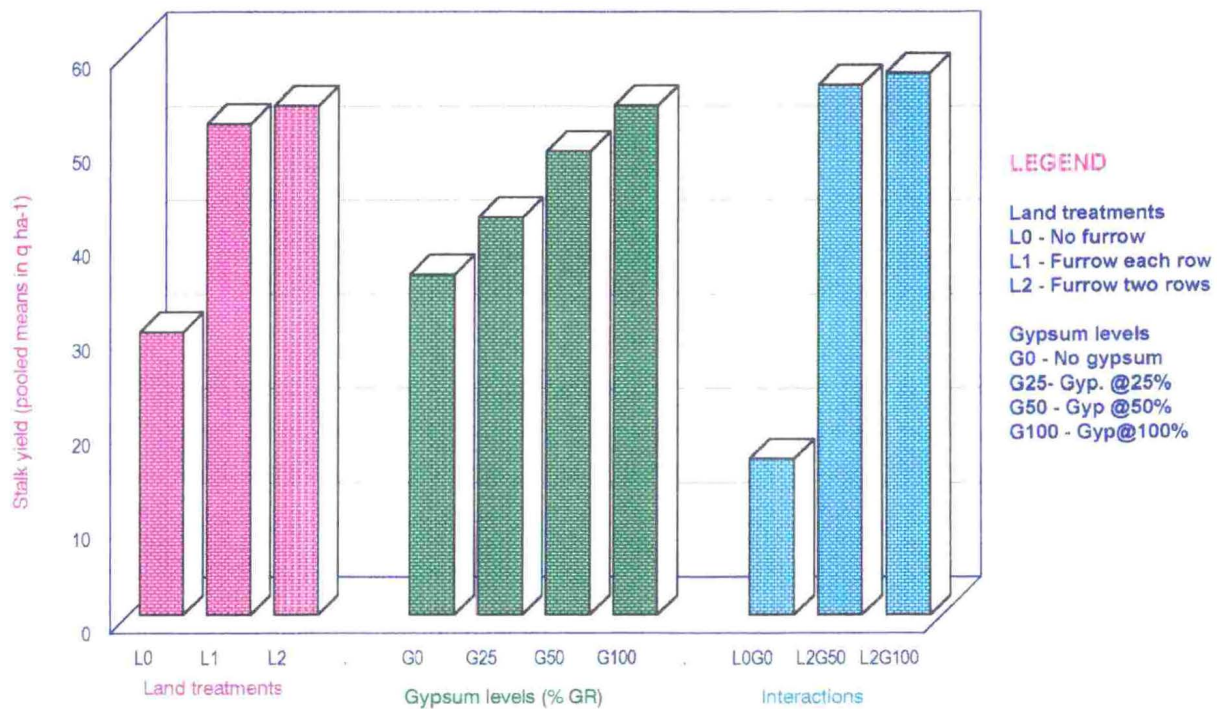


Fig. 4 : Stalk yield (q ha⁻¹) as influenced by land treatments and gypsum levels

over control. These findings are in conformity with those of Patel *et al.* (1989) and Sagare and Bhongale (1993) in respect of black clays.

Druvanarayana (1983) emphasised that soil and water conservation practices like broad bed and furrow system on soil upto 3 per cent slope reduced runoff and soil loss considerably which resulted into increasing biological yield of crops by conserving soil moisture and nutrients. Raised and sunken bed system was recommended by Verma and Sharma (1998) for alkali black clays to enhance the effectiveness of rainfall (less than 800 mm) and applied gypsum.

b) Gypsum levels

Physico - chemical characteristics of sodic Vertisols render salt leaching rather difficult (Verma, *et al.*, 1989); unless these soils are suitably amended to improve physico - chemical environment and therefore, in this investigation various gypsum levels were applied and the results pertaining to stalk yield are recorded in Table 4 (Fig.4).

Data clearly show that incorporation of gypsum at its various doses (@ 25, 50 and 100% GR) resulted into a significant increase in stalk yield of cotton as compared to control (G 0) during both the years of investigation and each higher level of gypsum was found significantly superior over its immediate lower level. Thus, a significantly maximum stalk yield was obtained with the incorporation of gypsum @ 100% GR followed by gypsum @ 50% GR.

Pooled means also exhibit a similar trend and a significantly highest enhancement in the stalk yield of cotton by about 50% over

control was observed due to incorporation of gypsum equivalent to 100 % GR. Interaction effect was nonsignificant in pooled analysis (Table 4 a). However, maximum stalk yield was noticed due to furrow opening after each row followed by furrow opening after two rows, in association with gypsum incorporation @ 100 per cent GR.

4.1.3 Economics of seed cotton

Gross and net monetary returns and B:C ratios were calculated on the basis of average cost of cultivation of cotton and other materials used in this investigation and data are presented in Table 5, and Fig. 5.

a) Land treatments

Highest gross (Rs. 26,570) and net monetary returns (Rs. 19,730) were obtained due to furrow opening after two rows of cotton and maximum benefit cost ratio (2.88) was also accrued with this land treatment. The respective benefits in net monetary returns and B:C ratio with furrow opening after two rows over control (no land treatment) and furrow opening after each row were Rs. 8307 and 4313 and 1.19 and 0.66.

A significantly maximum repression in the salinity/sodicity parameters of soil was also estimated in this land treatment. Conclusively, it can be seen that furrow opening after two rows of cotton ^{is} found more beneficial as compared to furrow opening after each row, not only in reclaiming salinity and sodicity of soil but also in achieving ^{benefit} more economical by considering net monetary returns and B:C ratios.

Table 5. Economics of seed cotton as influenced by land treatments and gypsum levels

Treatments	Gross monetary return (Rs. ha ⁻¹)	Cost of cultivation (Rs. ha ⁻¹)	Net monetary return (Rs. ha ⁻¹)	B : C Ratios
Land treatments				
No furrow	18,163	6,740	11,423	1.69
Furrow each row	22,357	6,940	15,417	2.22
Furrow two rows	26,570	6,840	19,730	2.88
Gypsum levels				
G 0	18,872	6,740	12,132	1.80
G 25	21,222	7,552	13,670	1.81
G 50	23,624	8,365	15,259	1.82
G 100	25,534	9,990	15,544	1.56

Cost of cultivation Rs. 6,740 ha⁻¹, cost of seed cotton Rs. 2,000 ha⁻¹, cost of stalk Rs. 100 ha⁻¹, cost of gypsum Rs. 650 ton⁻¹, cost of furrow opening after each row Rs. 200 ha⁻¹ and cost of furrow opening after two rows Rs. 100 ha⁻¹.

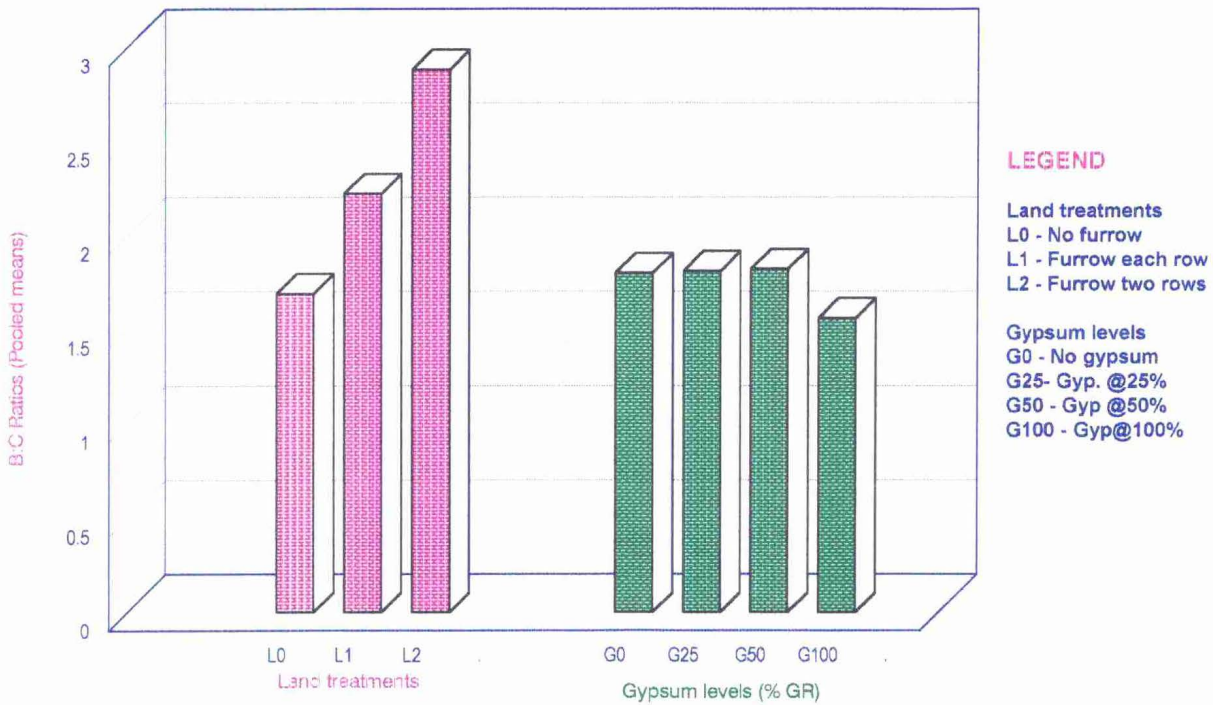


Fig. 5 : B:C ratios of cotton cultivation as influenced by land treatments and gypsum levels

b) Gypsum levels

A linear and progressive increase in gross and net monetary returns were accrued with increasing levels of gypsum incorporation (Table 5, Fig. 5). Thus, maximum gross and net monetary returns were obtained with the incorporation of gypsum @100 followed by 50% GR. Although, higher seed cotton yield and net and gross monetary returns were recorded in G 100, as compared to G 50, maximum B:C ratio (1.82) was accrued with the incorporation of gypsum @50% GR. Data further reveal that an incorporation of gypsum @100% GR estimated least B:C ratio (1.56) amongst all the gypsum levels including G0 due to cost of gypsum added. Thus, considering the B:C ratio which is the most important parameter in economical analysis, incorporation of gypsum @ 50%^{is} found more economically feasible as compared to application of gypsum @100% GR (B:C ratio 1.56). Enhancement in net monetary returns and B:C ratio due to this treatment (G 50) over control (no land treatment) was Rs. 3127 and 0.02, respectively. This^{treatment} also improved the physicochemical parameters of Sodic Haplusterts of Purna valley by suppressing its salinity/sodicity.

4.2 Physical Parameters of Soil

Sodic Vertisols swell on wetting and crack after drying due to predominance of smectite minerals. Alkali levels beyond ESP 10 lead to severe structural degradation (Gupta and Verma, 1983)^{which} resulted into high degree of clay dispersion. The dispersed clay clogs the pores and render salt leaching, rather difficult (Verma *et al.*, 1989) in absence of suitable

amendments and land configurations. Data in respect of physical parameters of soil as influenced by various land treatments and gypsum levels are tabulated and discussed thoroughly in this subtitle.

4.2.1 Bulk density

Initial bulk density (BD) of soil pedon of experimental ~~(BD)~~ field ranged between 1.55 to 1.70 Mg m⁻³ and it increases with depth (Table 1). The increasing trend of BD with increasing depth may be ascribed to compactness of soil at lower depth indicating illdrained nature of soil which render salt leaching rather difficult. To reduce the compactness and to improve the drainability of soil; various land treatments and gypsum levels were applied to Sodic Haplusterts under study and results pertaining to bulk density are given in Table 6 and Fig. 6.

a) Land treatments

Furrow opening after each row and after two rows of cotton reduced the bulk density of surface layer (0 to 20 cm. depth) significantly as compared to control (no land treatment) during both the years of experimentation and in pooled analysis. However, both the land configurations were at par ^{with} each other. Further, pooled results explicitly showed a suppression in BD to the extent of 6.25 and 6.87 per cent over L0 due to furrow opening after each row and two rows, respectively.

A repression in BD may be related to improvement in the reclaimative action of gypsum applied due to furrow opening, which might have resulted into improvement in drainability of sodic Vertisols. Increase in the effectiveness of gypsum in black alkali soils in association with raised and

Table 6. Bulk density (Mg m^{-3}) as influenced by various treatments

Treatments	Year		Pooled	
	94-95	95-96	Means	% decrease
Land treatments				
No furrow	1.64	1.57	1.60	-
Furrow each row	1.54	1.46	1.50	6.25
Furrow two rows	1.47	1.50	1.49	6.87
SE (m) \pm	0.03	0.01	0.02	-
CD (p=0.05)	0.09	0.04	0.06	-
Gypsum levels (% GR)				
G 0	1.76	1.73	1.74	-
G 25	1.46	1.53	1.49	14.37
G 50	1.52	1.43	1.48	14.94
G 100	1.48	1.36	1.42	18.39
SE(m) \pm	0.02	0.01	0.01	-
CD (p=0.05)	0.07	0.03	0.03	-
Interaction				
SE (m) \pm	0.01	0.02	0.02	-
CD (p=0.05)	0.04	NS	0.06	-

Table 6 (a). Interaction effect in respect of bulk density.

Land treatments	Gypsum Levels			
	G 0	G 25	G 50	G 100
No furrow	1.8	1.62	1.53	1.47
Furrow each row	1.69	1.51	1.43	1.37
Furrow two rows	1.73	1.37	1.47	1.41
SE (m) \pm			0.02	
CD (P=0.05)			0.06	

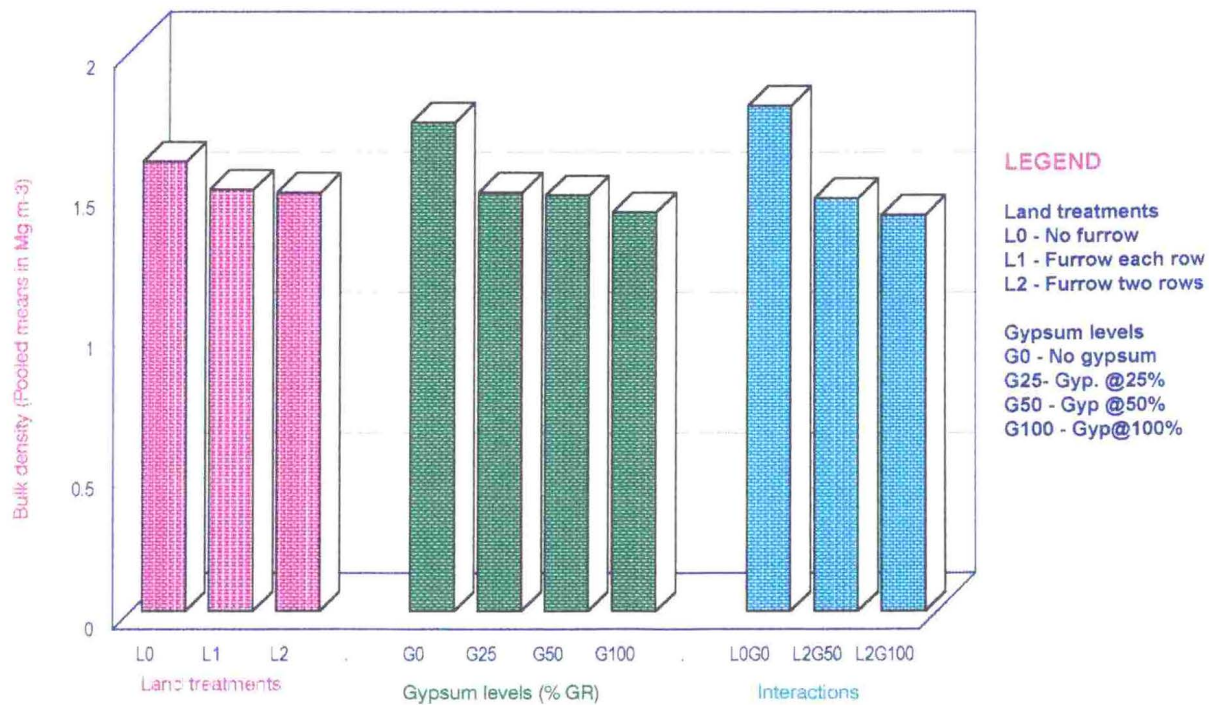


Fig. 6 : Bulk density (Mg m⁻³) as influenced by land treatments and gypsum levels

sunken bed system was noticed by Verma and Sharma (1998) under rainfed situation with modest annual rainfall (< 800 mm). In broad bed and furrow (BBF) system, a separate raised bed cropping zone and traffic zone on the furrow portion are created and therefore, cropping zone always remains loose and friable in Vertisols (Miranda, 1983).

b) Gypsum levels

Amending of gypsum at its various levels (25, 50 and 100% GR) reduced the bulk density of soil significantly over no gypsum incorporation (G0) during both years of experimentation (Table 6). Further, various doses of gypsum incorporation viz. 25, 50 and 100% GR were found comparable in 1994-95, whereas in 1995-96 a significant repression in BD over 25 and 50% GR was observed due to incorporation of gypsum @100% GR.

A significant decrease in BD of soil over G0 with an incorporation of gypsum at its various levels was also noticed in pooled analysis. When the various levels of gypsum were compared, an addition of gypsum @ 100% GR reduced BD significantly over G 25 and G 50 and suppression in BD due to incorporation of gypsum @100% GR was maximum to the extent of 18.4% over G 0. These observations are in accordance with those reported by More *et al.* (1987). Interaction effect of land treatment and gypsum levels was also significant (Table 6a).

The suppression of BD may be due to decrease in ESP/SAR of soil with an incorporation of gypsum in Sodic Haplusterts as observed in further studies. Surface of alkali Vertisols becomes very compact after

drying and BD decreases with reduction in sodium content on exchange complex (Verma and Gupta, 1984).

4.2.2 Hydraulic conductivity

Hydraulic conductivity (HC) of pedon excavated at experimental site varied in the range of 0.30 to 0.91 cm hr⁻¹, which decreased with depth (Table 1); indicating imperfect to poor internal drainage of soil. Balpande (1993) pointed out that low permeability of alkali black soils of Purna valley might be a combined effect of high smectite content, high exchangeable Na and Mg. To improve the drainability/ HC of soil, the land treatments of furrow opening and gypsum levels were applied and data reported in Table 7 and also graphically depicted in Fig. 7.

a) Land treatments

Furrow opening after each row and after two rows of cotton significantly enhanced the HC of soil under investigation over no furrow opening (control) during both the years of experimentation. In 1994-95, furrow opening after each row and after two rows found comparable, whereas, in 1995-96, opening of furrow after two rows observed significantly superior to furrow opening after each row. Pooled data also give an account of significant enhancement in HC of soil due to both land configurations. However, both land configurations applied were at par each other. The corresponding increases in HC of sodic Vertisols due to furrow opening after each row and after two rows were about 18.0 and 27.8 per cent over control. Enhancement of HC, due to land treatments

Table 7. Hydraulic conductivity (cm hr⁻¹) as influenced by land treatments and gypsum levels

Treatments	Year		Pooled	
	94-95	95-96	Means	% increase
Land treatments				
No furrow	0.60	0.84	0.72	-
Furrow each row	0.83	0.86	0.85	18.00
Furrow two rows	0.91	0.93	0.92	28.00
SE (m)±	0.05	0.01	0.03	-
CD (p=0.05)	0.17	0.03	0.10	
Gypsum levels (% GR)				
G 0	0.39	0.44	0.41	-
G 25	0.82	0.93	0.87	112.00
G 50	0.92	1.00	0.96	134.00
G 100	0.99	1.11	1.05	156.00
SE(m)±	0.06	0.01	0.03	
CD (p=0.05)	0.17	0.03	0.08	
Interaction				
SE (m)±	0.02	0.01	0.05	
CD (p=0.05)	NS	0.03	NS	

Table 7 (a). Interaction effect in respect of hydraulic conductivity

Land treatments	Gypsum Levels			
	G 0	G 25	G 50	G 100
No furrow	0.37	0.75	0.83	0.93
Furrow each row	0.39	0.93	0.98	1.08
Furrow two rows	0.48	0.94	1.09	1.16
SE (m)±			0.05	
CD (P=0.05)			NS	

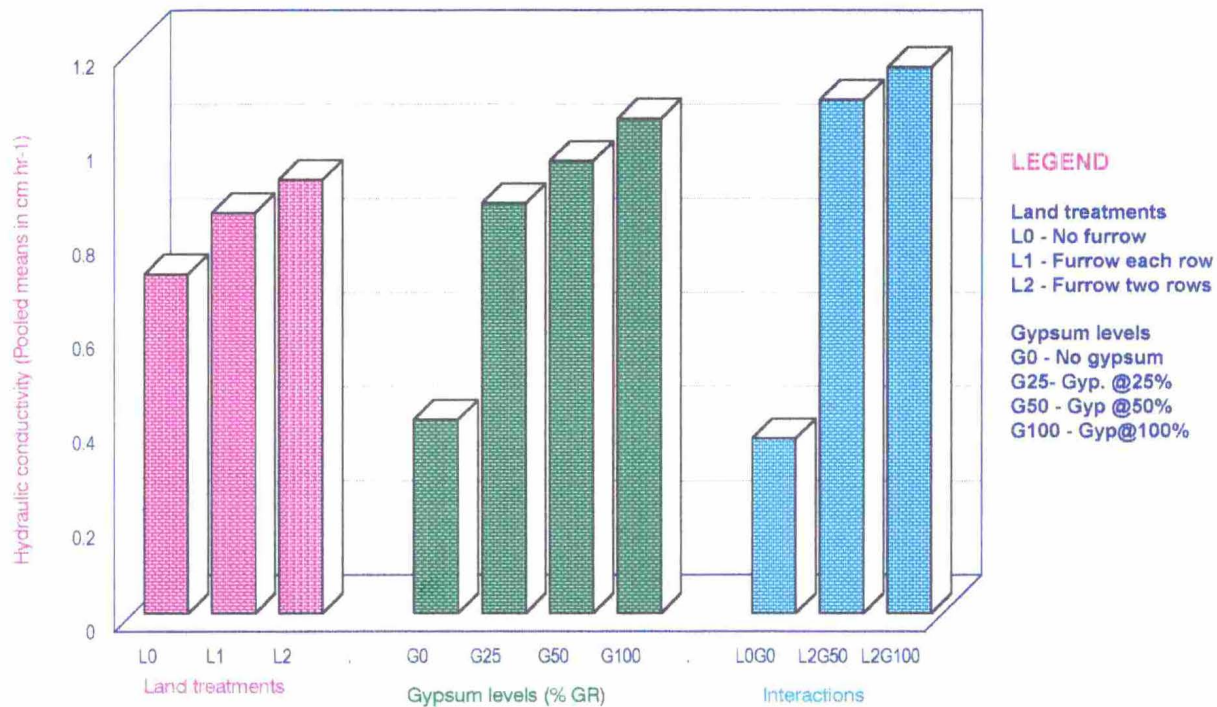


Fig. 7 : Hydraulic conductivity as influenced by land treatments and gypsum levels

could be associated with repression in SAR/ESP of soil as recorded in further observations.

The saturated hydraulic conductivity of soil decreases with increase in SAR and decrease in total electrolyte concentration and thus, swelling and dispersion of clays are main factors influencing on HC of soil (Minhas *et al.*, 1998). Relative saturation of Na as compared to that of Ca and Mg influences strongly on shear strength, swelling pressure, plasticity index and finally on HC (Minhas *et al.*, 1995). Suitable management practices are to be designed to overcome physical problems of Vertisols, since subsurface drainage is not feasible and economical due to very slow permeability and special attention has to be given to manage the Vertisols (Dudal, 1989). Furrows have a prominent feature in ridges and furrow system in Vertisols for effective conservation of surface water until it infiltrates in to soil solum (Kampen, 1979).

b) Gypsum levels

Gypsum incorporation at its various levels augmented significantly the HC of soil over G0 during both the years of investigation (Table 7, Fig. 7). In 1994-95, an addition of gypsum @ 25, 50 and 100% GR were found comparable in influencing the Hc of soil. However, in 1995-96, an incorporation of gypsum @ 100% GR observed significantly superior over G 25 and G 50. In pooled analysis also, a significant rise in HC of sodic Vertisols was appeared due to application of gypsum over no gypsum (G0) application (Table 7). Amongst the various doses, an incorporation of gypsum @ 100% GR gave a significant increase in HC as compared to

gypsum applied @ 25 and 50% GR. Respective increases in HC due to 25, 50 and 100% GR were about 112, 134 and 156 per cent over control (G 0). Enhancement in HC of sodic Vertisols due to gypsum incorporation was also reported by More *et al.* (1987).

Increase in the rate of HC due to incorporation of gypsum may be ascribed to repression of ESP/SAR of Sodic Haplusterts used in this investigation. Dubey and Mondal (1994) stressed that gypsum is more effective in ameliorating the sodic soils by improving infiltration rate. Gypsum incorporation reduces soluble salt content and ESP which resulted into increasing HC of sodic soil, was reported by Chauhan and Tripathi (1983). Highest oxygen diffusion rate (ODR) of sodic Vertisols was recorded with gypsum (5 t ha^{-1}) incorporation which was at par with FYM @ 10 t ha^{-1} (Kalane *et al.*, 1996). A layer method of gypsum incorporation was found more beneficial in enhancing initial rate of advancement of wetting front, increasing depth of wetting and ultimately reducing the time required for wetting the soil columns (Narkhede and Surve, 1996).

Interaction effect of land treatments and gypsum levels found ^{was} non-significant in pooled analysis (Table 7 a). However, maximum increase in HC of sodic Vertisols was estimated due to interaction of furrow opening after two rows amended with gypsum @ 100 per cent GR.

4.2.3 Soil moisture percentage

Soil samples from 0-30 and 30-60 cm depth at vegetative, square formation and boll development stages of cotton were collected and

results pertaining to gravimetric soil moisture percentage are presented in Table 8. A perceptible decrease in soil moisture percentage in both the layers (0-30 and 30-60 cm depth) was noticed from vegetative to boll development stage during both the years. Soil moisture percentages (gravimetric) as influenced by various land treatments and gypsum levels are discussed in this subhead.

a) Land treatments

Data (Table 8) explicitly show that furrow opening after each row and after two rows of cotton, enhanced soil moisture percentage over control (where furrows were not opened). However, highest soil moisture percentage (gravimetric) was recorded due to furrow opening after two rows of cotton during both the years of experimentation. Pooled means of two years also indicated a similar trend and maximum soil moisture percentage was noticed due to opening of furrows after two rows of cotton.

Lesser soil moisture percentage in the treatment of furrow opening after each row as compared to furrow opening after two rows could possibly be due to more exposure of soil surface which ^{have} might resulted in to higher surface runoff and lesser soil moisture percentage. Chittaranjan (1982) also stated that soil acts as reservoir for moisture storage and this characteristic of soil needs to be utilized to the maximum extent by adopting various suitable mechanical measures. Similar increases in soil moisture storage due to opening of furrows by reducing surface runoff in

Table 8. Soil moisture percentage (gravimetric) as influenced by land treatments and gypsum levels

Treatments	Dates of sampling																		
	7/8/94 (Vegetative stage)				21/9/94 (square formation)				27/10/94 (Boll formation)				Means		Profile means		Pooled means of two years		
	1994-95		95-96		94-95		95-96		94-95		95-96		94-95	95-96	94-95	95-96			
0-30 (cm)	30-60 (cm)	0-30 (cm)	30-60 (cm)	0-30 (cm)	30-60 (cm)	0-30 (cm)	30-60 (cm)	0-30 (cm)	30-60 (cm)	0-30 (cm)	30-60 (cm)	0-30 (cm)	30-60 (cm)	0-30 (cm)	30-60 (cm)	0-60 (cm)	0-60 (cm)	0-60 (cm)	
Land treatment																			
No furrow	22.6	16.0	20.5	23.7	15.2	15.2	11.8	10.5	8.2	8.0	10.9	11.5	15.3	13.1	14.4	15.2	14.2	14.8	14.5
Furrow each row	24.6	21.1	26.0	25.7	14.5	14.0	13.9	11.3	8.9	8.2	10.8	10.7	16.0	14.4	14.3	15.9	15.2	15.1	15.1
Furrow two rows	25.9	23.6	28.6	29.5	17.5	17.7	15.2	14.5	12.0	12.0	12.3	12.4	18.5	17.8	18.7	18.1	18.6	18.4	18.5
Gypsum levels (% GR)																			
G 0	21.4	17.4	23.8	22.9	12.7	13.0	13.1	10.7	7.8	12.0	10.1	10.0	14.0	14.1	15.7	14.5	14.0	15.1	14.5
G 25	24.3	20.1	26.1	25.6	14.3	16.5	13.9	12.0	10.0	12.3	11.2	12.3	16.2	16.3	17.1	16.6	16.2	16.8	16.5
G 50	25.9	21.8	27.5	26.9	18.2	15.3	13.7	12.7	9.9	10.0	12.1	12.4	18.0	15.7	17.8	17.3	16.8	17.5	17.2
G 100	25.8	21.6	30.4	29.8	17.8	17.8	14.0	13.1	11.3	12.0	12.0	12.6	18.3	17.1	18.8	18.5	17.7	18.6	18.2

Table 8 (a). Interaction effect in respect of soil moisture percentage (gravimetric)

Land Treatment	Gypsum levels			
	G 0	G 25	G 50	G 100
No furrow	12.8	15.1	15.5	17.1
Furrow each row	14.5	15.8	16.3	17.5
Furrow two rows	16.2	18.6	19.7	

cotton grown on black clays was also reported by Sagare and Bhongle (1993).

b) Gypsum levels

Incorporation of gypsum @ 25, 50 and 100% GR augmented soil moisture percentages (gravimetric) as compared to control (G 0). A linear and progressive increase in soil moisture percentages was estimated due to increasing doses of gypsum and highest soil moisture percentage was recorded due to incorporation of gypsum @ 100% GR during both the years and in pooled analysis.

An incorporation of gypsum greatly enhanced water retention characteristics of soil at a given level of soil moisture tension (Acharya and Abrol, 1978). The increase in seed cotton yield due to incorporation of gypsum could be ascribed to favourable soil water conditions with repression of ESP/SAR and enhancement in infiltration rate of soil with gypsum addition (Dubey and Mondal, 1994).

In pooled analysis (Table 8 a) a maximum soil moisture percentage was recorded due to combined effect of furrow opening after two rows, supplied with gypsum @ 100% GR followed by 50% GR.

4.2.4 Available soil moisture storage

Available water storage capacity (AWC) is very important characteristic of soil in semiarid regions with uncertain rainfall distribution. Vertisols have a relatively high water storage capacity in the root zone because of high content of clay minerals, dominantly of 2:1 type. Initial available moisture content of experimental soil found in the range of 11.14

to 13.80 per cent by volume. Similar range of AWC (10-20%) of sodic Vertisols of Purna Valley was also reported by (Nimkar, 1990). Available soil moisture storage upto 60 cm depth was calculated on the basis of soil moisture percentage (gravimetric), bulk density and PWP and data are presented in Table 9, Fig. 8.

a) Land treatments

From the data, it appears that available soil moisture storage augmented due to land treatment of furrow opening as compared to control (where furrows were not opened) during both the years and also in pooled analysis. In 1994-95, furrow opening after each row found comparable with no furrow opening, in respect of available soil moisture, however, a perceptible increase was recorded due to opening of furrows after two rows. In 95-96, opening of furrows after each row enhanced the soil moisture storage to some extent. However, opening of furrows after two rows gave considerable augmentation in the available soil moisture storage.

In pooled analysis also, a marked increase in available soil moisture storage of root zone (upto 60 cm depth) was noticed due to both land treatments. However, maximum available soil moisture storage was recorded due to furrow opening after two rows and it increased AWC by about 50 per cent over control and furrow opening after each row. These finding are in accordance with those reported by Sagare and Bhongale (1993). It is reported that furrows dykes can effectively conserve water by

Table 9. Available soil moisture storage (mm) as influenced by land treatments and gypsum levels

Treatments	Year		Pooled	
	94-95	95-96	Means	% increase
Land treatments				
No furrow	34.80	34.20	34.50	-
Furrow each row	34.80	37.20	36.00	4.30
Furrow two rows	52.80	54.00	53.40	54.70
Gypsum levels (% GR)				
G 0	36.60	40.20	38.40	-
G 25	35.40	43.80	39.60	3.12
G 50	42.60	43.80	43.20	12.50
G 100	46.80	41.40	44.10	14.80

Table 9 (a). Interaction effect in respect of available soil moisture storage

Land treatments	Gypsum levels			
	G 0	G 25	G 50	G 100
No furrow	27.6	36.6	32.4	41.4
Furrow each row	36.6	39.6	34.2	33.6
Furrow two rows	51.0	42.6	63.0	57.2

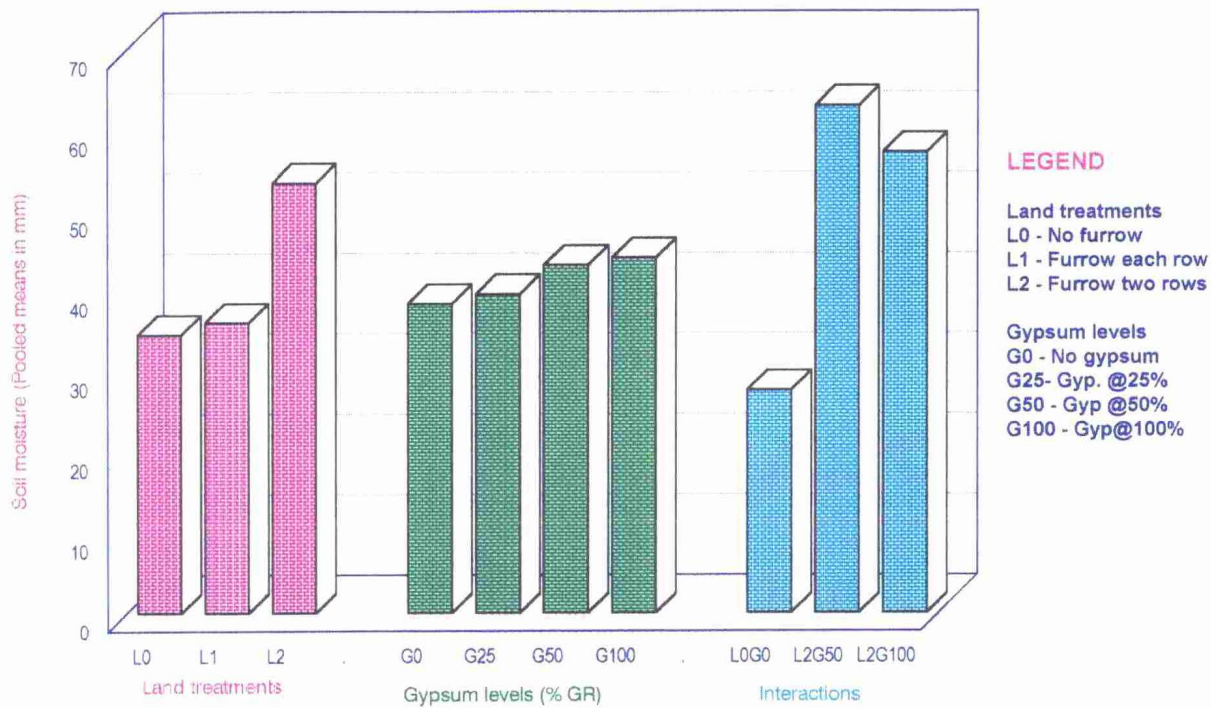


Fig. 8 : Available soil moisture storage (mm) as influenced by land treatments and gypsum levels

retaining potential runoff on field areas, until it infiltrate (Clark and Jonhs, 1981).

b) Gypsum levels

Table 9 (Fig. 8), reveals that incorporation of graded levels gypsum increased the available soil moisture storage of sodic Vertisols and this increase was linear and progressive, during both years and in pooled analysis. However, highest enhancement (14.8% over G 0) in available soil moisture storage was noticed due to incorporation of gypsum @ 100% GR followed by @ 50% GR (12.5% over G 0). Enhancement in the available soil moisture storage may be possibly due to repression in sodicity of Sodic Haplusterts; as indicated by ESP and SAR values; which may resulted into increase in hydraulic conductivity and finally the available soil moisture storage. Data (Table 9a) further, indicated that highest available soil moisture storage was noticed due to interaction of furrow opening after two rows supplied with gypsum @50% GR followed by 100% GR.

From the data of physical parameters, it may be noted that a significantly maximum reduction in BD by 6.87 per cent and a significantly highest enhancement in HC by 28 per cent were recorded due to land configuration of furrow opening after two rows over control (no furrow). A noticeable increase in AWC by 54.7 per cent over L0 was also observed with this land treatment. As regards gypsum levels, an incorporation of gypsum @50 and 100% GR suppressed soil BD significantly by 14.9 and 18.4 per cent and enhanced HC significantly by 134 and 156 per cent

over G 0. A marked increase in AWC by about 12.5 and 14.8 per cent was also found due to these treatments, respectively.

4.3 Chemical Parameters of Soil

4.3.1 pHs

Initial pHs value of pedon studied at the experimental site varied between 8.2 to 8.9 (moderate to very strongly alkaline) and it enhanced with increasing depth of pedon (Table 1). A high pH in sodic soil may be due to Na - bicarbonate/carbonate (Nakayama, 1970). In natural alkali soil, an intimate relationship between pH and sodicity (ESP) was reported by Gupta and Abrol (1990). Data pertaining to pHs of Sodic Haplusterts as influenced various land treatments and gypsum levels are recorded in Table 10 and Fig. 9.

a) Land treatments

A perceptible decrease in pHs of saturated paste of Sodic Haplusterts was noticed due to various land treatments over control during both the years of experimentation (Table 10, Fig.9). In 1994-95, a significant repression in pHs over control was seen due to furrow opening after two rows. However, it was at par with control due to opening of furrows after each row. In 1995-96, both the land treatments were significant in reducing the pHs of sodic Vertisols.

Pooled means also indicate a significant decrease in pHs value due to both land configurations over control and amongst land configurations, furrow opening after two rows found statistically superior over furrow opening after each row. The corresponding reduction in pHs

Table 10. pHs as influenced by land treatments and gypsum levels

Treatments	Year		Pooled	
	94-95	95-96	Means	% decrease
Land treatment				
No furrow	8.8	8.7	8.75	-
Furrow each row	8.7	8.6	8.65	1.14
Furrow two rows	8.6	8.5	8.55	2.28
SE (m)±	0.03	0.01	0.02	
CD (p=0.05)	0.11	0.04	0.08	
Gypsum levels (% GR)				
G 0	9.1	9.2	9.20	
G 25	8.8	8.6	8.73	5.11
G 50	8.6	8.5	8.55	7.06
G 100	8.4	8.2	8.30	9.78
SE (m)±	0.04	0.03	0.03	
CD (p=0.05)	0.13	0.08	0.08	
Interaction				
SE (m)±	0.04	0.05	0.05	
CD (p=0.05)	NS	NS	NS	

Table 10 (a). Interaction effect in respect of pHs

Land treatments	Gypsum levels			
	G 0	G 25	G 50	G 100
No furrow	9.29	8.84	8.69	8.40
Furrow each row	9.13	8.64	8.48	8.35
Furrow two rows	9.10	8.71	8.48	8.10
SE (m)±			0.05	
CD (p=0.05)			NS	

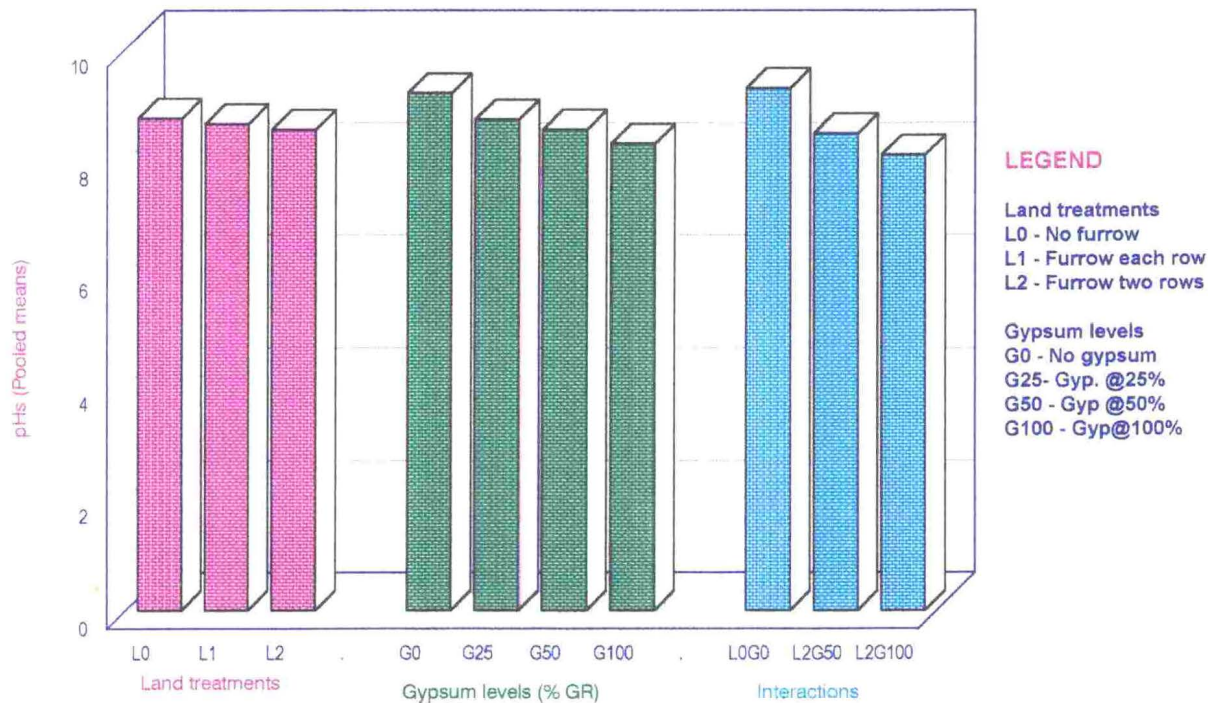


Fig. 9 : pHs as influenced by land treatments and gypsum levels

value due to opening of furrow after each row and after two rows were 0.1 and 0.2 units over no furrow opening and may be attributed to repression of ESP/SAR of sodic Vertisols due to various land configurations. Similar reduction in pH value of sodic Vertisols under raised and sunken bed system in presence of applied gypsum was also reported by Gupta *et al.* (1988), indicating effective utilization of gypsum in dismissal of Na from clay exchange complex under rainfed situation.

b) Gypsum levels

A replacement of exchangeable Na from sodic Vertisols with Ca supplied through gypsum, affects on pHs of sodic Vertisols and data are presented (Table 10). From the data, a linear and significant reduction in pHs of soil was noticed with the incorporation of gypsum @ 25, 50 and 100% GR over G-0 and each higher dose of gypsum application was found superior over its immediate lower level during both years. Thus, highest repression in pHs was recorded due to G 100 which was also significantly superior over G 25 and G 50 in reducing pH of sodic soil.

Pooled data also showed a similar trend in respect of repression of pHs value and a significantly maximum reduction was recorded with the incorporation of gypsum equivalent to 100% GR and this level of gypsum decreased the pH of Sodic Haplusterts from 9.2 (as recorded in control) to 8.3. Thus, pHs recorded in various gypsum levels was in order of G 100 < G 50 < G 25 < G 0. Decrease in pHs value due to gypsum incorporation could be possibly due to suppression of SAR/ESP of Sodic Haplusterts under study. Similar observations were reported by More *et al.* (1987) in

respect of sodic Vertisols of Marathwada (Maharashtra) region. Descending order of pHs with increasing levels of gypsum applied to cotton grown in salt affected Vertisols was also recorded by Tiwari *et al.* (1993). A significant positive correlation of pH with gypsum requirement was reported by Masih and Chauhan (1983).

A perceptible decrease in pHs of experimental soil was observed with the interaction of land treatments and gypsum levels, although the data were non-significant (Table 10 a). However, minimum pH of sodic Vertisols was estimated with the combination of furrow opening after two rows amending with gypsum @ 100% GR.

Conclusively, it may be inferred that a significantly maximum reduction in pHs of Sodic Haplusterts was noticed due to furrow opening after two rows of cotton and incorporation of gypsum @ 100% GR, either applied separately or in combination.

4.3:2 Electrical conductivity

Electrical conductivity of the saturation extract (EC_e) of pedon (saline-sodic Vertisols) ranged between 2.42 to 5.50 dSm⁻¹ and it augmented with the depth of pedon (Table 1). This was the general trend observed in rainfed Sodic Vertisols (Siddiqui and Ghonsikar, 1981), indicating accumulation of salts in the lower horizons of pedon.

a) Land treatments

Data (Table 11, Fig. 10) explicitly show that opening of furrows after each row and two rows of cotton reduced the EC_e of Sodic Haplusterts significantly over no furrow treatment during both years.

Table 11. ECe (dSm-1) as influenced by land treatments and gypsum levels

Treatments	Year		Pooled	
	94-95	95-96	Means	% decrease
Land treatment				
No furrow	3.84	3.34	3.59	-
Furrow each row	3.37	3.15	3.26	9.2
Furrow two rows	3.46	3.16	3.31	6.7
SE (m)±	0.08	0.03	0.04	
CD (p=0.05)	0.27	0.1	0.14	
Gypsum levels (% GR)				
G 0	4.51	4.42	4.47	-
G 25	3.57	3.05	3.31	25.9
G 50	3.16	2.80	2.98	33.3
G 100	3.00	2.60	2.80	37.3
SE (m)±	0.08	0.05	0.05	
CD (p=0.05)	0.24	0.15	0.15	
Interaction				
SE (m)±	0.14	0.08	0.088	
CD (p=0.05)	NS	NS	0.256	

Table 11 (a). Interaction effect in respect of ECe

Land treatments	Gypsum levels			
	G 0	G 25	G 50	G 100
No furrow	4.56	3.50	3.10	3.19
Furrow each row	4.45	3.13	2.86	2.61
Furrow two rows	4.40	3.29	2.97	2.60
SE (m)±			0.088	
CD (p=0.05)			0.256	

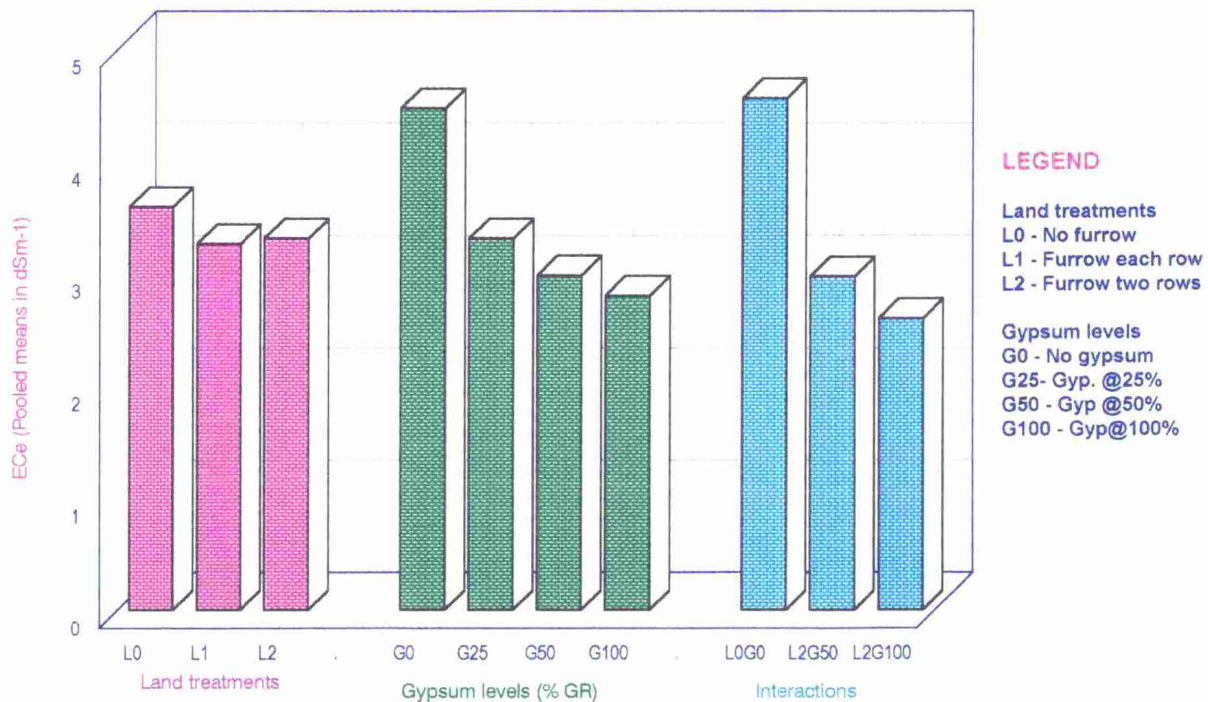


Fig. 10 : ECe (dSm-1) as influenced by land treatments and gypsum levels

However, both the land configurations were found comparable in respect of repression in ECe of saline-sodic Vertisols. Exactly similar trend was noticed after pooling the data of two years. The corresponding decreases in ECe due to furrow opening after each row and after two rows were 9.2 and 6.7 per cent over control. This may be possibly due to efficient leaching of salts due to opening of furrows, which may resulted into reduction of ECe of surface soil. Reclamation of alkali soils requires assured water supplies after incorporation of chemical amendments; the raised and sunken bed system has been suggested for improving drainage and water storage under rainfed which may resulted into repression in ECe of sodic Vertisols (Gupta *et al.*, 1988). In this investigation, furrow acts as a sunken bed, whereas raised portion between two furrows acts as raised beds.

b) Gypsum levels

An incorporation of gypsum @ 25, 50 and 100% GR suppressed ECe significantly over G 0 during both years (Table 11 and Fig. 10). Data, further reveal that each higher level of gypsum decreased ECe over its immediate lower level and significantly highest reduction in ECe was noticed with the incorporation of gypsum @ 100% GR during both years.

Pooled means of investigation also show a linear and significant reduction in ECe due to addition of gypsum as compared to control (G 0), where gypsum was not amended. Data, further give an account of maximum reduction of ECe with amending the gypsum @ 100% GR and this level was found significantly superior over G 0, G 25 and G 50 in

suppressing the ECe. Thus, ECe recorded in various gypsum levels was in the order of G 100 < G 50 < G 25 < G 0. Similar reductions in EC were also reported by More *et al.* (1987), in respect of sodic Vertisols of Marathwada region (Maharashtra). A Linear decrease in ECe with increasing gypsum levels applied to cotton grown in salt affected Vertisols was also indicated by Tiwari *et al.* (1993).

Interaction effect between land treatments and gypsum levels was significant in pooled analysis (Table 11a), indicating enhancement of gypsum efficiency in presence of furrow opening and highest repression in ECe was observed with furrow opening after two rows and supplied with gypsum @ 100% GR. These findings are in accordance with those of Gupta *et al.* (1988) and Verma and Sharma (1998).

4.3.3 Sodium adsorption ratio

Initial sodium adsorption ratio of saturation extract (SAR_e) of experimental field ranged between 11.94 to 25.80, which increased with the depth of soil pedon (Table 1), indicated the sodic nature of soil under study. Results pertaining to the impact of various land treatments and gypsum levels on SAR_e of soil are encompassed in Table 12 and Fig. 11.

a) Land treatments

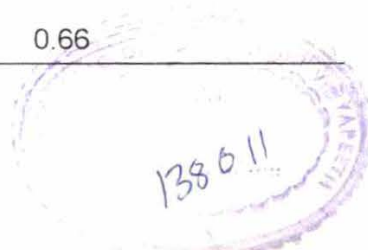
The SAR_e of surface soil under investigation was reduced significantly over control (no land treatment applied) due to furrow opening after each row and after two rows of cotton and latter (furrow opening after two rows) was also significantly superior to former (furrow opening after each row) during both the years.

Table 12. SARE as influenced by land treatments and gypsum levels

Treatments	Year		Pooled	
	94-95	95-96	Means	% decrease
Land treatments				
No furrow	14.12	11.60	12.86	-
Furrow each rows	12.37	10.44	11.40	11.3
Furrow two rows	10.14	9.42	9.78	23.9
SE (m)±	0.09	0.04	0.11	
CD (p=0.05)	0.32	0.15	0.38	
Gypsum levels (% GR)				
G 0	18.15	15.75	16.95	-
G 25	13.15	11.42	12.28	27.5
G 50	9.70	8.32	9.01	46.8
G 100	7.98	6.30	7.14	57.9
SE (m)±	0.09	0.08	0.13	
CD (p=0.05)	0.28	0.24	0.38	
Interaction				
SE (m)±	0.11	0.13	0.23	
CD (p=0.05)	0.38	0.39	0.66	

Table 12 (a). Interaction effect in respect of SARE

Land treatment	Gypsum levels			
	G 0	G 25	G 50	G 100
No furrow	18.96	13.44	10.34	8.70
Furrow each row	15.91	12.66	9.77	7.26
Furrow two rows	16.00	10.75	6.92	5.45
SE (m)±			0.23	
CD (p=0.05)			0.66	



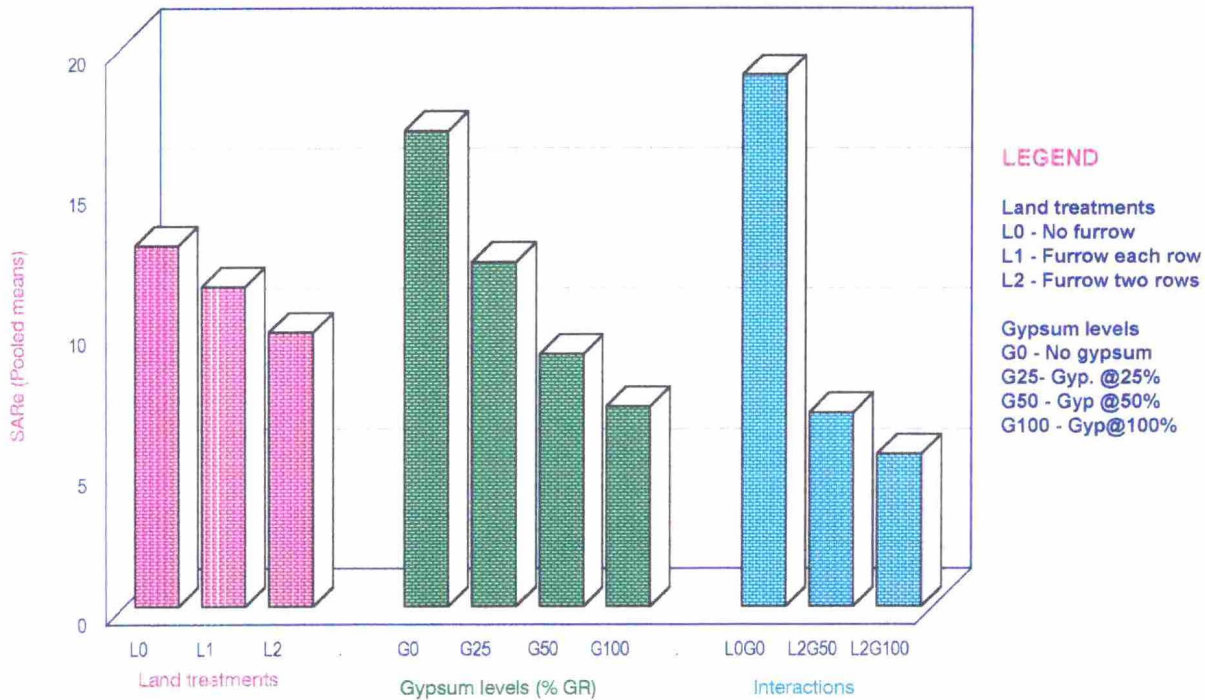


Fig. 11 : SARe as influenced by land treatments and gypsum levels

In pooled analysis, a significant and perceptible repression in the SARE of Sodic Haplusterts was recorded due to both land treatments, however, significantly maximum reduction in SARE was noticed with furrow opening after two rows, which was also statistically significant over opening of furrows after each row. The corresponding reductions due to opening of furrows after each and after two rows of cotton were 11.3 and 23.9 per cent over control. This may be ascribed to leaching of ionic Na^+ and relative enhancement in ionic Ca^{++} and Mg^{++} in soil solution due to furrow opening treatments. Positive relationship of SARE and exchangeable Na pertaining to Purna valley soils was recorded by Balpande (1993). Chemical amelioration of saline sodic soils is rather a complicated process, which involves complex chemical reactions and displacement and translocation of the original and newly formed soluble salts (Mkrtchyan, 1991).

b) Gypsum levels

A linear and significant decrease in SARE of Sodic Haplusterts (soil under study) of Purna valley was observed with incorporation of gypsum @ 25, 50 and 100% GR and each higher levels of gypsum addition found superior over lower levels of gypsum in reducing SARE during both the years. However, significantly maximum repression was noticed due to incorporation of gypsum @ 100% followed by 50% GR.

Pooled results also exhibit similar descending pattern and a maximum significant reduction of SARE was estimated due to incorporation of gypsum @ 100% GR which was superior over G 25 and

G 50 in respect of SARE reduction. The corresponding decreases due to G 25, G 50 and G 100 were 27.5, 46.8 and 57.9 per cent over G 0. Thus, SARE recorded in various gypsum levels was in the order of G 100 < G 50 < G 25 < G 0. Similar repression of SARE of sodic Vertisols was also reported by More *et al.* (1987). Gypsum is found more effective in dismissal of Na and increasing Ca and Mg ions on soil exchange complex, which may resulted in to improvement in physico-chemical parameters of sodic soils (Patel and Singh, 1991).

Interaction effect between land treatments and gypsum levels was significant during both the years and in pooled analysis, indicating more and more reduction of SARE in combinations of land treatments and gypsum levels. Highest reduction in SARE was noticed due to opening of furrows after two rows, amended with gypsum @ 100% followed by 50% GR.

From the foregoing discussion, it can be concluded that a significantly maximum reduction in SARE was noticed due to opening of furrows after two rows and application of gypsum @ 100% GR followed by gypsum @ 50% GR applied either separately or in combination.

4.3.4 Ionic composition of saturation extract

Initial composition pertaining to saturation extract of various horizons of representative pedon (Table 1) indicated that sodium was dominant in the saturation extract (18.7 to 35.6 Cmol L⁻¹) followed by calcium (2.25 to 4.05 Cmol L⁻¹) and Mg (1.18 to 1.69 Cmol L⁻¹). Similar domination of Na over Ca and Mg in saturation extract of sodic Vertisols

of Purna Valley was noticed by Balpande (1993). Ionic composition of saturation extract of surface soil samples pertaining to ionic Na^+ , Ca^{++} and Mg^{++} ; as influenced by various land treatments and gypsum levels is presented in Table 13, 14 and 15 and Fig. 12, 13 and 14, respectively.

(I) Ionic Na

a) Land treatments

Land treatments reduced ionic Na^+ in saturation extract of soil over no furrow opening (Table 13, Fig. 12) and amongst two land configurations, furrow opening after two rows suppressed ionic Na significantly as compared to control and furrow opening after each row and minimum ionic Na was noticed in this treatment during both the years. Pooled results also show a similar trend and significantly maximum decrease in ionic Na, by about 22 per cent over control was estimated due to furrow opening two rows. Repression in ionic Na in saturation extract might be attributed to effective utilization of gypsum due to land treatment applied and removal of Na from surface layer of sodic Vertisols by Ca supplied through gypsum, which may further resulted into reduction in SARE of experimental soil.

b) Gypsum levels

Data in Table 13 (Fig. 12), evident that incorporation of gypsum at its various levels (25, 50 and 100% GR) decreased ionic Na^+ in saturation extract of soil over G 0 (no gypsum application) and each higher dose of gypsum addition was found significantly superior over lower level in suppressing ionic Na^+ from saturation extract during both the years of

Table 13. Ionic Na⁺ (Cmol L⁻¹) as influenced by land treatments and gypsum levels

Treatments	Year		Pooled	
	94-95	95-96	Means	% decrease
Land treatments				
No furrow	20.42	20.22	20.32	
Furrow each row	19.2	18.99	19.09	6.05
Furrow two rows	15.92	15.58	15.75	22.5
SE (m)±	0.1	0.03	0.46	
CD (p=0.05)	0.35	0.11	1.61	
Gypsum levels (% GR)				
G 0	24.87	24.45	24.66	
G 25	20.49	18.07	19.28	21.8
G 50	15.90	15.60	15.75	36.1
G 100	14.56	13.14	13.87	43.7
SE (m)±	0.09	0.06	0.53	
CD (p=0.05)	0.26	0.16	1.54	
Interaction				
SE (m)±	0.15	0.09	0.92	
CD (p=0.05)	0.45	0.28	NS	

Table 13 (a). Interaction effect in respect of ionic composition of Na⁺

Land treatments	Gypsum levels			
	G 0	G 25	G 50	G 100
No furrow	26.74	22.72	18.00	15.84
Furrow each row	24.35	20.15	17.20	14.68
Furrow two rows	22.88	17.00	12.04	11.11
SE (m) ±			0.92	
CD (p=0.05)			NS	

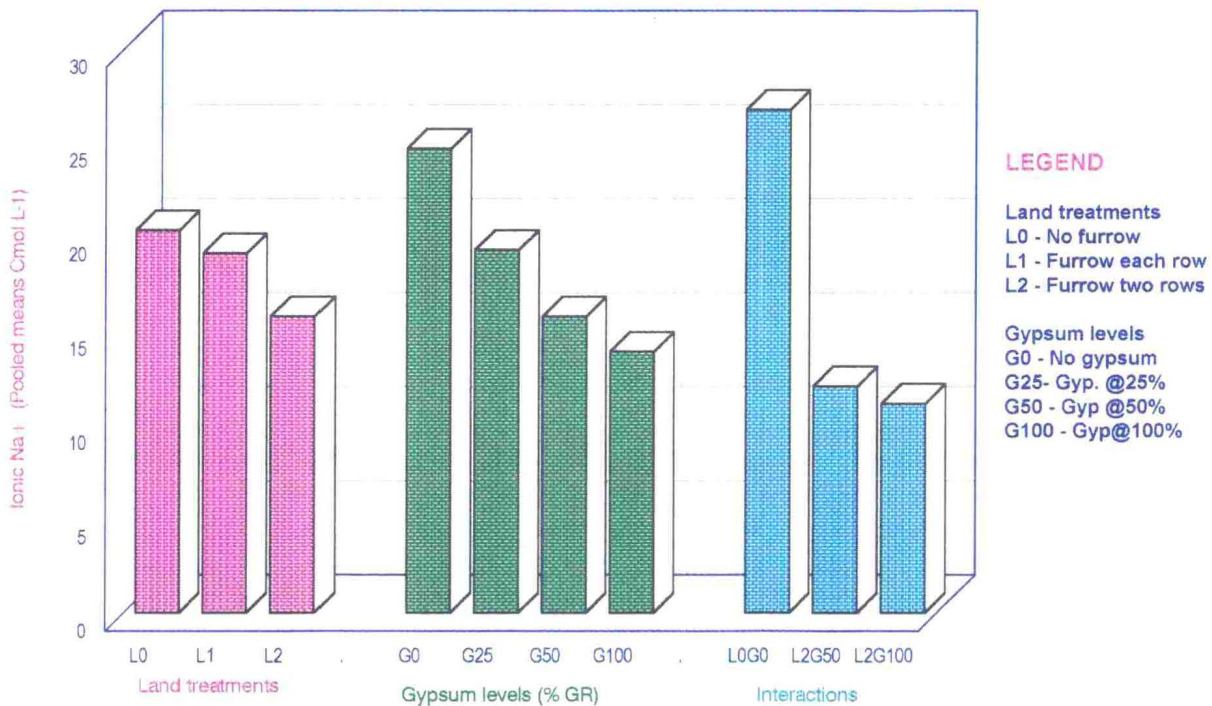


Fig. 12 : Ionic Na+ (Cmol L-1) as influenced by land treatments and gypsum levels

experimentation. Similar trend in respect of repression of ionic Na^+ was also observed in pooled data and significantly maximum reduction by about 44% over control (no gypsum) was observed due to incorporation of gypsum @ 100% GR followed by gypsum @ 50% GR. Ionic Na^+ composition followed the order as $G\ 100 < G\ 50 < G\ 25$ and $< G\ 0$.

It is obvious to reduce the ionic Na due to addition of Ca through gypsum, which replaces Na from the clay complex of surface soil. In the leachate collected from gypsum amended soil, Na^+ increased with increasing levels of applied gypsum (Singh *et al.*, 1980). While studying the effect of various amendments on leachate composition, Patel and Singh (1991), reported that gypsum was found more effective in removing Na as compared to pressmud cake and pyrites.

Interaction effect in pooled analysis (Table 13a) was non significant. However, highest decrease in ionic Na was found due to interaction of furrow opening after two rows and gypsum incorporation @ 100% GR followed by gypsum @50% GR.

II) Ionic Ca

a) Land treatments

It is obvious and interesting to note that by and large opposite trend was observed pertaining to ionic composition of Ca^{++} in saturation extract, as compared to ionic Na^+ . Data further implied that (Table 14, Fig.13) furrow opening after each row and after two rows of cotton significantly enhanced the ionic Ca^{++} in saturation extract over control during the both years. However, in 1994-95, furrow opening after tow rows

Table 14. Ionic composition of Ca⁺⁺ (Cmol L⁻¹) as influenced by land treatments and gypsum levels

Treatments	Year		Pooled	
	1994-95	95-96	Means	% increase
Land treatments				
No furrow	3.66	5.21	4.43	-
Furrow each row	3.97	6.05	5.01	13.1
Furrow two rows	4.17	5.62	4.90	10.6
SE (m)±	0.03	0.03	0.04	
CD (p=0.05)	0.09	0.11	0.14	-
Gypsum levels (% GR)				
G 0	2.92	4.00	3.46	-
G 25	3.87	4.27	4.07	17.6
G 50	4.20	6.02	5.11	47.7
G 100	4.77	8.27	6.52	88.4
SE (m)±	0.05	0.06	0.02	
CD (p=0.05)	0.14	0.17	0.09	
Interaction				
SE (m)±	0.08	0.1	0.03	
CD (p=0.05)	0.24	0.29	0.08	

Table 14 (a). Interaction effect in respect of ionic composition of Ca⁺⁺

Land treatments	Gypsum levels			
	G 0	G 25	G 50	G 100
No furrow	3.22	3.80	5.05	5.65
Furrow each row	3.89	4.30	5.20	6.65
Furrow two rows	3.25	4.02	5.07	7.25
SE (m)±			0.03	
CD (p=0.05)			0.08	

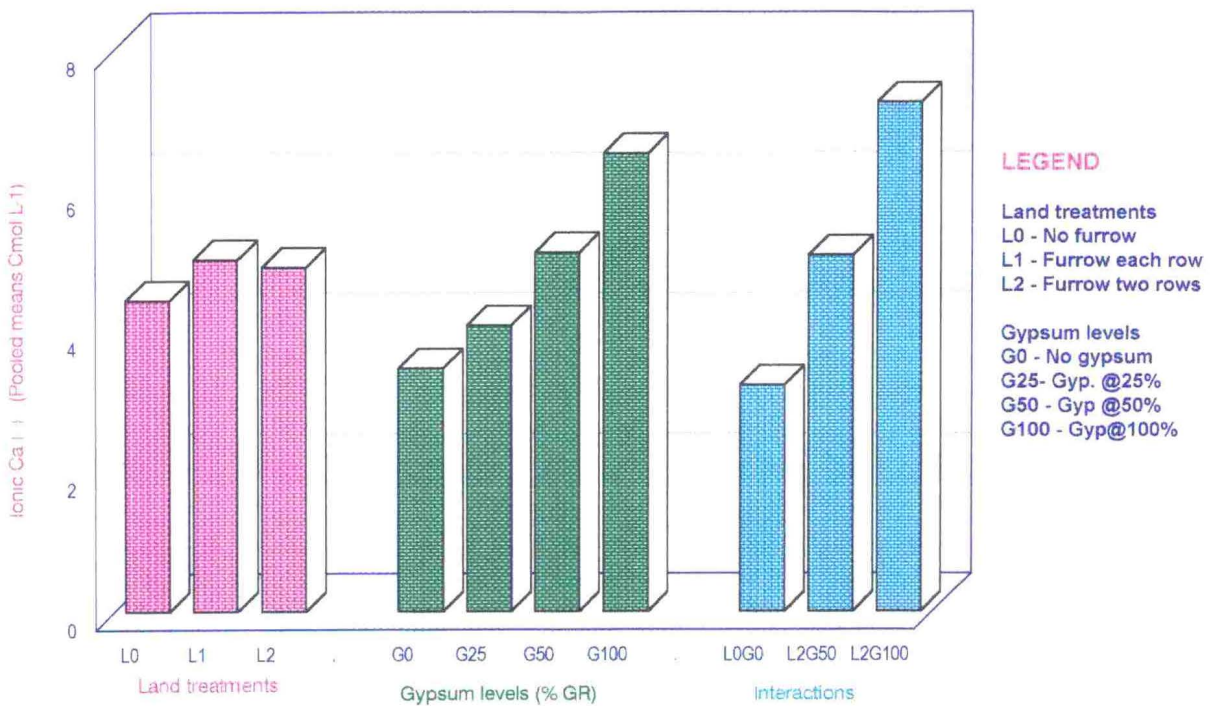


Fig. 13 : Ionic Ca⁺⁺ (Cmol L⁻¹) as influenced by land treatments and gypsum levels

found superior over furrow opening after each row, whereas, reverse trend was observed in 1995-96, in respect of enhancing ionic composition of Ca in saturation extract.

Pooled data give an account of augmentation in the ionic composition of Ca^{++} due to land treatments as compared to control. However, both were at par with each other. The corresponding increases in the ionic composition of Ca^{++} in saturation extract due to opening of furrows after each row and after two rows were 13.1 and 10.6 per cent as compared to control; where no land treatment was given. This could be possibly due to dismissal of Na with Calcium (added through gypsum), as effectiveness of incorporated gypsum enhanced with the opening of furrow treatment. Enhancement in the reclaimative efficiency of gypsum due to land configuration of raised and sunken bed system in sodic Vertisols was also noticed by Verma and Sharma (1998).

b) Gypsum levels

Table 14 (Fig. 13), implies that incorporation of gypsum @25,50 and 100% GR augmented significantly the calcium content in saturation extract during both the years. Further, it is clearly showed that each higher dose of gypsum incorporation found significantly superior over its lower levels and thus, significantly highest enhancement of calcium concentration in saturation extract of sodic Vertisols was estimated due to gypsum incorporation @ 100% GR followed by 50% GR, during 1994-95 and 95-96.

Pooled means also indicate a significantly progressive increase in ionic Ca^{++} in saturation extract with gypsum incorporation @ 25, 50 and 100% GR; indicating additive effect of each higher dose of gypsum over its lower dose. A significantly highest enhancement in ionic composition of calcium was appeared due to gypsum application @ 100% GR followed by 50% GR. The respective increases in ionic calcium in saturation extract due G 25, G 50 and G 100 were 17.6, 47.7 and 88.4 per cent over G 0. Thus, the efficiency gypsum levels in increasing ionic Ca^{++} followed the order as $\text{G 100} > \text{G 50} > \text{G 25} > \text{G 0}$.

While studying the effect of gypsum on rice and wheat in sodic soil, Dubey and Mondal (1994) observed an increase in the exchangeable Ca^{++} Mg^{++} with gypsum incorporation. In the leachate collected from amended soil, its calcium content was enhanced with increasing levels of applied gypsum (Singh *et al.*, 1980). Gypsum not only supplies soluble calcium but also resulted in greater solubilization of native CaCO_3 as indicated by a greater build of bivalent cations and reduction of monovalent once (Shivakant and Rajkumar, 1992).

Interaction effect (Table 14 a) between land treatments and gypsum levels was significant in pooled analysis and highest ionic concentration of calcium was noticed in the interaction of furrow opening after two rows alongwith incorporation of gypsum @ 100% GR.

III) Ionic magnesium

a) Land treatments

Land configuration treatments enhanced significantly the ionic composition of Mg^{++} in saturation extract over control (Table 15, Fig.14) and maximum increase in the ionic Mg^{++} was found due to furrow opening after two rows in 1994-95. However, reverse trend was noticed during 1995-96.

In pooled data, a numerical increase in the ionic composition of Mg in saturation extract over control was noticed due to furrow opening treatments. However, results were statistically at par. This may be ascribed to removal of sodium due to addition of gypsum and effective leaching of it as sodium sulphate due to land treatment and corresponding increase in divalent cations of Ca^{++} and Mg^{++} and solubilization of native Mg^{++} .

b) Gypsum levels

A significant enhancement in the ionic composition of Mg^{++} was estimated due to incorporation of graded levels of gypsum over G 0, where no gypsum was applied, during both years. However, in 1994-95 the various levels of gypsum (@ 25, 50, 100% GR) were at par, whereas in 1995-96, incorporation of gypsum @ 100% GR enhanced significantly the ionic composition of Mg^{++} over G 25, whereas it was at par with G 50.

A significant enhancement in the ionic composition of Mg^{++} due to incorporation of gypsum over control was also appeared in pooled

Table 15. Ionic composition of Mg⁺⁺ (Cmol L⁻¹) as influenced by various treatments and gypsum levels

Treatments	Year		Pooled	
	1994-95	95-96	Means	% increase
Land treatments				
No furrow	0.87	1.00	0.93	
Furrow each row	0.99	0.95	0.97	4.3
Furrow two rows	1.08	0.87	0.98	5.4
SE (m)±	0.02	0.01	0.03	
CD (p=0.05)	0.07	0.04	NS	
Gypsum levels (% GR)				
G 0	0.86	0.74	0.80	
G 25	1.01	0.98	0.99	23.7
G 50	1.03	0.98	1.00	25.0
G 100	1.03	1.06	1.05	31.2
SE (m)±	0.02	0.04	0.02	
CD (p=0.05)	0.07	0.11	0.06	
Interaction				
SE (m)±	0.039	0.065	0.029	
CD (p=0.05)	0.115	0.093	NS	

Table 15 (a). Interaction effect in respect of ionic composition of Mg⁺⁺

Land treatments	Gypsum levels			
	G 0	G 25	G 50	G 100
No furrow	0.75	0.95	1.05	1.00
Furrow each row	0.80	1.07	1.00	1.05
Furrow two rows	0.85	0.99	0.97	1.10
SE (m)±			0.029	
CD (p=0.05)			NS	

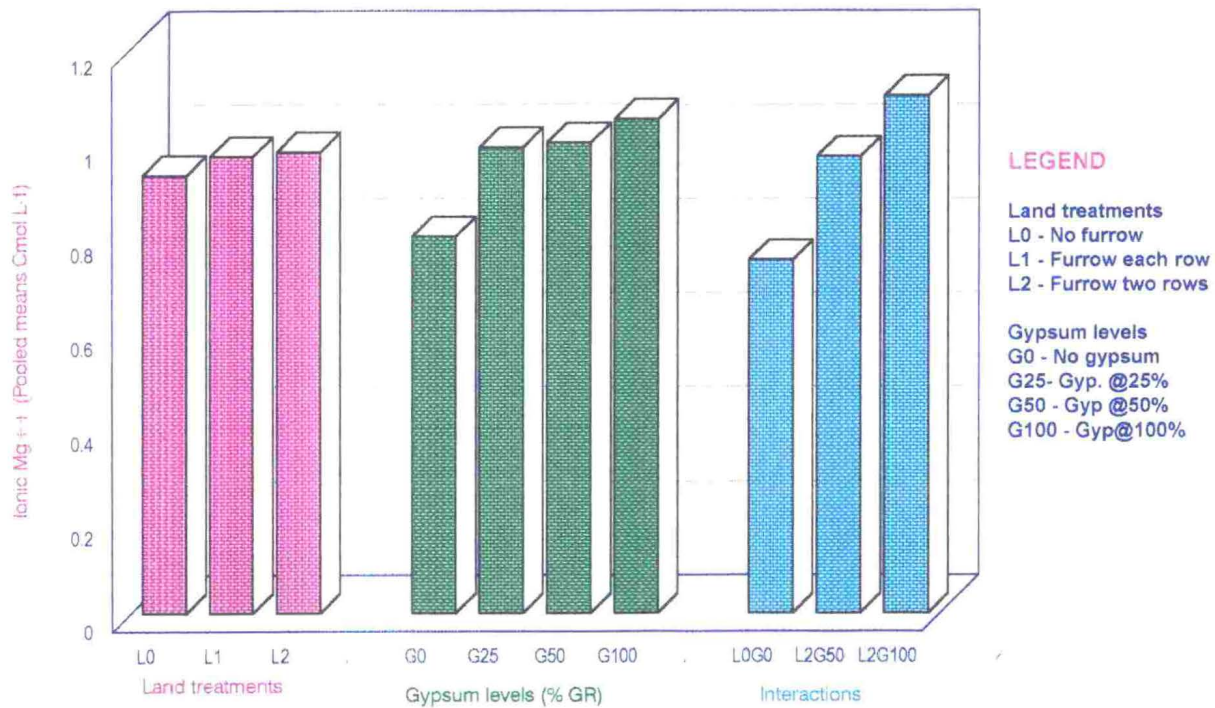


Fig. 14 : Ionic Mg⁺⁺ (Cmol L⁻¹) as influenced by land treatments and gypsum levels

analysis. However, various levels of gypsum (G 25,50 and 100% GR) were comparable with each other. Maximum numerical increase in ionic Mg^{++} by about 31 per cent over G 0 was noticed due to incorporation of gypsum @ 100% GR. Interaction effect in pooled analysis was non-significant.

Gypsum incorporation built up bivalent cations in soil by reducing the monovalent once. However, since the diamemer of a hydrated calcium ions is slightly less than that of magnesium ions, calcium is adsorbed slightly more strongly as compared to Mg^{++} on the clay surfaces. As the repulsive force (responsible of swelling and dispersion) in a calcium clay is smaller, the aggregates in a calcium soils are more stable (Shivakant and Rajkumar, 1992).

To summarize, in pooled analysis a significant decrease in ionic Na^+ and increase in ionic Ca^{++} over control were noticed due to furrow opening after two rows. Further, a significantly maximum decrease in ionic Na^+ and increase in ionic Ca^{++} and Mg^{++} were observed over G 0 due to incorporation of gypsum @ 100% GR followed 50% GR.

4.3.5 Exchangeable sodium percentage

Exchangeable sodium percentage (ESP) of representative pedon of experimental site varied in between 14.06 to 27.85 (Table 1) and it increased with the depth of soil solum; indicating development of sodicity in lower horizons of pedon and migrating towards surface horizons, which might be attributed to the dry and hot climatic conditions and draught prone rainy season of this valley.

a) Land treatments

The results recorded in Table 16 and Fig. 15, explicitly show that the highest ESP recorded in control and a significant and perceptible decrease in ESP was noticed due to various land treatments over the treatment without it. Within the land treatments, significantly maximum suppression in ESP was noticed due to furrow opening after two rows of cotton which was significantly superior to furrow opening after each row in respect of ESP reduction, during both years and also in pooled analysis.

In pooled results, opening of furrows after each row and after two rows reduced the ESP by about 11.8 and 22.6 per cent over control. Repression in ESP due to land treatments may be possibly due to dismissal of Na from exchange complex with an incorporation of gypsum and effective leaching of sodium sulphate from the surface soil with land treatments applied. These findings are in accordance with those of Verma and Sharma (1998) in respect of raised and sunken bed system, practiced in sodic Vertisols of Madhya Pradesh. They further, reported a higher ESP in sunken bed as compared to raised bed and effective utilization of gypsum under rainfed situation.

b) Gypsum levels

A linear and significant reduction in ESP was appeared due to increasing levels of gypsum during both years and in pooled analysis. Further, each higher dose of gypsum incorporation found significantly superior over its lower level and a minimum ESP was noticed due to incorporation of gypsum @ 100% GR, in 1994-95, 95-96 and even in

Table 16. ESP as influenced by land treatments and gypsum levels

Treatments	Year		Pooled	
	94-95	95-96	Means	% decrease
Land treatments				
No furrow	15.13	14.29	14.71	-
Furrow each row	13.19	12.77	12.98	11.8
Furrow two rows	11.87	10.9	11.38	22.6
SE (m)±	0.15	0.05	0.09	
CD (p=0.05)	0.5	0.18	0.31	
Gypsum levels (% GR)				
G 0	19.69	17.83	18.76	-
G 25	14.17	13.47	13.82	26.3
G 50	10.59	10.09	10.34	44.9
G 100	9.13	9.23	9.18	51.1
SE (m)±	0.17	0.06	0.08	
CD (p=0.05)	0.50	0.17	0.24	
Interaction				
SE (m)±	0.30	0.1	0.14	
CD (p=0.05)	0.87	0.3	0.42	

Table 16 (a). Interaction effect in respect of ESP

Land treatments	Gypsum levels			
	G 0	G 25	G 50	G 100
No furrow	20.70	15.40	11.99	10.75
Furrow each row	17.80	14.15	10.55	9.45
Furrow two rows	17.78	11.90	8.49	7.35
SE (m)±			0.14	
CD (p=0.05)			0.42	

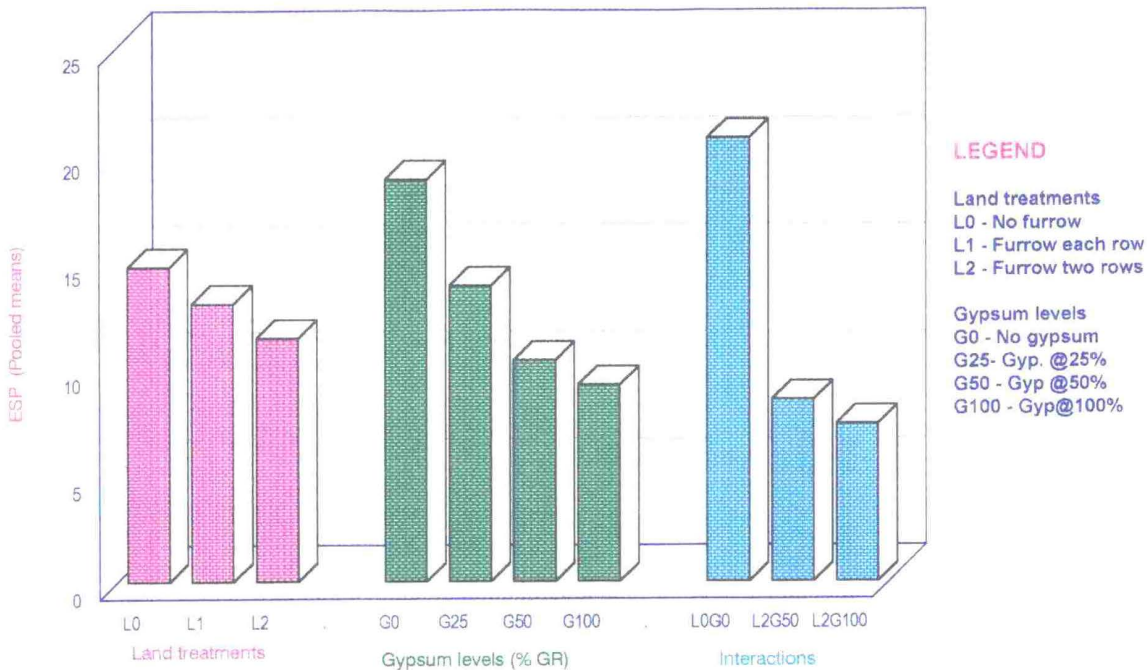


Fig. 15 : ESP as influenced by land treatments and gypsum levels

pooled analysis. The corresponding reductions in ESP (pooled analysis) due to G 25, 50 and 100 per cent GR were 26.3, 44.0 and 51.0 over G 0. Thus, performance of various gypsum levels in the reduction of ESP can be expressed as $G\ 100 > G\ 50 > G\ 25 > G\ 0$.

A significant reduction in ESP of soil and subsequent increase in Ca^{++} and Mg^{++} on exchange complex of sodic soils of Karnal (Haryana) was also recorded by Dubey and Mondal (1994). In the leachate collected from gypsum added soil; Na, K, Ca, CO_3 and HCO_3 and SO_4 were increased with enhancement of gypsum level. Further, a greater decline in ESP was estimated with repression in calcium concentration in leaching solution (Masih and Chauhan, 1983). Patel and Singh (1991), pointed out that gypsum was found more effective in dismissal of Na^+ as compared to pressmud cake and pyrites and increasing the calcium and magnesium on soil complex.

Interaction effect (Table 16 a) between gypsum levels and land treatments were significant during 1994-95, 95-96 and after pooling the data and minimum ESP in pooled analysis was recorded due to combination of furrow opening after two rows of cotton supplied with gypsum @ 100 % GR followed by gypsum @ 50 % GR.

From the data, it can be concluded that a significantly maximum decrease in ESP of Sodic Haplusterts was recorded due to furrow opening after two rows, which was significantly superior over control and furrow opening after each row in reducing ESP. Amongst the

gypsum levels, incorporation of gypsum @ 100 % and 50 % GR reduced ESP significantly over G 0 and G 25.

4.4 Correlation and Regression Studies

4.4.1 Correlation studies

a) Yield and soil attributes

The correlation matrix was worked out to decide the relationship of soil parameters amongst themselves and seed cotton yield. Data are recorded in Table 17.

A highly significant positive correlation was observed between seed cotton yield and hydraulic conductivity ($r=0.759^{**}$) and ionic Ca^{++} ($r=0.658^*$); indicating enhancement in seed cotton yield with increasing HC and ionic Ca^{++} in Sodic Haplusterts. In this investigation, these soil parameters were found to be enhanced due to applied land treatments and gypsum levels.

Considering the management of soil, the characteristics of Vertisols appear to be more important are: hardness when dry, plasticity when wet, HC, AWC, sodium saturation and salt content (Dudal, 1989). Amongst these properties, soil moisture regime is the major parameter of Vertisols that influence the productivity of crops, which is mainly governed by hydraulic conductivity of soil (Blokhuis, 1989). A significantly highest seed cotton yield grown in Vertisols was also recorded in the treatment in which available soil moisture storage was maximum (Sagare and Bhongle, 1993). Positive relationship of soil moisture storage and productivity of

Table 17. Correlation matrix of soil parameters and seed cotton yield

Parameters	pHs	ECe	BD	HC	ESP	SARe	Ionic Na ⁺	Ionic Ca ⁺⁺	Yield (Seed cotton)
pHs	1.000								
ECe	0.883**	1.000							
BD	0.856**	0.922**	1.000						
HC	-0.901**	-0.975**	-0.932**	1.000					
ESP	0.890**	0.930**	0.873**	-0.939**	1.000				
SARe	0.881**	0.940**	0.917**	-0.959**	0.991**	1.000			
Ionic Na ⁺	0.851**	0.880**	0.895**	-0.921**	0.967**	0.980**	1.000		
Ionic Ca ⁺⁺	-0.883**	-0.832**	-0.754**	0.801**	-0.899**	-0.868**	-0.836**	1.000	
Yield (Seed cotton)	-0.658*	-0.657*	-0.688*	0.759**	-0.760**	-0.791**	-0.822**	0.658*	1.000

* Significant at p=0.05

** Significant at p=0.01

crops was reported by various workers (Johnson and Davis, 1972; Unger and Wiese, 1979). ^{Swarup (1991) noticed} augmentation in the biological yield of rice grown in sodic soils ^{and} was mainly associated with increased availability of soluble Ca^{++} (due to gypsum application).

However, a significant negative relationship was obtained between seed cotton yield and ionic Na^+ ($r = -0.822^{**}$) followed by SARE ($r = -0.791^{**}$), ESP ($r = -0.760^{**}$), BD ($r = -0.688^*$), pHs ($r = -0.658^*$) and ECe ($r = -0.657^*$). This clearly indicated that these soil parameters adversely affected yield of seed cotton grown in Sodic Haplusterts. An increase in yield of rice grown in sodic soils by reducing pH and ESP (with gypsum incorporation) was reported by Swarup (1991). Negative relationship of wheat yield with ESP of soil was established by Khandelwal and Lal (1991). Further, they stated that it might be related to nutritional imbalance which affects negatively on the yield of wheat. The effect of gypsum on yield of rice (Rajkumar *et al.*, 1991) and cotton (Tiwari *et al.*, 1993) is chiefly through the influence of gypsum in reducing soil alkalinity.

Khandelwal and Lal (1991) reported that salinity effect on the reduction of wheat yield might be attributed to restricted water availability to the plants. Salinities of $NaCl$ and Na_2SO_4 exerted a negative influence on the translocation of photosynthetic assimilates. Transport of radio activity from the source to the sink (pod) and other plant parts was adversely affected by salinity regimes (Bhivare and Chavan, 1987).

b) Between soil parameters

In this investigation, a highly significant and positive correlation of HC was observed with ionic Ca ($r = 0.801^{**}$), whereas a highly significant negative relationship was noticed with ECe ($r = -0.975^{**}$), SARe ($r = -0.959^{**}$), ESP ($r = -0.939^{**}$), BD ($r = -0.932^{**}$), ionic Na⁺ ($r = -0.921^{**}$) and pHs ($r = -0.901^{**}$). This suggested that increase in HC in this investigation was mainly the effect of increasing ionic Ca⁺⁺, Whereas decrease HC of Soil was mainly associated with increase in ECe, SARe, ESP, BD and ionic Na. A negative relationship of HC with ESP/SAR and BD in respect of Vertisols of Purna valley (Vidarbha region) was also reported by Balpande (1993) and Badole (1996). An enhancement in ESP, the rate of penetration of moisture of drying front declines and moisture changes in lower layers are much slower (Gupta and Verma, 1983).

Relationship of pHs with ESP ($r = 0.890^{**}$), ECe ($r = 0.883^{**}$), SARe ($r = 0.881^{**}$), BD ($r = 0.856^{**}$), ionic Na⁺ ($r = 0.851^{**}$) was found highly significant and positive. However, negative correlation of pHs with HC ($r = -0.901^{**}$) and ionic Ca⁺⁺ ($r = -0.883^{**}$) was indicated in this experimental findings. A close relationship between pH and sodicity (ESP/SAR) for natural alkali soil conditions was reported by Gupta and Abrol (1990). This clearly shows that increase in pH of sodic Vertisols under rainfed conditions is mainly attributed to augmentation of sodicity of these soils.

A highly significant and positive correlation of SARe with ESP ($r = 0.991^{**}$), ionic Na⁺ ($r = 0.980^{**}$), ECe ($r = 0.940^{**}$), BD ($r = 0.917^{**}$),

pHs ($r = 0.881^{**}$), whereas highly negative relationship between SAR_e and HC ($r = -0.959^{**}$) and ionic Ca⁺⁺ ($r = -0.868^{**}$) was noticed. Similarly, ESP was highly significantly and positively correlated with SAR_e ($r = 0.991^{**}$) followed by ionic Na⁺ ($r = 0.967^{**}$), EC_e ($r = 0.930^{**}$), pHs ($r = 0.890^{**}$), BD ($r = 0.873^{**}$) and negatively correlated with HC ($r = -0.939^{**}$), ionic Ca⁺⁺ ($r = -0.899^{**}$). A highly significant and positive relationship between ESP and SAR was also reported by Badole *et al.* (1996). This clearly indicated that enhancement in ionic Na, EC_e, BD and pHs, increases SAR_e/ESP of Vertisols, whereas repression in HC and ionic Ca⁺⁺ increases SAR_e/ESP of sodic Vertisols. Sodidity is generally associated with salinity in similar trend, indicating positive relationship between EC and ESP values (Mohamed, 1989). pH, EC_e and soluble Na are found appreciably high during sodification (Tiwari *et al.*, 1983). Suppression of Na⁺ as compared with Ca⁺⁺ and Mg⁺⁺ has strongly influence on HC and shearstrength of soil (Blokhus, 1989).

Relationship of EC_e with SAR_e ($r = 0.940^{**}$), ESP ($r = 0.930^{**}$), BD ($r = 0.922^{**}$), pHs ($r = 0.883^{**}$) and ionic Na⁺ ($r = 0.880^{**}$) was highly significant and positive. However, with HC ($r = -0.975^{**}$), ionic Ca⁺⁺ ($r = -0.832$) was highly significant but negative. These findings explicitly show that enhancement in EC was mainly ascribed to increased SAR_e/ESP, BD and pHs, whereas, decrease in HC and ionic Ca⁺⁺ augmented electrical conductivity of saturation extract of salt affected Vertisols.

4.4.2 Regression studies

Simple Linear Regression equations between seed cotton yield (Y) and soil parameters affecting on yield (x) are given below.

Factors	Linear models	R ²
a) Positive		
HC	$Y=5.16+4.543x$	0.5757
Ionic Ca ⁺⁺	$Y=4.9+0.839x$	0.4329
b) Negative		
Ionic Na ⁺	$Y=13.99-0.276x$	0.6752
SAR _e	$Y=12.95-0.310x$	0.6261
ESP	$Y=12.35-0.297x$	0.5772

From the 'b' values in regression models, it is inferred that individual response in increasing seed cotton yield under this system follows the order as HC > Ca⁺⁺. Amongst the positive contributors, the R² Value of HC is highest (R²= 0.5757), which indicates that hydraulic conductivity of Sodic Haplusterts has major contribution in enhancing the seed cotton yield under rainfed situation. However, negative effect of soil attributes towards seed cotton yield follows the order as SAR_e > ESP > Ionic Na⁺. Thus, from the data, it can be concluded that positive yield response was mainly due to enhancement in HC and ionic Ca⁺⁺ by the various treatments applied during this investigation. However, negative

response in respect of seed cotton yield was chiefly due to sodicity of Vertisols, which may have direct impact on reducing the HC of soil; the major positive yield contributory factor. Therefore, Balpande *et al.* (1996) might have suggested that ESP 5 should be used as the lower limit for sodic subgroups of Vertisols of central India, rather than ESP 15 as given in Keys to Soil Taxonomy (USDA, 1994); as these soils have severe limitations in terms of very poor drainage even at low ESP.

The foregoing discussion mainly deals with individual effect of soil characteristics as influenced by land treatments and gypsum levels on seed cotton yield. However, in true sense, individual effect may be less valid since, a soil is a medium defined by set of interactions among themselves. In view of this, the statistical relationship between the soil characteristics (x_1 to x_n) altogether and the seed cotton yield were established by multiple linear regression (MLR) equation of the type:

$$Y = a + b_1x_1 + b_2x_2 + \dots + b_n x_n$$

where 'a' is intercept and b_1 to b_n are the partial regression coefficients of x_1 to x_n , respectively. Among the number of models so developed (Table 18), the best model was chosen based on following criteria:

- 1) Higher and significant in R^2 value at or below 5 % level of significance.
- 2) Most of the independent variables in the model should also be significant at or below 5 % level.
- 3) SE of 'a', SE of 'Y' estimate (θ) and the index of multicollinearity (δ) should be comparatively low.

Table 18. Multiple linear Regression Coefficients of soil parameters on seed cotton yield in different models

Parameters	Model number								
	I	II	III	IV	V	VI	VII	VIII	IX
	Partial Regression Coefficients								
pHs	0.662	-1.222	0.041	0.569	3.420	1.508	1.498	-	0.517
Ece	-	-	-	3.984	5.551	4.149	4.107	3.021	3.298*
BD	-	-	-	-	-	8.604	8.662	37.216**	35.904**
HC	5.281	3.132	-1.266	9.445	17.040	13.043	12.986	17.489**	18.467**
ESP	-	-0.193	0.609	0.190	0.500	1.321	1.323	3.624*	3.495**
SARe	-	-	-0.978	-0.518	-0.544	-1.562	-1.553	-2.758	-2.609**
Ionic Na ⁺	-	-	-	-	-	-	-0.009	-0.766	-0.754**
Ionic Ca ⁺⁺	-	-	-	-	1.190	1.050	1.048	1.523	1.581**
Exch. Na	-	-	-	-	-	-	-	-3.439	-3.411**
a	-1.23	-2.11	15.54	-12.03	-58.23	-42.22	-42.01	-47.23	-52.59
θ	1.17	1.20	1.18	1.01	0.88	0.93	1.07	0.19	0.21
R ²	0.5972*	0.6056*	0.6647*	0.7924**	0.8671**	0.8825**	0.8825**	0.9965**	0.9969**

* Significant at p=0.05

** Significant at p=0.01

The equations of seed cotton yield predictivity models (No. 9) are formulated and given below

Model No	Equation	R ²
I	Yield = - 1.23 + 0.662 pHs + 5.281 HC ...	0.5972*
II	Yield = - 2.11 + 1.222 pHs + 3.132 HC - 0.193 ESP... SARe ...	0.6056*
III	Yield = 15.54 + 0.041 pHs - 1.266 HC + 0.609 ESP - 0.978 SARe ...	0.6647*
IV	Yield = -12.03 + 0.569 pHs + 3.984 ECe + 9.445 HC + 0.190 ESP - 0.518 SARe	0.7924**
V	Yield = -58.23 + 3.420 pHs + 5.551 ECe +17.040 HC + 0.500 ESP - 0.544 SARe + 1.190 ionic Ca ⁺⁺	0.8671**
VI	Yield = - 42.22 + 1.508 pHs + 4.149 ECe + 8.604 BD +13.043 HC +1.321 ESP -1.562 SARe +1.050 ionic Ca ⁺⁺ - - - - -	0.8825**
VII	Yield = - 42.01 + 1.498 pHs + 4.107 ECe + 8.662 BD + 12.986 HC + 1.323 ESP - 1.553 SARe -0.009 ionic Na ⁺ + 1.048 ionic Ca ⁺⁺ - -	0.8825**
VIII	Yield = - 47.23 + 3.021 ECe + 37.216** BD +17.489** HC + 3.624* ESP - 2.758 SARe - 0.766 ionic Na ⁺ + 1.523 ionic Ca ⁺⁺ - 3.439 Exch Na - -	0.9965**
IX	Yield = - 52.59 + 0.517 pHs +3.298* ECe +35.904** BD + 18.467** HC + 3.495** ESP -2.609** SARe - 0.754** ionic Na ⁺ + 1.581** ionic Ca ⁺⁺ -3.411** Exch Na - -	0.9969**

Out of nine models, in model number I to III, the "R²" values ranged between 0.5972 to 0.6647 which appear significant at 5% level, where as the "R²" values of model number IV to VII are ranged between 0.7924 to 0.8825 which appear significant at 1% level. Although the "R²" values are significant in models I to VII; partial regression coefficients of the independant variables of these models are non-significant at or below 5% level.

In model VIII, the "R²" value is 0.9965 which found significant at 1% level and partial regression coefficients of three soil parameters i.e. BD, HC and ESP are significant. However, in the last model No. IX, the "R²" value noticed 0.9969 which is significant at 1% level and partial regression coefficients of all the soil parameters except pH, are significant with minimum deviation in sum of square and therefore, the model i.e. yield = - 52.59 + 0.517 pHs + 3.298* ECe + 35.904** BD + 18.467** HC + 3.495** ESP - 2.609** SARe - 0.754** ionic Na⁺ + 1.581** ionic Ca⁺⁺ -3.411** Exch Na - - R² = 0.9969** was found to be best in forecasting the seed cotton yield. Further, the "R²" value of this model indicates the nine soil parameters i.e. pHs, ECe, BD, HC, ESP, SARe and ionic Ca⁺⁺, Mg⁺⁺ and Na⁺, describes 99.69 per cent variability in seed cotton yield, grown in sodic Haplusterts of Puna valley.

CHAPTER V

SUMMARY AND CONCLUSION

The Purna basin is a faulted valley of late cretaceous to eocene period with basement of the Daccan trap and is bounded on the north by the scarp of the Satpudas and on the south by the Ajanta plateau. It is an oval or concave convex shaped basin covering on area of 7,500 Km² in the districts of Amravati, Akola and Buldana of Vidarbha region. Purna basin soils at many locations do have salinity/sodicity problem in the subsoil zone. Because of poor drainability and high intensity rain storms, water stagnation takes place in rainy season, which obviously upsets the productivity of *Kharif* crops. In *rabi*, deep and wide cracks are developed which intensify evapotranspiration and thus, *rabi* crops suffer mainly due to deficiency of moisture in soil.

Reclamation technologies so far developed for salt affected soils, s mainly related to alluvial soils, which may not be feasible and practicable as such for the improvement of saline/sodic Vertisols of this valley. In view of degraded nature of valley and the urgent need of the farming community of this basin; studies entitled "Investigation on the effect of soil amendments and land treatments on soil characteristics and productivity of cotton grown in salt affected Vertisols" was planned.

A field experimentation on Hybrid cotton (cv AHH 468) in split plot design pertaining to the research problem was conducted during 1994-95 and 95-96 at Gopalkheda, the village at the bank of Purna Valley. The experimental soil is a member of very fine, montmorillonitic, hyperthermic

family of Sodic Haplusterts, having profile pH in the range of 8.2 to 8.5, EC_e 2.42 to 4.18 dSm⁻¹ and ESP 14.06 to 22.97. Main treatments comprised of no land treatments, furrow opening after each row and furrow opening after two rows of cotton, immediately after first hoeing; whereas subtreatments included various gypsum levels, equivalent to 0, 25, 50 and 100 % GR. The conclusions based on pooled data of two years are summarised below:

5.1 Land Treatments

- A significantly maximum increase of 39.6 and 13.1 per cent in the seed cotton yield was obtained due to furrow opening after two rows and furrow opening after one row respectively over control i.e. no furrow opening. A significantly highest stalk yield was also noticed with the opening of furrows after two rows.
- Maximum B:C ratio (2.88) and net monetary returns were accrued in furrow opening after two rows followed by furrow opening after each row (B:C ratio 2.22). The respective benefits in the net monetary returns due to these land configurations were Rs. 8307/- and 3994/- ha⁻¹ over control.
- Opening of furrows after each rows and after two rows reduced BD and enhanced HC significantly over control. However, a significant and maximum reduction in BD by 6.87 per cent and significant and highest increase in HC by 28 per cent were observed due to furrow opening after two rows. A perceptible increase in available soil moisture storage by about 54 per cent was also recorded in this treatment.

- Furrow opening after each row and after two rows decreased significantly the pHs of saturated paste and ECe of saturation extract over control. The respective reductions in pHs were 1.14 and 2.28 and in ECe were 9.2 and 6.7 per cent as compared to no land treatment.
- A perceptible decrease in yield reduction factors like SARE and ESP was noticed due to both land configurations. However, a significant and highest repression in SARE and ESP were noticed with furrow opening after two rows as compared to control and furrow opening after each row. The respective reductions in SARE and ESP due to furrow opening after two rows were about 23.9 and 22.6 per cent over control, indicating the effective utilization of gypsum in dismissal of Na from clay complex and efficient leaching of salts in this land treatment.
- A significantly maximum suppression in ionic Na⁺ and significantly highest enhancement in ionic Ca were recorded due to both land configurations. The respective per cent reduction in ionic Na and per cent increase in ionic Ca due to furrow opening after two rows were 22.4 and 10.6 over no land treatment.

5.2 Gypsum Levels

- A significantly progressive enhancement in seed cotton yield was noticed due to incorporation of gypsum at its various levels (25, 50 and 100 % GR) over control. Thus, a significantly highest increase in seed cotton yield was obtained due to application of gypsum @ 100 % GR followed by 50 % GR. and corresponding increases were 22.5 and 31 per cent over control (G0). Interaction effects between land treatments

and gypsum levels were significant during both the years but nonsignificant in pooled analysis.

- An incorporation of gypsum @ 100 % GR also gave significantly highest stalk yield of cotton which was followed by 50 % GR.
- Gypsum application @ 50 % GR gave highest B:C ratio (1.82) followed by G 25 (1.81), G 0 (1.80) and G 100 (1.56). This clearly implies that although maximum yield was noticed in G 100, the least B:C ratio was estimated due to this gypsum level; suggesting the economical superiority of G 50 over G 100.
- An incorporation of gypsum @ 50 and 100 % GR reduced BD of soil significantly by about 14.9 and 18.4 per cent and also enhanced HC significantly by 134 and 156 per cent over G 0. A perceptible enhancement in available soil moisture storage by 12.5 and 14.8 per cent was also found due to application of gypsum @ 50 and 100 % GR over G 0.
- A significant and linear reductions in yield detrimental factors like pHs, ECe, SARe and ESP were recorded due to incorporation of gypsum at its various levels (25, 50 and 100 % GR) and each higher level of gypsum addition found significantly superior over its lower level in suppressing these parameters. However, a significantly maximum reduction in pHs, ECe, SARe and ESP were noticed due to incorporation of @ 100% GR, followed by 50% GR. The respective decreases noticed in pHs were 7.06 and 9.78, ECe 33.3 and 37.3, SARe 46.8 and 57.9 and ESP 44.9 and 51.1 per cent due to

incorporation of gypsum @ 50 and 100 % GR over G 0. Interaction effects between land treatments and gypsum levels in repression of ECe, SARE and ESP were significant.

- A significant and linear reductions in ionic Na and a significant and progressive increases in ionic Ca and Mg were estimated due to gypsum incorporation @ 25, 50 and 100 % GR. Further, it appears that each higher level of gypsum addition found statistically superior in respect of decreasing ionic Na and increasing ionic Ca. In pooled analysis, interaction effects between land treatments and gypsum levels found significant in respect of increasing ionic Ca.

5.3 Correlation and Regression studies

- A highly significant and positive correlation of seed cotton yield with HC and ionic Ca, whereas, highly significant but negative correlation of seed cotton yield with SARE/ESP, ionic Na, BD, pHs and ECe were noticed in Sodic Haplusterts.
- A highly significant and positive relationship between HC and ionic Ca⁺⁺; whereas negative relationship of HC with ECe, SARE, ESP, BD, ionic Na⁺ and pHs were noticed in this investigation.

The relationship between SARE and ESP was highly significant and positive. Further significantly positive relationship of SARE/ESP with ionic Na, ECe, BD and pHs whereas, negative relationship of SARE/ESP with HC and ionic Ca⁺⁺ were observed.

- Relationship of ECe with SARE, ESP, BD, pHs and ionic Na was highly significant and positive but with HC and ionic Ca⁺⁺ was highly significant but negative.
- Regression studies indicated that HC and ionic Ca⁺⁺ of Sodic Haplusterts have major contribution in increasing the seed cotton yield under rainfed situation, whereas negative impact of soil attributes towards seed cotton yield follows the order as SARE > ESP > ionic Na.
- Amongst the various multiple linear regression (MLR) models, model No.IX (Table 18) appeared to be best as it describes 99.69 per cent variability ($R^2 = 0.9969$) in the yield of seed cotton grown in Sodic Haplusterts. This model includes nine soil parameters i.e. pHs, ECe, BD, HC, ESP/SARE and ionic Ca⁺⁺, Mg⁺⁺ and Na⁺.

From the data it can be concluded that:

- (i) Hydraulic conductivity has major contribution for enhancing the seed cotton yield, whereas negative effect on it was mainly due to SARE/ESP followed by ionic Na⁺ in Sodic Haplusterts.
- (ii) Opening of furrows after two rows and incorporation of gypsum @50% GR to hybrid cotton are essential for increasing seed cotton yield and improving physico-chemical conditions and sustainability of Sodic Vertisols of Purna Valley tract of Vidarbha region.
- (iii) The model i.e. yield = - 52.59 + 0.517 pHs + 3.298* ECe + 35.904** BD + 18.467** HC + 3.495** ESP - 2.609** SARE - 0.754** ionic Na⁺ + 1.581** ionic Ca⁺⁺ -3.411** Exch Na - - - $R^2 = 0.9969$ ^{is best} in forecasting the yield of cotton grown in sodic Haplusterts of Purna valley.

LITERATURE CITED

- Abhange, G.V. (1986): Drainage problems in Maharashtra: Past experience and future challenges. *Sinchan*, **4** : 50-80.
- Abhange, G.V.; L.V. Pisolkar, S.D. More, P.R. Bharambe and C.P. Ghonsikar (1986): Problem soils in Jayakwadi and Purna command areas. Published by *Marathwada Agri. Univ.*, Parbhani, P. 156-165.
- Abrol, I.P. and M. Fireman (1977): Alkali and Saline soils, identification and improvement for crop production CSSRI, *Karnal Bull. No. 4*, PP. 32
- Acharya, C.L. and I.P. Abrol (1978): Exchangeable sodium and soil water behaviour under field conditions. *Soil Sci.* **125** (5): 309-310.
- Acharya, H.S. and S.B. Varade (1980): Envelop material for sub-surface drainage in deep black cotton soils. *Report on U.G.C. project No. F/25/1/7966*.
- Adyalkar, P.G. (1963): Paleogeography, nature and pattern of sedimentation and ground water potentially of the Purna basin of Maharashtra *Proc. Natn. Inst. Sci.* **29**: 25-44.
- Agrawal, O.P. and Indrapati Singh (1970): Effect of contour cultivation on soil conservation and yield of sugarcane. *J. soil and water conserv. India.* **18** (3 & 4): 29-30.
- Anonymous (1995) : Districtwise Statistics. Department of Agriculture Maharashtra State, Pune (1994-95).
- Anonymous (1998) : Kapus Utpadan Vadhisathi Israel Tantradhnyan (In Marathi) Bull. Agri. Commisionorate, Maharashtra State, Pune, pp. 1.
- *Arkin, G.F., E. Burnett and R. Monk (1978): Wide-bed narrow- row - sorghum yields in the black land prairie. *Miscellaneous Publ., Texas Agril. Expt. station No. 1377*.

- Arora, C.L. and V.K. Nayyar (1983): The role of monocalcium phosphate and gypsum in alleviating the effect of high sodium on the yield and nutrient composition of barley. *J. Indian Soc. of soil Sci.* **31** (1): 152-55.
- *ASAE (American Society of Agricultural Engineers). (1981): Design, layout, construction and maintenance of terrace systems. Agricultural engineers yearbook, Michigan, USA: 527-530.
- Badole, R.B. (1996): Land evaluation for agricultural crops of Adsul Village in saline tract of Purna Valley of Vidarbha. M.Sc. (Agri.) Thesis, Dr. Panjabrao Dehsmukh Krishi Vidyapeeth, Akola (M.S).
- Balpande, S.S. (1993): Characterization, Genesis and degradation of Vertisols of the Purna valley, Maharashtra. Ph.D. (Agri) Thesis, Punjabrao Krishi Vidyapeeth, Akola, Maharashtra.
- Balpande, S.S., S.B. Deshpande and D.K. Pal (1996): Factors and processes of soil degradation in Vertisols of Purna valley, Maharashtra, India. *Land Degradation and Rehabilitation* **7**.
- Balpande, S.S., S.B. Deshpande and D.K. Pal (1997): Plasmic fabric of Vertisols of the Purna valley of India in relation to their cracking. *J. Indian Soc. Soil Sci.* **45** (3): 553-562.
- Bansal, R.K. and K.L. Srivastava (1981): Improved animal drawn implements for farming in the semi-arid tropics. *Agricultural Mechanization in Asia, Africa and Latin America* **12** (2): 33-38.
- Basu, J.K. (1950): Problems of saline soils in Bombay, Maharashtra state (India), Trans, 4th *India Intl. soil sci. congr., Amsterdam, Netherlands*, **3**: 169-172.
- Belgaumi, M.I. and G.D. Radder (1994) : Land treatments for efficient soil and water conservation in Vertisols, Vasantrya Naik Memorial National Seminar on Farming Sysetms Based on Watershed Management Research and Development, P.K.V., Akola and Vasantrya Naik Smruti Pratisthan Pusad, held at Nagpur, Dec. 29,30. PP. 49-43.

-
- Bernstein, L. (1961) : Osmotic adjustments of plants to saline media. I steady state *Am. J. Bot.* **48** : 909-918.
- Bhamodkar, M.A. and S.S. Hiwase (1996): Improvement of drainage properties of salt affected soil by mechanical operations. State Level Seminar on Management of Problematic soils, Akola Chapter, *Indian Soc. of Soil Sci., Dr. PDKV, Akola* Dec. 12-13, PP. 1-2
- Bharad, G.M.; B.G. Bathkal; M.B. Nagdeve; S.K. Kohale; S.N. Ingle; R.L. Gawande; V.K. Mahorkar and K.S. Kayande (1991): Watershed approach in rainfed agriculture, Dr. PDKV., Akola, Maharashtra, India, Bull. I.
- Bharad, G.M. (1994) : Rain water management for developing sustainable farming systems in rainfed micro-watersheds. Vasant Rao Naik memorial National Seminar on Farming Systems based on Watershed Management Research and Development. By PKV, Akola and Vasant Rao Nike Pratishthan, Pusad held at Nagpur, Dec. 29-30, pp. 35-42.
- Bharambe, P.R. and C.P. Ghonsikar (1985): Physico-chemical characteristics of soils in Jayakwadi command, *J. Maharashtra Agric. Univ.* **10** : 247-249.
- Bhargava, G.P.; I.P. Abrol and D.R. Bhumbla (1976): On the nomenclature of salt affected soils in Indo-gangetic alluvial plains, *J. Indian Soc. Soil Sci.* **24** (1): 81-83.
- Bhattacharya, T.R.; J.P. Srivastava, Sharma and J.L. Sehgal (1994): Classification of saline sodic Vertisols in the plains of Gujrat; *J. Indian Soc. Soil Sci.* **42** (2): 306-309.
- Bhatti Aman Ullah and Ahmad Bakhsh (1995): A management strategy of using gypsum for reclamation of salt affected soils. *J. Indian Soc. Soil Sci.* **43** (4): 657-59.
- Bhivare, V.N. and P.D. Chavan (1987): Effect of salinity on translocation of assimilates in french bean. *Plant and Soil* **102** (2): 295-297.

- Bhumbla, D.R. (1981): Land and water management agricultural production in India. *J. Indian Soc. Soil Sci.*, **29** (4): 403-418.
- Black, C.A., D.D. Evans, J.L. White, L.E. Ensminger and F.E. Clark (1965): Methods of Soil Analysis, Part 2. *Am. Soc. Agron.*, Madison, Wisconsin, USA 1572 P. ^
- *Blanford, W.T. (1869): In the geology of the Taptee and Narmada valleys, *Mem. G.S.I. Vol. VI*, pp.3.
- Blokuis, W.A. (1989) : Vertisols of the semi-arid tropics, Management of Vertisols for Improved Agricultural Production, Proceeding IBSRAM Inaugural Workshop, 1985. ICRISAT (India), Feb. 18-22, pp. 37-44.
- Bonde, W.C.; J.P. Nema and Kamannawar (1978): Inter-terranced land treatment for maximization of production through effective moisture conservation in ravine land of Gujarat under rainfed condition, Vasad, *Annual Report 1978. CSWRTI, Dehradun, India*, PP. 109-110.
- Burnett Earl (1989): Land and water management practices for Vertisols, Management of Vertisols for Improved Agricultural Production: *Proceedings IBSRAM inaugural workshop*, Feb. 18-22, 1985, pp. 133-145.
- Challa, O. (1995): Gilgai microrelief in swell shrink soil-A case study from Solapur district, Maharashtra. *J. Indian Soc. Soil Sci.* **43** (4): 649-652.
- Chandrasekaram, S. (1969): Production of organic acids by soil micro-organisms. *Plant and Soil* **30** : 299-304.
- Chauhan, C.P.S. and B.R. Tripathi (1983): Reclamation studies on highly saline-sodic soil of semi-arid tract in Uttar Pradesh. *J Indian Soc. Soil Sci.* **31** (4): 587-95.
- Chittaranjan, S. (1982): Rain water harvesting and recycling. *Indian J. Soil Conserv.* **9** (2 & 3): 100-106.

- Clark, R.N. and O.R. Jones (1981): Furrow dams for conserving in a semiarid climate. Crop production with conservation in the 80's; proceedings of the American society of Agricultural Engineers Conference, 1-2 Dec. 1980, PP. 198-200.
- Dahiya, I.S.; I.P. Abrol and S. Hajrasuliha (1980): Miscible displacement of reactive solutes in saline-sodic soils under varying flow conditions. *J. Agri. Sci.* **94** (3): 709-714.
- Dev Burman, G.K. and M. Mehta (1996): Aquifer geometry and possibilities of improving ground water quality in Purna saline tract, Symposium on "Integrated approach to management of water and soil of Purna river basin with special reference to salinity characteristics" VRCE, Nagpur Maharashtra (India), Feb, 2-4, pp. 45-51.
- Dhruva Narayana, V.V.; (1983): Efficient use of environment soil erosion. Dryland Agril Res. in India -Thurst in eighties, AICRP, Dryland Agri., Hyderabad, India, PP. 113-119.
- Douglas, M.G. (1992): Simple farmer usable tools for suveying contour and graded lines. *Contour* **4** (1): 8-11.
- Dubey, D.D.; K.K. Shah and O.P. Sharma (1981) : Correlation of some physico-chemical properties of medium black saline-alkali soils of Madhya Pradesh. *JNKKV, Res. J.* **15** : 154-158.
- Dubey, D.D.; G.P. Verma and O.P. Sharma (1983): Differences in the nature and properties between the salt-affected and normal Vertisols. *Curr. Agric.* **7** : 129-137.
- Dubey, D.D. and O.P. Sharma (1987): Characteristics and classification of coastal salt-affected soils. *J. Indian Soc. Soil Sci.* **35** (4): 712-716.
- Dubey, S.K.; R.C. Mondal and A. Swarup (1987): Effect of gypsum and pyrite with different moisture regimes on sodic soil improvement and rice yield, *International Rice Research, News Letter* **12** (6): 35

- Dubey, S.K. and R.C. Mondal (1994): Effect of amendments and saline irrigation water on soil properties and yields of rice and wheat in a highly sodic soil. *J. Agricultural Sci., Cambridge* **122**: 351-357.
- Dudal, R. (1989): Vertisols of subhumid and humid zones. Management of Vertisols for Improved Agricultural Production: Proceedings of an IBSRAM inaugural workshop, ICRISAT, India Patancheru, A.P. India : pp. 55-60.
- Ghatol, S.G. and R.L. Karale (1996): Studies on degraded soils of Amravati District, their Nature, characteristics and management needs, State Level Seminar, Management of Problematic Soils, Akola chapter, *Indian Soc. of Soil Sci.*, Dr. PDKV., Akola Dec. 12-13, 1996, pp. 17.
- Gill, M.P.S. and M.K. Sinha (1981): Effect of gypsum and submergence on chemical fractions of Mn in sodic soils. *J. Indian Soc. Soil Sci.* **29** (2): 199-203.
- Girdhar, I.K. (1988): Effect of saline irrigation water on the growth, yield and chemical composition of rice crop grown in a saline soil. *J. Indian Soc. Soil Sci.* **36** (2): 324-329.
- Griffith, D.R.; J.V. Mannering, W.C. Moldenhauer (1977): Conservation tillage in the eastern corn belt. *J. Soil and Water Conserv.* **32** (1) : 20-28.
- Gupta, R.K. and U.S. Gupta (1978): Volume change in a swelling clay and its influence on soil moisture relation: *J. Indian Soc. Soil Sci.* **26** (4): 323-327.
- Gupta, R.K. and S.K. Verma (1983) : Water behaviour of black clay soils as influenced by degree of sodicity. *Curr. Agric.* **7** : 114-121.
- *Gupta, R.K. and S.K. Verma (1983): Influence on soil ESP and electrolyte concentration of permeating water on hydraulic properties of a Vertisol. 2. *Pflan2 Bodenk.* **147**: 77-84 (cited from 25 year Res. On Mgmt. Of Salt affected soils and use of saline water in Agriculture, CSSRI, Karnal, 1998).
- Gupta, R. K.; O.P. Sharma and S.K. Dubey (1988): Effect of dose and frequency of gypsum application on properties of sodic soil and

on performance of rice (*Oryza sativa*) and bread wheat (*Triticum aestivum*). *Indian J. Agril. Sci.* 58 (6): 449-53.

Gupta, R.K. and I.P. Abrol (1990): Salt affected soils: Their reclamations and management for crop production. *Adv. Soil Sci.* 11: 223-288.

*Halitim, A.; M. Robert, D. Tessier, R. Prost (1984): Influence des cations échangeables (Na, Ca, Mg) et de la concentration saline sur le comportement physique (retention en eau, conductivité hydraulique) de la montmorillonite *Agronomie* 4: 451-459 (Cited from Blokhuis (1989) Vertisols of Semi-arid tropics. Management of Vertisols for Improved Agril. Production, ICRISAT, (India).

Hayward, H.E. and C.H. Wadleigh (1949) : Plant growth on saline and alkali soils, *Adv. Agron. I.* : 1-38.

Holsambre, D.G.; S.B. Varade; H.S. Acharya and S.L. Rapte. (1982): Drainage characteristics of Vertisols. *J. Indian Soc. Soil Sci.* 30 (2): 116-121.

ICRISAT (1978): Annual report, ICRISAT 1977/78. Patancheru, Andhra Pradesh, India.

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

Jackson, M.L. (1979): Soil Chemical Analysis Advanced course, Second Edn, University of Wisconsin, Modison (USA), PP. 895.

Johnson, W.C., and R.G. Davis (1972): Research on stubble-mulch farming of winter wheat. USDA Conservation Research Report no. 16. Washington, D.C., USA.

Kadu, P.R. (1991): Physical and chemical properties affecting hydraulic conductivity of black soils of the Purna valley. M. Sc. (Agri.). Thesis, Dr. PDKV, Akola, Maharashtra.

Kalane, R.L., A.S. Deshmukh and P.T. Kharkar (1996): Effect of gypsum, sand, FYM and farm residues on soil moisture regime, oxygen diffusion and yield of soybean on Vertisols. State Level Seminar, Management of Problematic Soils, Akola chapter, *Indian Soc. Soil Sci.* Dr. PDKV., Akola Dec. 12-13, pp. 10.

- Kampen Jacob (1979): Watershed management and technology transfer in semiarid tropics, Proc. Intern. symposium on development and transfer of technology for rainfed agricultural and SAT farmers, ICRISAT, Patancheru, 28th Aug. to 1 Sept. : PP 111-119.
- Kanwar, J.S., J. Kampen, and S.M. Virmani (1982): Management of Vertisols for maximising crop production ICRISAT experience. Vertisols and rice soils of the tropics symposia papers 2. Transactions of the 12th International Congress of Soil Science, 8-16 Feb. 1982, IARI, New Delhi, India pp. 94-118.
- *Kelley, W.P. (1951): Alkali soils, their Formation, Properties and Reclamation, Reinhold publishing cooperation, New York, U.S.A.
- Khandelwal, R.B. and P. Lal (1991): Effect of salinity, sodicity and boron on irrigation water on the properties of different soils and yield of wheat. *J. Indian Soc. Soil Sci.* **39** (3): 537-541.
- Kumar Ashok, K.L. Chawla, M.K. Sharma, D.R. Sharma and B.K. Khosla (1997): Response of sunflower to irrigation with waters of different salinities. *J. Indian Soc. Soil Sci.* **45** (2): 409-410.
- Magar, A.S. (1990): An appraisal of the nature of salinity and sodicity in black soils of the Purna valley. M.Sc. (Agri.) Thesis, Dr. PDKV, Akola, Maharashtra.
- Malewar, G.U. and S.D. More (1988): Soil plant behaviour in relation to salt-affected Vertisols of Maharashtra: Restrospects and prospects- A Review, *J. Maharashtra agric. Univ.* **13**: 249-253.
- Masih, F. and R.P.S Chauhan (1983): Studies on salt affected soils of Agra region. *J. Maharashtra agric. Univ.* **8** (3): 201-203.
- *Michaels, G.H. (1982): The determinants of *Kharif* following on the Vertisols in semi-arid tropical India Ph.D. Thesis, Univ. Of Minnesota.(USA)
- Minhas, P.S., D.R. Sharma and B.K. Khosla (1989a) : Mungbean response to irrigation with waters of different salinity. *Irrig. Sci.* **11** : 57-62.

- Minhas, P.S., D.R. Sharma and B.K. Khosla (1989b) : Response of sorghum to the use of saline waters. *J. Indian. Soc. Soil Sci.* **37** : 140-146.
- Minhas, P.S. , D.R. Sharma and Y.P. Singh (1995): Response of wheat and paddy to applied gypsum and farm yard manure on an alkali water irrigated soil. *J. Indian Soc. Soil Sci.* **43**: 452-5.
- Minhas, P.S. and S.K. Dubey (1998): Strategic use of brackish waters for fruit trees. *First Int. specialised conf. Water quality and its management*, March 2-6, CBIP, New Delhi. pp. 431-40.
- Miranda, S.M.; P. Pathak and K.L. Shrivastava (1983): Runoff management on small agricultural watersheds the ICRISAT experience. Dryland Agri. Res. In India, Thrust in Eighties, AICRP, Dryland Agri, (ICAR), CRIDA, Hyderabad, A.P., PP. 88 - 96.
- Misopolinos, N.D. (1985) : A new concept for reclaiming sodic soils with high-salt water. *Soil Sci.* **140** : 69-74.
- Mkrtchyan, S.M. (1991): Ameliorative processes in saline sodic soils. *J. Indian Soc. Soil Sci.* **39** (1): 212-214.
- Mkrtchyan, S.M. (1991): Drainage functions in soil desalinization. *J. Indian Soc. Soil Sci.*, **39** (1): 164-168.
- Mohamed Hassan Hag Abdulla (1989): Vertisols in the seasonally dry central clay plain in the sudan. Management of Vertisols for Improved Agricultural production: proceedings IBSRAM Inaugral workshop, ICRISAT, India 18-22 Feb. 1985.
- Mohite, A.V., and A.K. Shingte (1981): Evaluation of high salt water dilution schedule for reclamation of saline sodic and sodic soils. *Indian Soc. of Soil Sci.* **29** (1): 55-60.
- More, S.D., G.U. Malewar and K.R. Pawar. (1987): Marathwadyatil Kshar-Yukta Ani Chopan Jaminivaril Upay Yojana (in Marathi) Bull. 1, *Agril. Chemistry and Soil Sci.* Dept., MAU, Parbhani (M.S.): PP 14-18.

- More, S.D., J. S. Shinde and G.U Malewar (1987): Studies on salt affected soils of Purna command. *J. Maharashtra agric. Univ.* **12**(2): 145-146.
- More, S.D.; J.S. Shinde and Malewar, G.U. (1988): Characterization of some salt-affected soils of Purna command area of Maharashtra. *J. Indian Soc. Soil Sci.* **36** (1): 146-150.
- More, P.V., B.B. Desai and U.D. Chavan (1994): Effect of salt stress on biochemical parameters of sugarcane. *J. Maharashtra agric. Univ.* **19** (3): 431-433.
- Morrison, J.E., Jr. and T.J. Gerik (1983): Wide beds with conservation tillage. *Soil and Water Conserv.* **38** (3): 231-232.
- Mukhtar, O.M.A., A.R. Swoboda., and C.L. Godfrey (1974): The effect of sodium and calcium chlorides on structural stability of two Vertisols: Gezira clay from sudan, Africa and Houston Black clay from Texas, U.S.A., *Soil Sci.* **118**: 109-119.
- Nakayama, F.S. (1970): Hydrolysis of CaCO_3 , Na_2CO_3 and NaHCO_3 and their combinations in the presence and absence of external CO_2 source, *Soil Sci.* **109**: 391-398.
- *Narayanan, A. (1966): Physiological studies on salt tolerance of wheat. Ph.D. Thesis. I.A.R.I., New Delhi.
- Narkhede, P.L. and S.P. Surve (1996): Efficiency of different methods of gypsum application in advancement of wetting front in sodic soil., state level seminar, Management of Problematic soils, Akola chapter, *Indian Soc. of Soil Sci.*, Dr. PDKV., Akola Dec. 12-13, pp.5.
- Nimkar, A.M. (1990): Evaluation of physical and chemical characteristics of soils of the Purna valley of Maharashtra. M.Sc. (Agri.), Thesis, Dr. PDKV, Akola, Maharashtra.
- Nimkar, A.M., S.B. Deshpande and P.G. Babrekar, (1992): Evaluation of salinity problems in swell-shrink soils of Purna valley, Maharashtra, *Agropedology* **2** : 59-65.

- Olsen, S.R. (1954): Estimation of available phosphorus in soil of extraction with sodium bicarbonate, *USDA circ* : 939.
- Oster, J.D. (1982): Gypsum usage in irrigated agriculture : A review. *Fertilizer Research* 3, 78-89.
- Padole, V.R. and H.N. Ravankar (1996): An appraisal of characteristic of soils in Akola district from saline tract of Purna valley. State Level Seminar, Management of Problematic Soils, Akola chapter, *Indian Soc. of Soil Sci., Dr. PDKV., Akola*, Dec. 12-13, pp.4.
- Paliwal, K.V. (1972): Irrigation with saline water, water technology centre, Indian Agricultural Research Institute, monograph No.2 (New Series), New Delhi.
- Pandey, R.N., B. Narain., and A.N. Pathak (1974): Effect of electrolyte concentrations on the hydraulic conductivity of Bundelkhand soils: *J. Indian Soc. of Soil Sci.* 22 (2): 191-193.
- Panse, V.G. and P.V. Sukhatme (1985): Statistical methods for Agricultural Workers, I.C.A.R., New Delhi.
- Parihar, S.S. and P.R. Gajari (1988): Fertilization of dryland crops. *Indian J. Dryland Agric. Res. And Dev.* 3 (1): 1-33.
- Patel, U.G.; K.G. Patel; P.G. Patel; N.P. Mehata and K.N. Lad (1989): Cultural management of soil and rain water in rainfed cotton. G. Cot (*G. herbaceum* L.) using various improved cultural practices in black cotton soil of middle Gujrat. *Gujrat agric. Univ. Res. J.* 14 (2): 25-29.
- Patel, K.P. and Bhajan Singh (1991): A comparative study on the effect of gypsum, pressmud and pyrites on leachate composition, soil properties and yield of rice and wheat on a sodic soil. *J. Indian Soc. Soil Sci.* 39 (1): 154-59.
- Pathak, A.N., D.N. Sharma and H.L. Sharma (1978) : -Use of sedimentary pyrites in reclamation of Akola soils, FAI- PPCL, New Delhi, P, 45.

- *Pathak, A.N. and D.N. Sharma (1981): Water soluble B concentration as affected by different amendments and its impact on B content of paddy and barley crops in salt affected soil, *Agrokem. Talajit.* **30** (suppl.): 198-204.
- Patil, P.P. and G.B. Bangal (1987): Effect of field soil conservation practices on soil erosion and runoff. *Indian J. Soil Conserv.* **15** (2): 72-76.
- Patil, G.D., T.S. Mungare, P.H., Shinde and P.L. Narkhede (1996) : Effects of salinity levels on dry matter yield and chlorophyll content of rice cultivars. State Level Seminar. Management of Problematic soils, Akola Chapter, ISSS, Dr. P.D.K.V., Akola, Dec. 12-13, pp. 6
- Piper, C.S. (1966): Soil and Plant Analysis, Asian Reprint, Hans publ., Bombay, pp. 368.
- Prakas Vinay and M.M. Verma (1994): Response of varying levels of gypsum and urea in alkali soils on wheat crop. *J. New Agriculturist.* **5** (2): 205-208.
- Rajkumar, Room Singh, Shivakant, S.K. Pandey and S. Kumar (1991): Effect of different soil amendments on chemical changes and yield of rice [*oryza sativa*] in salt-affected soils. *Indian J. Agri. Sci.* **61** (2): 139-42.
- Ram, R.S. and K.E. Mohan (1973): Note on the effect of deep ploughing and contour ridging on moisture conservation in arid tracts. *Indian J. agric. Sci.* **43** (2): 207-208.
- *Rathert C. et al. (1982): *J. Plant Nutrition* **5**: 97-102 (Cited from V.N. Bhivare and P.D. Chavan, (1987) : Effect of salinity and translocation assimilates in french bean, *Plant and Soil*, **102**, 295-297).
- Raut, R.S., S.S. Mane and G.U. Malewar (1996): Relative performance of vermicompost in Improvement of Alkali Soil. State Level Seminar, Management of Problematic Soils. Akola chapter, *Indian Soc. of Soil Sci.*, Dr. PDKV, Akola Dec. 12-13, pp. 3.

- Reev, R.C. and Bower, C.A. (1960): Use of high-salt waters as a flocculant and source of divalent cations for reclaiming sodic soils, *Soil Sci.* **90**, 139-144.
- Richards, L.A. (Ed.). (1954): Diagnosis and Improvement of Saline and Alkali soils,, USDA, Hand Book 60 Washington DC.
- Richardson, C.W. (1973): Runoff, erosion, and tillage efficiency on graded-furrow and terraced watersheds *J. Soil and Water Conserv.* **28** (4): 162-164.
- Robbins, C.W. (1985): The $\text{CaCO}_3\text{-CO}_2\text{-H}_2\text{O}$ system in soils. *J Agron. Educ.* **14**: 3-7.
- Robbins, C.W. (1986): Sodic calcareous soil reclamation of affected by different amendments and crops; *Agron J.* **78**. 916-920.
- Ryan, J.G., S.M. Virmani and L.D. Swindale (1982): Potential technologies for deep black soils in relatively dependable rainfall regions of India. Innovative Technologies for Integrated Rural Development, Indian Bank, New Delhi, India. ICRISAT, (India), April 15-17.
- Sagare, B.N., R.L. Kalane and Y.S. Guhe (1991): Characterization of salt affected Vertisols of Purna valley tract in Vidarbha region. *J. Maharashtra agric. Univ.* **16** (3): 310-312.
- Sagare, B.N. and A.T. Bhongle (1993): Soil moisture storage and productivity of cotton as influenced by broad base furrows. *Agropedology*, **3**
- Sagare, B.N., V.P. Babhulkar and P.V. Rane (1996): Integrated Approach to soil and water management in Purna river basin of Vidarbha region. State Level Seminar, Management of Problematic Soils, Akola chapter *Indian Soc. of Soil Sci.*, Dr. P.D.K.V., Akola Dec. 12-13, pp. 18.
- *Sarin, M.V. (1961): Influence of Na_2SO_4 on poly phenodase activity of wheat. *Sci. Cult.* **27**: 104-105.

- Sharma, D.P. (1986): Effect of gypsum application on longterm changes in soil properties and crop growth in sodic soil under field conditions. *J. Agronomy and Crop Sci.* **156**. 166-172.
- Sharma, D.P., K.V. G.K. Rao and R.J. Oosterbaan (1997): Soil salinity-wheat yield relationship on farmers fields. *J. Indian Soc. of Soil Sci.* **45** (2): PP 406-409.
- Sharma, D.R. and P.S. Minhas (1997): Evaluation of the infiltration hazard of saline sodic and sodic waters in an Illitic sandy loam soil., *J. Indian Soc. Soil Sci.* **45** (3): 610-612.
- Sharma, O.P. and R.K. Gupta (1986): Comparative performance of gypsum and pyrites in sodic Vertisols. *Indian J. Agri. Sci.* **56** (6): 423-9.
- Sharma, O.P., D.D. Dubey and G.P. Verma (1986): Factors responsible for development of salt-affected soils in Narmada valley. *J. Indian Soc. Soil Sci.* **35** : 109-113.
- Sharma, O.P., D.D. Dubey and G.P. Verma (1987): Factors responsible for development of salt affected soils in Narmada valley. *J. Indian Soc. Soil Sci.* **35** : 109-13.
- Shivakant and Rajkumar (1992): Effect of gypsum, pyrite, pressmud and FYM on soil properties and yield of rice (*Oryza sativa*). *Indian J. of agri. Sci.* **62** (3): 191-5.
- Shrivastava, A.K. and O.P. Shrivastava (1994): Gypsum Requirement in relation to sodicity Indices in typical Natraqualf. *Indian Soc. of Soil Sci.* **42** (1): 161-3.
- Shukla, K. and Pandey, J. (1987): Effect of organic and inorganic amendments on rice in saline sodic soil. *Indian J. Agronomy.* **32** (3): 238-40.
- Siddiqui, M. and Ghonsikar,, C.P. (1981): Salinity status of some soils of Marathwada region. MAU, Parbhani. Res. Bull 5.
- Singh, Charanjeet, M.R. Chaudhary, Yogesh Arora and N.T. Singh (1980): Efficet of different concentrations of gypsum solution on sodic soils. *J. Indian Soc. of Soil Sci.* **28** (2): 223-226.

- Singh, D., R.K. Tripathi, P.K. Vilay, I.C. Mediratta and K.N. Bansal (1980): Comparative effect of gypsum and pyrite on soil properties and yield of wheat and rice. *J. Indian Soc. Sci.* **28** (2): 213-218.
- Singh, Dharmendra and Bijendra Singh (1997): Influence of Residual sodium carbonate in sodic water on the yield, oil content and oil production of lemon grass [cymbopogon cytratus]. *J. Indian Soc. Soil Sci.* **45** (2): 354-357.
- Singh, Mohan, (1991): Microbial Activity during decomposition of sugarcane trash. *J. Indian Soc. Soil Sci.* **39** (4): 811-813.
- Singh, O.P. and R.S. Pandey (1986): Land levelling on saline soils. *Indian J. Agricultural Sci.* **56** (5): 363-5.
- Singh, R.D. and H.N. Sinha (1987): Water management practices for wheat: *Indian J. Soil Conserv.* **15** (2): 101-6.
- Singh, R.P., S. Sharma, M.V. Padmanabhan, S.K. Das and P.K. Mishra (1990): Field manual on watershed management. CRIDA, Hyderabad, pp.4.
- Sleeman, J.R. (1963): Cracks, peds and their surfaces in some soils of the riverine plain, New South wales, *Australian J. Soil Res.* **1**: 91-102.
- Smith, R.M. (1959): Some structural relationships of Texas blackland soils, with special attention to shrinkage and swelling. ARS, US, *Agricultural Research Service no. 41*: 28. 51 pp
- Stewart, J.I., R.D. Misra, W.O. Pruitt and R.M. Hagan (1975): Irrigating corn and grain sorghum with a defecient water supply. *Trans. American society of Agricultural Engineers* **18**: 270-280.
- *Strogonov, B.I. (1964): Physiolosical basis of salt tolerance of plants as affected by various types of salinity. Translated from Russian Old Bourne Press. 1-5 post pool lane, London, E.O.P.
- *Strongnov, B.P. (1973) : Timiryazev lectures XXXVIII, USSR Academy of Sci. Moscow, Nauka, Cited from V.N. Bhivare and P.D. Chavan (1987), *Plant & Soil*, 102, 295-297.

- Subbiah, B.V., G.L. Asija (1956): A.R. apid procedure for the estimation of available nitrogen in soils. *Curr. Sci.* **25** : 259-260.
- Swamy, K. Ramalinga and Rao, K. Veerabhadra, (1991): Reduction of adverse effect of sodic water on greengram (*Phaseolus radiatus*) by treatment of soil and water with gypsum. *Indian J. agri. Sci.* **61** (10): 763-765.
- Swarup Anand (1986): Effect of gypsum, pyrites, FYM and rice husk on the availability of zinc and phosphorus to rice in submerged sodic soil. *J. Indian Soc. Soil Sci.* **34** (4): 844-48.
- Swarup Anand (1991): Effect of gypsum, greenmanure, farmyard manure and zinc fertilization on the zinc, Iron and manganese nutrition of wet land rice on a sodic soil. *J. Indian Soc. Soil Sci.* **39** (3): 530-536.
- Swarup Anand, S. Adhikari and A.K. Biswas (1994): Effect of gypsum on the behaviour of soil phosphorus during reclamation of a sodic soil. *J. Indian Soc. Soil Sci.* **42** (4): 543-547.
- Swarup, Anand (1985): Yield and nutritional of rice as influenced by pre-submergence and amendments in a highly sodic soil. *J. Indian Soc. Soil Sci.* **33** (2): 352-357.
- Swindale, L.D. (1989): Approaches to agrotechnology transfer, particularly amongst Vertisols. Management of Vertisols for Improved Agricultural Production, proceedings IBSRAM Inaugural workshop, ICRISAT, Feb. 18-22, 1985.
- Talati, R.P. (1960): Water quality and use of saline water for crop production with special reference to Gujrat state. Symposium on soil and water management (1969), held at Hisar, March 11-13.
- Tanpure, V.D.; N.K. Barde and D.K. Ballal (1977): Nature and quality of well waters in Purna valley of Vidarbha. *J. Maharashtra agric. Univ.* **2**(2): 94-100.
- Thakare, V.S.; H.N. Rawankar and R.M. Deshpande (1989). Role of ridges and furrows on contours in the management of rain water and soil moisture in cotton production, *Cotton Development.* **18** (3&4) : 33-36.

- Tiwari, K.N., Anil kumar and A.N. Pathak (1983): Characterisation of salt affected soils in central alluvial region of Uttar Pradesh. *J. Indian Soc. Soil Sci.* **31**(2): 272-280.
- Tiwari, K.N. and D.N. Sharma (1989): Soil salinity Research, AICRP, management of salt affected soils and use of saline water in Agriculture, CSAUAT, Kanpur. 89 P.
- Tiwari, M.P., H.Y. Bhai, R.N. Padhi and K.P. Bandopadhyay (1996): Geomorphology and geology of the Purna valley. Symposium on "Intergrated approach to management of water and soil of Purna river basin with special reference to salinity characteristics" 2-4 Feb., VRCE, Nagpur PP. 11-20.
- Tiwari, R.J., K. Dwivedi and S.K. Verma (1993): Effect of gypsum on leaf water potential of cottons (*Gossypium hirsutum*, *G. herbaceum* and *G. arboram*) Varieties grown in salt affected Vertisols of Madhya Pradesh. *Indian J. agri. Sci.* **63** (11): 734-736.
- Unger, P.W. and A.F. Wiese, (1979): Managing irrigated winter wheat residues for water storage and subsequent dryland grain surghum production. *Soil Sci. Soc. American Journal* **43**: 582-588.
- *Unger P. W. and Ordie R. Jones (1989): Effective tillage practices for conserving soil and water Resources. Management of Vertisols for improved Agricultural production: Proceedings IBSRAM Inaugral workshop, 18-22 Feb. 1985, ICRISAT, Feb. 18-22, 1985. pp. 161-171.
- USDA (1951): Soil Survey Manual. USDA., U.S. Govt. Printing office Washington, D.C. 503 P.
- USDA. (1960) : Soil classification, a comprehensive system 7th Approximation. Washington, D.C., USA: 754 PP.
- USDA (1992): Key to Soil Taxonomy, Sixth Edition. Soil Conservation Service, USDA, Washington, D.C. 306 P.

- USDA (1994): 'Keys to Soil Taxonomy, Sixth Edition'. (U.S.D.A. : Washington, D.C.)
- Vancura, V. and A. Hanzlikova (1972): Root exudates of plants. Differences in chemical composition of seed and seedling exudates. *Plant & Soil*, **36** : 271-282.
- Varade, S.B. (1982): Water management problems of black soils. Proc. Workshop, Water resources planning and management. Walmi. Aurangabad. Jan. 22-29, pp. 19-25.
- Varade, S.B., M.S. Palaskar and S.D. More (1985): Characteristics and reclamation of salt affected Vertisols in canal commands. *J. Maharashtra agric. Univ.* **10** (2): 115-120.
- Verma, S.K. and R.K. Gupta (1984): Effectiveness of pyrite in reclaiming a sodic clay soils under laboratory conditions. *J. plant Nutr. and Soil Sci.* **147**: 222-9.
- Verma, S.K. and R. K. Gupta (1985): Relative effectiveness of pyrites and gypsum in reclaiming a sodic clay soil. *J. Indian Soc. Soil Sci.* **33** (2): 465-8.
- Verma, S.K.; R.K. Gupta and R.A. Sharma (1987): Hydraulic properties of sodic clay soil as modified by quality irrigation water. *J. Indian Soc. Soil Sci.* **35**: 1-4.
- Verma, S.K.; R.K. Gupta and R.A. Sharma (1989): Field studies on leaching behaviour of sodic clay soil. *J. Indian Soc. Soil Sci.* **37**: 809-14.
- Verma, S.K. and O.P. Sharma (1998) : Cited from "25 years Research on Management of Salt Affected Soil and Use of Saline water in Agril". AICRP project on Management of salt affected soils and use of saline water in Agril., CSSRI, Karnal, pp. 83-84.
- Virmani, S.M., K.L. Sahrawat and J.R. Burford (1982): Physical and chemical properties of Vertisols and their management. Vertisols and rice soils of the tropics. Symposia papers 2. Trans. of the 12th International Congress of Soil Sci., IARI, New Delhi, India.: Feb. 8-16, pp. 80-93.

- Yadav, J.S.P. and R.R. Agarwal (1961): A comparative study on the effectiveness of gypsum and dhaincha (*Sesbania aculeata*) in the reclamation of a saline alkali soil. *J. Indian Soc. Soil Sci.* **9** (3): 151-156.
- Yadav, J.S.P. and I.K. Girdhar (1981): The effect of different magnesium : calcium ratios and sodium adsorption ratios values of leaching water on the properties of calcareous versus noncalcareous soils. *Soil Sci.* **13**: 994-998.
- Yadav, J.S.P. and I.C. Gupta (1984): Usar Bhumi Ka Sudhar (In Hindi), Sinchan, Jan., PP. 91-98.

• *Originals not seen*

Appendix I. Metrological data for 1994-95 recorded at Agricultural metrological observatory; Dr. PDKV, Akola

N - Normal

A - Actual

Month	Rainfall (mm)		Rainy days		Temperature °C				Relative humidity (%)				Open pan evaporation (mm)	
					Max.		Min.		Morn.		Even.			
	N	A	N	A	N	A	N	A	N	A	N	A	N	A
June	155.2	140.6	7.6	1	37.2	35.6	25.6	24.1	71	78	41	51	11.0	7.3
July	224.3	328.8	10.8	10	32.5	29.9	23.7	22.3	84	89	61	73	5.6	3.3
August	220.5	263.9	10.4	9	30.3	29.1	22.9	21.7	87	92	68	74	4.4	2.8
September	103.2	116.7	5.8	7	32.7	31.5	22.1	19.7	83	88	55	55	5.2	4.2
October	47.3	22.0	2.3	10	33.9	34.0	18.5	18.3	76	82	37	36	5.5	4.9
November	14.7	11.0	1.0	0	31.7	31.2	13.9	14.0	70	77	30	32	5.0	4.1
December	8.6	0.0	0.7	0	28.2	29.6	10.5	8.2	70	80	29	24	4.5	3.6
January	9.5	40.6	0.8	1	30.0	26.9	11.4	9.0	67	85	28	32	5.0	3.4
February	9.2	0.0	0.7	1	32.6	31.9	13.2	12.6	56	73	21	24	6.8	5.8
March	10.7	71.2	1.1	1	37.3	34.8	17.8	17.6	41	75	20	30	10.1	6.5
April	3.6	8.2	0.4	0	41.2	39.9	23.2	20.6	35	47	14	17	13.9	9.5
May	17.9	7.6	1.0	1	42.6	41.1	27.1	25.3	46	58	17	21	17.1	12.0
Total/Mean	824.7	1010.6	42.6	41	34.38	32.96	19.16	17.78	65.50	77.00	35.08	39.08	94.1	67.40



Appendix II. Metrological data for 1995-96 recorded at agricultural metrological observatory Dr. PDKV. Akola

Month	Rainfall (mm)		Rainy Days		Temperature °C				Relative humidity (%)				Open pan evaporation (mm)	
	N	A	N	A	Max.		Min.		Morn.		Even.		N	A
					N	A	N	A	N	A	N	A		
June	155.2	54.8	7.6	1	37.2	40.8	25.6	26.8	71	71	41	33	11.0	13.2
July	224.3	323.9	10.8	1	32.5	32.8	23.7	23.6	84	88	61	64	5.6	5.4
August	220.5	14.9	10.4	10	30.3	32.9	22.9	23.7	87	81	68	56	4.4	5.6
September	103.2	147.6	5.8	9	32.7	32.8	22.1	22.1	83	88	55	57	5.2	4.8
October	47.3	2.0	2.3	7	33.9	34.3	18.5	18.2	76	82	37	36	5.5	5.3
November	14.7	0.0	1.0	10	31.7	32.1	13.9	11.6	70	76	30	26	5.0	4.6
December	8.6	0.0	0.7	0	28.2	31.4	10.5	10.5	70	82	29	35	4.5	4.1
January	9.5	5.2	0.8	0	30	31.3	11.4	12.5	67	82	28	33	5.0	4.3
February	9.2	4.4	0.7	1	32.6	33.8	13.2	13.3	56	64	21	25	6.8	6.6
March	10.7	5.8	1.1	1	37.3	38.9	17.8	17.9	41	46	20	17	10.1	9.7
April	3.6	0.0	0.4	1	41.2	41.0	23.2	21.1	35	44	14	15	13.9	11.9
May	17.9	3.8	1.0	0	42.6	42.9	27.1	27	46	47	17	17	17.1	17.2
Total/ Mean	824.7	562.4	42.6	41	34.18	35.42	19.16	19.02	65.5	70.92	35.08	34.5	94.1	92.7

VITA

Shri Shridhar Shankarrao Rewatkar, Assistant Professor of Agriculture Chemistry and Soil Science, was born on 18th July, 1952 at Daroda, Tq.Hinganghat, Dist. Wardha, Maharashtra. He passed his HSSC in 1971 from Gangabai Bulakidas Mohata Municipal High School, Hinganghat. He received his B.Sc. (Agri.) degree in 1975 from College of Agriculture, Nagpur and M.Sc. (Agri) degree in 1978 from Post Graduate Institute, Dr.P.D.K.V., Akola. His M.Sc. (Agri.) thesis was on **"Distribution of Different Forms of Manganese in Typical Soil Properties of Central Demonstration Farm, Panjabrao Krishi Vidyapeeth, Akola"** He has worked in Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola as a Junior Research and Senior Research Assistant since 8th May, 1978 and presently working as Assistant Professor of Agricultural Chemistry and Soil Science, College of Agriculture, Dr.Panjabrao Deshmukh Krishi Vidyapeeth, Akola.

THESIS ABSTRACT

- a) Title of the thesis : **Investigation on the effect of soil amendments and land treatments on soil characteristics and productivity of cotton grown in salt affected vertisols**
- b) Name of the student : Shridhar Shankarrao Rewatkar
- c) Name and address of the major advisor : Dr. B.N.SAGARE,
Associate Professor,
Department of Agril. Chemistry and
Soil Science, Dr.P.D.K.V., Akola (M.s.)
- d) Degree to be awarded : DOCTOR OF PHILOSOPHY
in Agriculture (Agril. Chemistry & Soil
Science)
- e) Year of award of degree : 1998
- f) Major subject : Agril. Chemistry and Soil Science
- g) Total No. of pages in the thesis : 173
- h) Number of words in the abstract : 601
- i) Signature of the student: 
- j) Signature, Name and address of forwarding authority : 
Head,
Department of Agril. Chemistry
and Soil Science,
Dr. Panjabrao Deshmukh Krishi
Vidyapeeth, Akola

ABSTRACT

The effect of gypsum levels and land configurations on changes in soil characteristics and productivity of hybrid cotton (cv. AHH-468) grown in Sodic Haplusterts was evaluated in split plot design during 1994-95

and 1995-96 at Gopalkheda, the village at the bank of Purna Valley, of Vidarbha region. The pH, ECe and ESP of representative profile varied in the range of 8.2-8.5, 2.42-4.18 $d\text{ Sm}^{-1}$ and 14.06-22.97, respectively. Main treatments comprised of no land configuration (Control), furrow opening after each row and two rows of cotton, whereas subtreatments were various gypsum levels equivalent to 0, 25, 50 and 100% GR.

A significantly maximum enhancement of 39.6 and 13.1 per cent in seed cotton yield was recorded due to furrow opening after two rows and furrow opening after one row respectively over control. The highest stalk yield, B:C ratio and net monetary returns were also obtained due to this land configuration. A maximum and significant increase in yield contributing factors i.e. HC and ionic Ca by 28 and 10.6 per cent and significant repression in yield detrimental parameters i.e. pHs, ECe, SARe, ESP and ionic Na by 2.28, 6.7, 23.9, 22.6 and 22.4 per cent over control were also noticed due to furrow opening after two rows, respectively. The highest stalk yield, B:C ratio and net monetary returns were also obtained due to this land configuration. A maximum and significant increase in yield contributing factors i.e. HC and ionic Ca by 28 and 10.6 per cent and significant repression in yield detrimental parameters i.e. pHs, ECe, SARe, ESP and ionic Na by 2.28, 6.7, 23.9, 22.6 and 22.4 per cent over control were also noticed due to furrow opening after two rows, respectively.

An incorporation of gypsum @ 50 and 100 per cent GR enhanced significantly the seed cotton yield by 22.5 and 31.0 per cent as compared to G0, respectively. Significantly highest stalk yield was also noticed with gypsum @ 100% followed by gypsum @50% GR. Gypsum application @ 50% GR gave maximum B:C ratio followed by G25, G0 and G100, indicating economical feasibility of G50 over G100. Further, it implies that an addition of gypsum @ 50 and 100 per cent GR enhanced significantly the yield contributing factors i.e. HC by 135 and 156 and ionic Ca 47.7 and 48.4, whereas a significant suppression in yield reducing parameters like pHs by 7.06 and 9.78, ECe 33.3 and 37.3, SARe 46.8 and 57.9 and ESP 44.9 and 51.1 and ionic Na 36.1 and 43.7 per cent were noticed

over G0, respectively. Interaction effects between land treatments and gypsum levels were significant in increasing ionic Ca and reducing E_{Ce}, SARE and ESP of Sodic Haplusterts.

A highly significant positive correlation of seed cotton yield with HC and ionic Ca, whereas, highly significant but negative correlation of seed cotton yield with SARE/ESP, ionic Na, BD, pHs and E_{Ce} were also noticed in Sodic Haplusterts. A significantly positive relationship between HC and ionic Ca⁺⁺; whereas negative relationship of HC with E_{Ce}, SARE, ESP, BD, ionic Na⁺, and pHs were noticed in this investigation. Regression studies indicated that HC and ionic Ca⁺⁺ have major contribution in increasing the seed cotton yield under rainfed situation, whereas negative impact of soil attributes towards seed cotton yield followed the order as SARE > ESP > ionic Na. Amongst the various multiple linear regression (MLR) models, model No.IX (Yield = -52.59 + 0.517 pHs + 3.298*E_{Ce} + 35.904** BD + 18.467** HC + 3.495** ESP - 2.609** SARE - 0.754** ionic Na⁺ + 1.581** ionic Ca⁺⁺ - 3.411** Exch. Na R² = 0.9969**) appeared to be best as it describes 99.69 per cent variability in the yield of seed cotton grown in Sodic Haplusterts. This model includes nine soil parameters i.e. pHs, E_{Ce}, BD, HC, ESP/SARE and ionic Ca⁺⁺, Mg⁺⁺ and Na⁺. From the data, it can be concluded that :

1. Hydraulic conductivity has major contribution for enhancing the seed cotton yield, whereas negative effect on it was mainly due to SARE/ESP followed by ionic Na⁺.
2. Opening of furrows after two rows and incorporation of gypsum @ 50% GR to hybrid cotton are essential for increasing seed cotton yield, improving physico-chemical conditions and sustainability of Sodic Vertisols of Purna Valley tract of Vidarbha region.
3. The model i.e. yield = -52.59 + 0.517 pHs + 3.298*E_{Ce} + 35.904** BD + 18.467** HC + 3.495** ESP - 2.609** SARE - 0.754** ionic Na⁺ + 1.581** ionic Ca⁺⁺ - 3.411** Exch. Na R² = 0.9969** is found to be best in forecasting the yield of cotton grown in Purna valley of Vidarbha region.

138011.